CARDIOVASCULAR IMAGING FOR NUCLEAR CARDIOLOGISTS

Cardiovascular Imaging for Nuclear Cardiologists: First Step of Coronary Computed Tomography Angiography

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Abstract

Cardiac computed tomography (CT) is now widely accepted for evaluating coronary artery disease, owing to the rapidly developing technology since 64-detector row CT was first introduced over a decade ago. Coronary CTA enables us to detect not only coronary organic stenosis but also the plaque burden and composition of coronary atherosclerotic disease. Therefore, if coronary stenosis is present, the report should describe the plaque morphology as well as the stenosis severity. Herein, we describe the basic principles of coronary CTA interpretation according to the Society of Cardiovascular Computed Tomography reports.
Keywords: Coronary CT angiography, Coronary artery disease
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In recent years, due to clinical needs of diagnosing coronary artery disease (CAD), the technological developments of cardiac computed tomography (CT) have been rapid. Especially, coronary CT angiography (CTA) is frequently performed for patients with suspected angina. To assess CAD by coronary CTA, clinicians should become familiar with several aspects of CT, including the image quality, patient selection, appropriate scanning parameters, contrast enhancement protocol, heart rate control for scanning, and minimum radiation exposure, among others. Moreover, cardiac CT may provide extensive information not only on the coronary tree morphology but also on the cardiac valve, myocardial, and pericardial anatomies and functions.

Clinically, coronary CTA is mainly performed for excluding or detecting coronary artery stenosis. Several meta-analyses have reported that coronary CTA can effectively identify CAD patients with >50% stenosis in the coronary artery, with high negative (median 99.0%, range 83-100%) and positive predictive values (median 90.5%, range 76-100%) (1). Generally, coronary CTA should be used in non-acute, symptomatic patients with low-to-intermediate pretest probability of CAD (2). In addition to excluding CAD, coronary CTA can also identify luminal stenosis with intracoronary plaque burden, which may warrant further examination or treatment. Owing to this clinical importance, this article is focused on the essentials of coronary CTA interpretation as a first step of diagnosis.

1. CT images for interpretation

Transaxial images

Transaxial images are the basic grayscale dataset, which consists of a series of planar images in the cranial-caudal direction. Although these images show less blurring and error by post-processing, the interpreters should scroll only in the longitudinal direction and grasp the three-dimensional continuous object of interest (Fig. 1).

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Multiplanar reformat (MPR)
Previous terms and abbreviations (not recommended) (2): Multiplanar reconstruction

MPR is a two-dimensional reconstruction image displaying data at any angular slice through the acquisition volume. Based on transaxial images, MPR can create a new slice so that the interpreting physician can rotate the image 360° through the course of the coronary artery. To diagnose CAD, MPR is widely used for detecting the coronary stenosis severity and plaque morphology (3) (Fig. 2).

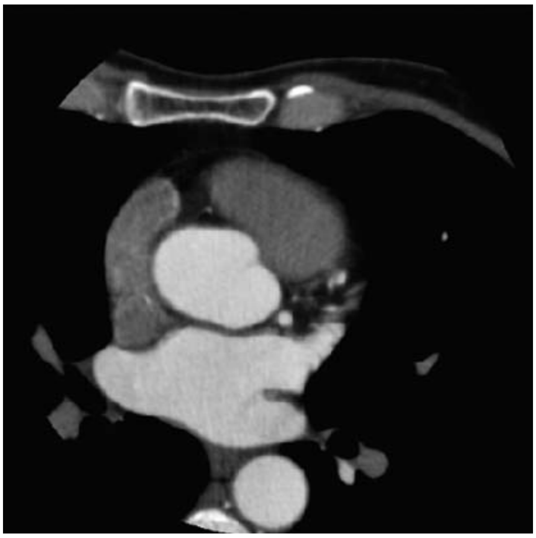


Fig. 1 Transaxial image
Transaxial images show less blurring and error by post-processing.

