1 Reversible Myocardial Ischemia

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Abstract

Reversible myocardial ischemia is a common disease that occurs in patients with atherosclerosis of coronary artery, myocardial microcirculation disturbance, and other infrequent etiologies. It is mainly due to the blood perfusion insufficiency of the myocardium. Ischemia is the single most important predictor of future hard cardiac events and ischemia correction remains the cornerstone of current revascularization strategies (Kennedy MW, Fabris E, Suryapranata H, Kedhi E, Cardiovasc Diabetol 16:51, 2017). Early accurate diagnosis of reversible myocardial ischemia is of great importance for reducing the incidence of myocardial infarction and improving the prognosis of patients. The electrocardiogram (ECG), functional testing, cardiac stress test (including exercise stress test and pharmacological stress test), and myocardial perfusion imaging were all the methods of choice for detecting myocardial ischemia. Among all these methods, the myocardial perfusion imaging approaches, which traditionally consist of radionuclide myocardial perfusion and magnetic resonance (MR) myocardial perfusion, have been considered as effective and accurate. Recently, with the rapid development of CT imaging techniques, CT myocardial perfusion imaging has been demonstrated as a promising noninvasive diagnostic strategy for myocardial ischemia. Up to now, the invasive fractional flow reserve (FFR) has been regarded as the "gold standard" for diagnosing hemodynamically significant coronary artery disease (CAD). In this chapter, based on a case of reversible myocardial ischemia, we will discuss the cardiac CT imaging manifestations of myocardial ischemia, and further possibly promising role of new cardiac CT technology, particularly the CT myocardial perfusion, in reversible myocardial ischemia.

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1.1 Case of Reversible Myocardial Ischemia

1.1.1 History

- A 66-year-old male patient felt intermittent shortness of breath for more than 2 months, which can be relieved by deep breathing.
- He was appointed to coronary CT angiography and myocardial CT perfusion imaging for suspected CAD.

1.1.1.1 Physical Examination

- Blood pressure: 160/95 mmHg; Breathing rate: 17/min.
- Heart rate: 64 bpm without arrhythmia.
- No pathological murmurs were detected in the auscultation area.

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1.1.1.2 Electrocardiograph

Standard 12 lead ECG revealed sinus rhythm, PR 0.914 s, ST-T segment elevated 0.1mv on leads V2.

1.1.1.3 Laboratory

Serum myocardial enzyme spectrum showed negative results.

1.1.2 Imaging Examination

1.1.2.1 CT Images

A coronary CT angiography (CTA) combined with adenosine triphosphate (ATP)-stress myocardial CT perfusion was requested to investigate the coronary artery status and myocardial blood flow (Figs. 1.1, 1.2, and 1.3).

1.1.2.2 Conventional Coronary Angiography and FFR (Fig. 1.4)

1.1.3 Imaging Findings and Diagnosis

The coronary CTA images results showed there were mixed plaques in the proximal segments of LAD and D1, resulting in moderate to severe lumen stenosis. However, the severe calcified plaques on the CTA images make it difficult to assess the lesion accurately. In addition, the evaluation of CTA was limited to morphological information. After the imaging of myocardial CT perfusion, results of bull-eye polar-maps and two-short chamber views demonstrated the reduction of myocardial blood flow in the anterior wall of left ventricular myocardium without delayed enhancement, which means there was reversible myocardial ischemia corresponding to the coronary blood supply region of lesion vessels. The invasive coronary angiography (ICA) images and FFR result confirmed the hemodynamically significant CAD.

1.1.4 Management

- Conventional medical therapy for Secondary Prevention of CAD
- Out-patient follow-up observations for CAD with reversible myocardial ischemia

1.2 Discussion

Reversible myocardial ischemia is one of the most common diseases, which most often occurs in patients with CAD. This mainly results from the hemodynamically significant coronary stenosis. The common clinical symptoms include slight chest tightness, stable effort angina (chest tightness, palpitations, shortness of breath, exercising and anxious prone, self-relief during rest), and rest pain (during rest state or sleeping).

Prompt accurate diagnosis of reversible myocardial ischemia has important significance in helping not only guiding downstream decision-making for medical therapy versus revascularization and PCI versus CABG, but also evaluating clinical prognosis. Clinically, ECG is a mostly practical and convenient method, yet it is unable to provide comprehensive information and sometimes may not be accurate. Functional and cardiac stress tests are other approaches for myocardial ischemia detection; however, some patients are not capable of cooperating satisfactorily.

In recent decades, myocardial perfusion imaging is being recognized as a most direct and accu-