Maximum Intensity Projection (MIP)

Compared to MPR, MIP is a thicker two-dimensional projection of the entire imaged volume and displays only the pixel with the highest CT number within the stack of images. These features facilitate visualization of the vessel course, especially for tortuous coronary arteries. Although MIP may be helpful for evaluating the presence and site of vessel lesions, it should not be used to assess the stenosis grade or plaque burden, as MIP images may mask lower CT numbers of stenosis and plaque composition within the slab volume (4) (Fig. 3).

Curved multiplanar reformat (cMPR)
Previous terms and abbreviations (5): Curved multiplanar reconstruction

cMPR is created by tracing the centerline of the

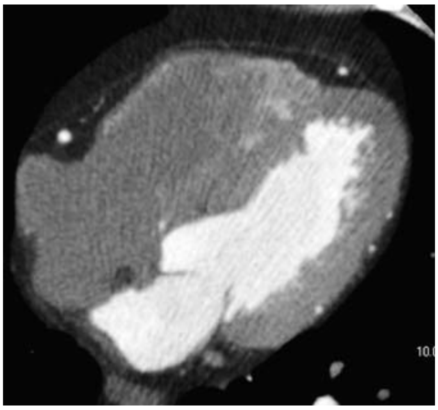


Fig. 2-1 Axial image

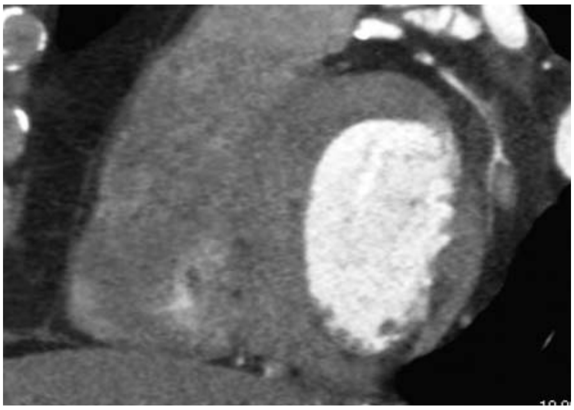


Fig. 2-2 Sagittal image

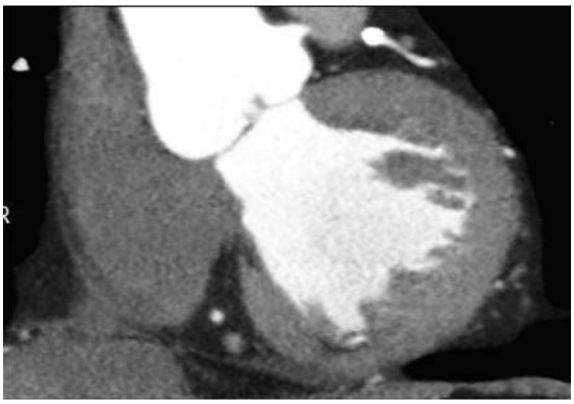


Fig. 2-3 Coronal image

Fig. 2-4 Oblique MPR

Fig. 2 Multiplanar reformat (MPR)
MPR is utilized for assessing the coronary lumen and plaque composition in detail. Orthogonal (axial, coronal, sagittal) and oblique sections are created from transaxial images.

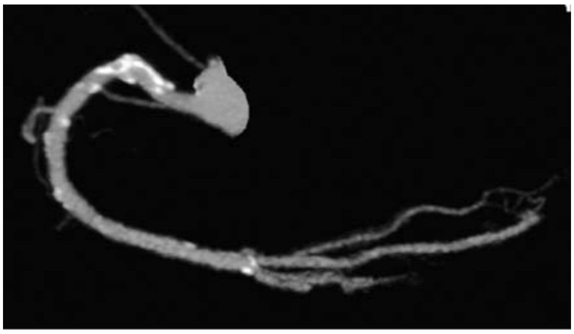


Fig. 3 Maximum Intensity Projection (MIP)
MIP displays the highest CT number within the stack of pixels to the specified section. It is helpful for following tortuous coronary arteries.

Fig. 4 Curved multiplanar reformat (cMPR)
cMPR produces a view of the entire vessel course. LAD, left anterior descending artery.

artery, and displays MPR following a vessel from the proximal to distal end in one image. cMPR is utilized only to provide an overview of the target vessel and provides a longitudinal and cross-sectional image at any point in its course for determining the stenosis length and plaque extension (Fig. 4).

Volume-rendering technique (VRT)

VRT is a three-dimensional technique that provides an overview of the whole heart. Since the volumetric color image display is adjusted according to the window level and width, it should not be used for coronary stenosis assessment. VRT is suitable in limited circumstances such as for detecting coronary anomalies and congenital heart disease, and for teaching purposes (Fig. 5).

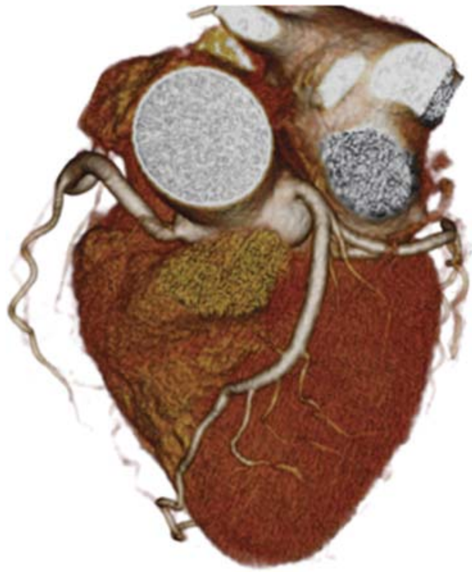


Fig. 5 Volume-rendering technique (VRT)
VRT provides an overview of the whole heart as a three-dimensional image.

2. Before coronary CTA interpretation

This section is focused on the potential artifacts of CT.

Beam-hardening artifacts

Beam-hardening artifacts (5,6) appear as dark zones or streaks between highly attenuating structures such as bones or stents. Such artifacts indicate an increase in the average energy of the x-ray beam as it passes through the patient. As inferior energy x-rays are absorbed more rapidly than upper energy x-rays, the x-ray beam becomes harder (increased mean energy). Physicians should take care not to misdiagnose the site of a beam-hardening artifact as a low CT value structure (overestimation of coronary stenosis).

Partial volume averaging

Previous terms and abbreviations (5): calcium blooming

Each CT pixel image is represented as a non-linearly averaged CT number. When high-contrast structures such as calcification occupy each pixel area, it may be visualized larger than the actual size (5). If luminal stenosis presents next to a heavily calcified lesion or stent edges, the narrowing site, which has low CT number pixels, might be masked by the high attenuating expanded materials. Physicians should understand this limitation for evaluating coronary stenosis around calcification or stent sites (underestimation of coronary stenosis).

Table 1 Evaluation of the Agatston score and percentage ranking (12, 13)

Step Ⅰ		Step Ⅱ	
Agatston score	Interpretation	Percentage ranking (%)	Risk assessment
0-10	No/minimal plaque	0-25	Small risk
11-100	Some plaque present	26-50	Moderate risk
111-400	Moderate plaque burden	51-75	Increased risk
401-1000	Severe plaque burden	76-90	High risk
>1000	Very severe plaque burden	>90	Very high risk

Algorithm for interpreting coronary calcium scoring. First, the Agatston score is calculated; a high calcium score indicates greater total coronary plaque burden. Second, the percentage ranking is considered; greater percentage indicates increased cardiovascular risk.

Motion artifact

Previous terms and abbreviations (5): blurring

Due to patient motion and respiratory movements, images may show obscure margins or linear artifacts.

Misalignment artifact

Previous terms and abbreviations (5): step artifact, stair-step artifact, misregistration artifact, slab artifact

Misalignment artifacts are induced by patient motion, and respiratory, arrhythmia, and heart rate variabilities (5). Images of oblique vessels along the z-axis may be visualized as stair-steps (7).

3. Non-enhanced electrocardiography-gated calcium-scoring study, Agatston score

Previous terms and abbreviations (5): Calcium score, CS, CCS, CACS, CAC score

Calcific deposits in the coronary arteries suggest pathognomonic atherosclerosis or bone formation changes triggered by inflammation (8-10). The degree of coronary calcification is proportional to age for both genders, while it develops differently between the genders in age-adjusted populations (11). For CT, a representative calcium scoring method is the Agatston score (12), which is easily calculated semi-automatically by CT workstation software. This score is a quantitative measurement based on the definition of calcification as a >130-Hounsfield unit pixel area. Numerous studies have reported that the Agatston score more highly relates to cardiovascular events than the standard risk factors.

The algorithm for interpreting coronary calcium scoring (13) is shown in Table 1. First, the Agatston score is interpreted. The higher the score, the more plaque burden the coronary arteries have. Second, the percentage ranking, calculated by the standardized Agatston score from age and gender, is considered; a greater percentage indicates higher cardiovascular risk.

4. Coronary artery segmentation

For invasive coronary angiography (ICA) evaluation, reporting of the coronary artery anatomy is based on the standard American Heart Association (AHA) segmentation proposed in 1975 (14). Conversely, for assessment of coronary CTA, the Society of Cardiovascular Computed Tomography (SCCT) guidelines recommend the “SCCT coronary segmentation diagram” (Fig. 6), which is partly altered from the AHA segmentation (4). This model has minimal modifications, including that the left posterolateral branch is defined as segment 18, and a ramus intermedius branch has been added as segment 17.

5. Assessment of luminal stenosis severity by coronary CTA

To assess CAD by coronary CTA, as well as by ICA, it is important to determine and report the lesion severity. Some studies (14,15) have compared the quantitative assessment of the percent maximal diameter stenosis in 64-row coronary CTA with quantitative coronary angiography of ICA; these suggested that CTA correlated well with quantitative coronary angiography but that it showed large standard deviations. Therefore, the SCCT guidelines propose that stenosis lesion severity should be determined as follows (4):

Recommended stenosis grading

0- Normal: absence of plaque and no luminal stenosis
1- Minimal: plaque with <25% stenosis
2- Mild: 25-49% stenosis
3- Moderate: 50-69% stenosis
4- Severe: 70-99% stenosis
5- Occluded

6. Plaque composition in coronary CTA

One difference between ICA and coronary CTA is that coronary CTA can depict not only coronary stenosis but also assess the plaque burden and

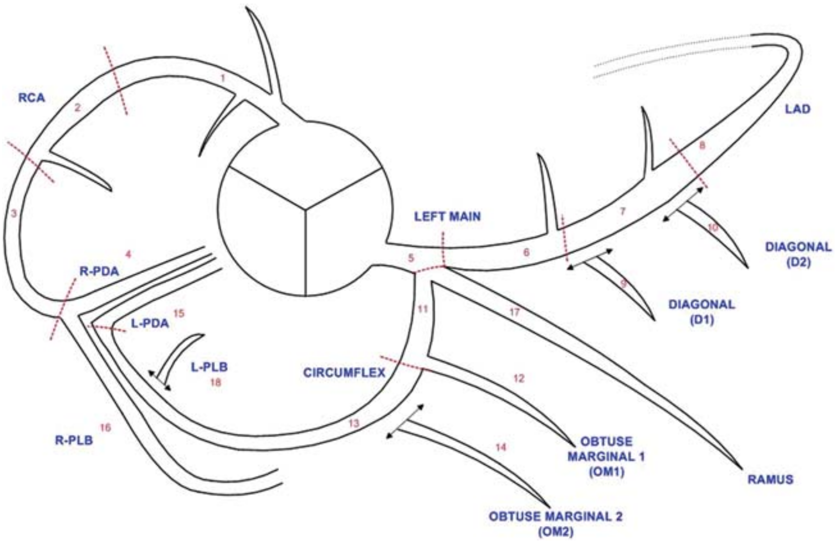


Fig. 6 Society of Cardiovascular Computed Tomography (SCCT) coronary segmentation diagram

Dashed lines represent the division between the RCA, LAD, and LCx and the end of the LM.

D1, first diagonal branch; D2, second diagonal branch; LCx, left circumflex coronary artery; LM, left main trunk; L-PDA, PDA from LCx; L-PLB, PLB from LCx; OM1, first obtuse marginal branch; OM2, second obtuse marginal branch; PDA, posterior descending artery; PLB, posterior-lateral branch; Ramus, Ramus intermedius branch RCA, right coronary artery; R-PDA, PDA from RCA; R-PLB, PLB from RCA; LAD, left anterior descending artery.

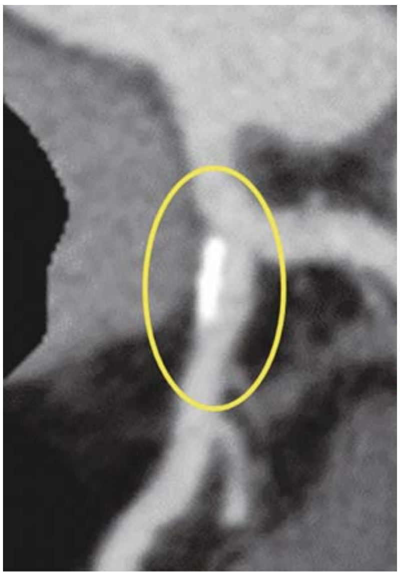


Fig. 7-1 Calcified plaque. Atherosclerotic plaque appearing fully as a calcium density.

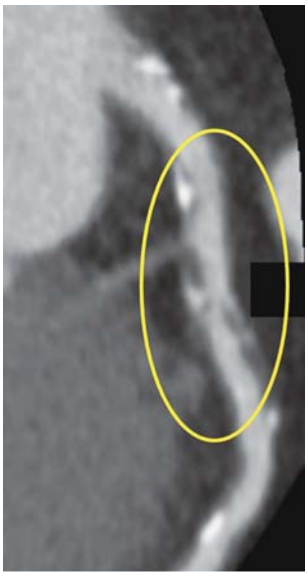


Fig. 7-2 Partially calcified plaque. Atherosclerotic plaque with two visible plaque components, one of which is calcified.

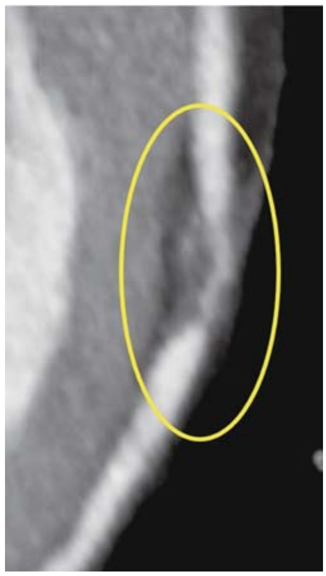


Fig. 7-3 Non-calcified plaque. Atherosclerotic plaque completely devoid of calcium density.

Fig. 7 Plaque composition in coronary computed tomography angiography

composition in coronary atherosclerotic disease. Plaques detected by coronary CTA are classified into three types by the SCCT (2): calcified, partially calcified, and non-calcified plaques (previously hard, mixed, and soft plaques, respectively). Calcified plaques are atherosclerotic plaques in which the entire plaque appears as a calcium density (Fig. 7-1); partially calcified plaques comprise 2 visible plaque components, one of which is calcified (Fig. 7-2); and non-calcified plaques are fully devoid of calcium density (Fig. 7-3).

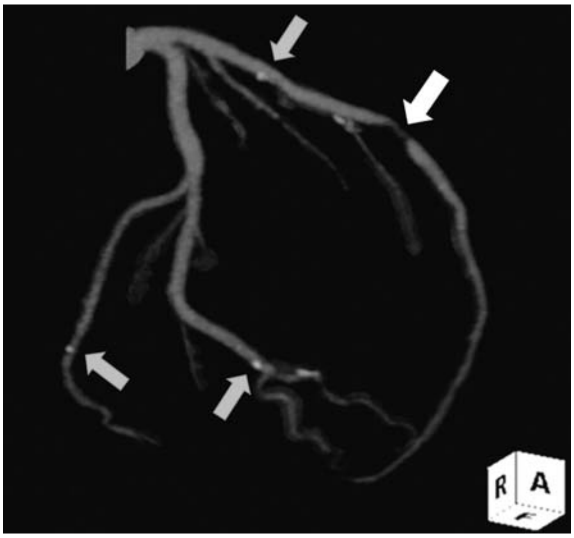
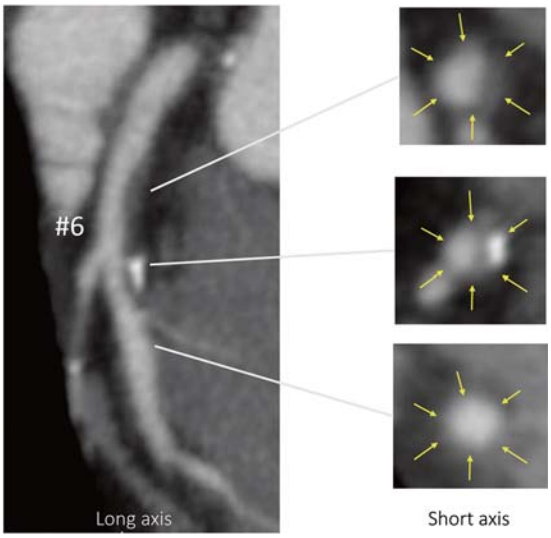


Fig. 8-1 Maximum Intensity Projection (MIP) image of the left anterior descending artery (LAD)
Segment 6 shows a small calcified plaque. Segment 7 shows suspected stenosis (arrow). The LAD stenosis grade should be evaluated in detail by MPR.

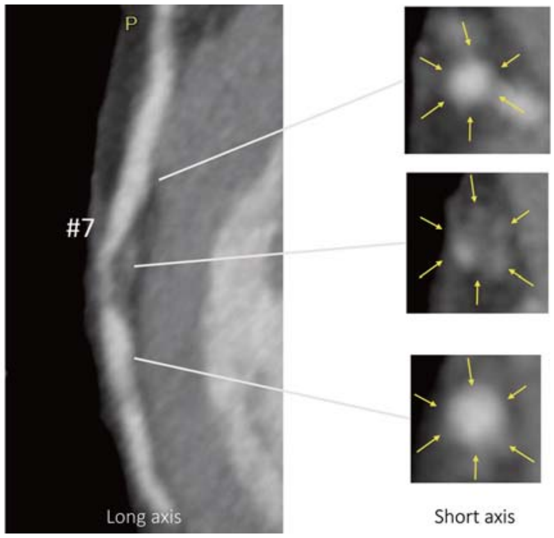
Fig. 8-2 Curved multiplanar reformat (cMPR) image of the LAD
In this image, segment 6 appears normal. Segment 7 shows stenosis (arrow) with eccentric plaque burden. The LAD stenosis grade and plaque composition should be evaluated in detail by MPR.

A



A. MPR image of segment 6
Segment 6 shows moderate stenosis with a partially calcified plaque

B



B. MPR image of segment 7
Segment 7 shows severe stenosis with a non-calcified plaque.

Fig. 8-3 Multiplanar reformat (MPR) image

Fig. 8 Case study: Man in his 50s with atypical chest pain

7. Coronary CTA assessment

The coronary CTA report should contain not only the coronary artery findings but also the patient's clinical background, procedure data, technical quality, and findings of non-coronary vessels such as the aorta or pulmonary veins, cardiac chambers, valves, myocardium, pericardium, and non-cardiac structures like the lung or esophagus etc.

This section is focused on the coronary artery assessment report, as demonstrated by the case study below. In coronary CTA for coronary artery stenosis, both the stenosis grading and plaque component should be mentioned, which differs from ICA reports, in which only the AHA stenosis grading needs to be included.

Case study: Man in his 50s

Atypical chest pain with intermediate risk.

Agatston score 20.23, percentage ranking 51% (Fig. 8).

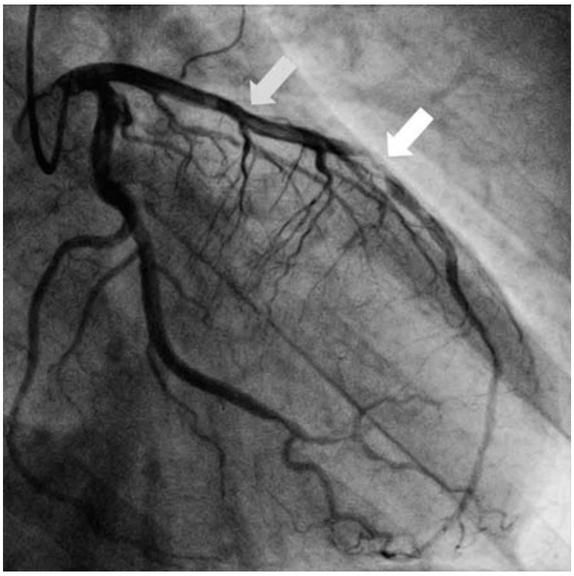


Fig. 9 Invasive coronary angiography (ICA)
Segment 7 shows American Heart Association 90% stenosis, which corresponds to the coronary computed tomography angiography (CTA) findings (white arrow), while segment 6 shows no narrowing by luminogram (gray arrow). Coronary CTA could detect the early stage of non-stenotic atherosclerosis with plaques in the coronary artery, whereas ICA visualizes mainly progressive stenotic lesions.

The technical quality was good and the images had no artifacts. According to the calcium scoring, the vessels presented some plaque and the patient was classified as at increased risk.

MIP (Fig. 8-1) showed small calcifications in segments 6, 13, and 14 (gray arrows), and the left anterior descending artery (LAD) showed luminal narrowing in segment 7 (white arrow). The LAD in cMPR is shown in Fig. 8-2. In this image, segment 6 appears normal, while segment 7 shows stenosis (white arrow) with eccentric plaque burden. The LAD stenosis grade and plaque composition should be evaluated in detail by MPR. For assessing more detailed images, using a CT workstation, long and short axes views along the entire LAD from the proximal to distal lesion are evaluated in various angles (Fig. 8-3). Although segment 6 seemed normal in MIP, MPR revealed moderate stenosis with a partially calcified plaque (Fig. 8-3A). Moreover, segment 7 showed severe stenosis with a non-calcified plaque following positive remodeling (Fig. 8-3A).

Consequently, the coronary artery report for the LAD is as follows:

Segment 6, moderate stenosis with partially calcified plaque

Segment 7, severe stenosis with non-calcified plaque (positive remodeling)

The ICA of this case is shown in Fig. 9. AHA 75% stenosis was detected in segment 7, corresponding to severe stenosis upon coronary CTA. Conversely, ICA did not visualize AHA 50% or 75% in segment 6. This discrepancy might be partly due to the true stenosis being masked by several patterns of angiographic views, or the plaque detection power of CT, which emphasizes luminal narrowing more than stenotic lesions for ICA. From this viewpoint, coronary CTA could detect not only significant vessel stenosis but also non-stenotic lesions as an early stage of atherosclerosis in the coronary arteries, noninvasively.

Conclusion

We described the basic interpretation formats and coronary artery assessment by coronary CTA. Compared with ICA, coronary CTA has the advantage of evaluating atherosclerotic plaque components with vessel stenotic lesions. Accordingly, physicians should interpret and diagnose CAD by coronary CTA in clinical practice. However, artifacts due to motion, calcified deposits, and stents might disturb the interpretation.

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Conflicts of Interest

We have no potential conflicts of interest to report for any of the activities.

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References

1. Paech DC, Weston AR. A systematic review of the clinical effectiveness of 64-slice or higher computed tomography angiography as an alternative to invasive coronary angiography in the investigation of suspected coronary artery disease. BMC Cardiovasc Disord 2011; 11: 32. doi: 10.1186/1471-2261-11-32.
2. Taylor AJ, Cerqueira M, Hodgson JM, et al. ACCF/SCCT/ACR/AHA/ASE/ASNC/NASCI/SCAI/SCMR 2010 Appropriate Use Criteria for Cardiac Computed Tomography. A Report of the American College of Cardiology Foundation Appropriate Use Criteria Task Force, the Society of Cardiovascular Computed

Tomography, the American College of Radiology, the American Heart Association, the American Society of Echocardiography, the American Society of Nuclear Cardiology, the North American Society for Cardiovascular Imaging, the Society for Cardiovascular Angiography and Interventions, and the Society for Cardiovascular Magnetic Resonance. J Cardiovasc Comput Tomogr 2010; 4: 407-33.

3. Schoepf UJ, Zwerner PL, Savino GU, et al. Coronary CT angiography. Radiology. 2007; 244: 48-63.
4. Leipsic J, Abbara S, Achenbach S, et al. SCCT guidelines for the interpretation and reporting of coronary CT angiography: A report of the Society of Cardiovascular Computed Tomography Guidelines Committee. J Cardiovasc Comput Tomogr 2014; 8: 342-58.
5. Weigold WG, Abbara S, Achenbach S, et al. Standardized medical terminology for cardiac computed tomography: A report of the Society of Cardiovascular Computed Tomography. J Cardiovasc Comput Tomogr 2011; 5: 136-44.
6. Mahesh M. MDCT Physics: The Basics Technology, Image Quality and Radiation Dose, Lippincott Williams & Wilkins, 2009: ISBN 078176811X, 9780781768115.
7. Kroft LJ, de Roos A, Geleijns J. Artifacts in ECG-synchronized MDCT coronary angiography. AJR Am J Roentgenol 2007; 189: 581-91.
8. Ross R. The pathogenesis of atherosclerosis: a perspective for the 1990s. Nature 1993; 362: 801-9.
9. Stary HC. Composition and classification of human atherosclerotic lesions. Virchows Arch A Pathol Anat Histopathol 1992; 421: 277-90.
10. Stary HC, Chandler AB, Dinsmore RE, et al. A definition of advanced types of atherosclerotic lesions and a histological classification of atherosclerosis. A report from the Committee on Vascular Lesions of the Council on Arteriosclerosis, American Heart Association. Circulation 1995; 92: 1355-74.
11. Hoff JA, Chomka EV, Krainik AJ, et al. Age and gender distributions of coronary artery calcium detected by electron beam tomography in 35, 246 adults. Am J Cardiol 2001; 87: 1335-39.
12. Agatston AS, Janowitz WR, Hildner FJ, et al. Quantification of coronary artery calcium using ultrafast computed tomography. J Am Coll Cardiol 1990; 15: 827-32.
13. Schoepf UJ. CT of the heart; principles and applications, Springer Science & Business Media, 2007; ISBN 159259818, 9781592598182.
14. Austen WG, Edwards JE, Frye RL, et al. A reporting system on patients evaluated for coronary artery disease. Report of the Ad Hoc Committee for Grading of Coronary Artery Disease, Council on Cardiovascular Surgery, American Heart Association. Circulation 1975; 51: 5-40.
15. Miller JM, Rochitte CE, Dewey M, et al. Diagnostic Performance of Coronary Angiography by 64-Row CT. N Engl J Med 2008; 359: 2324-36.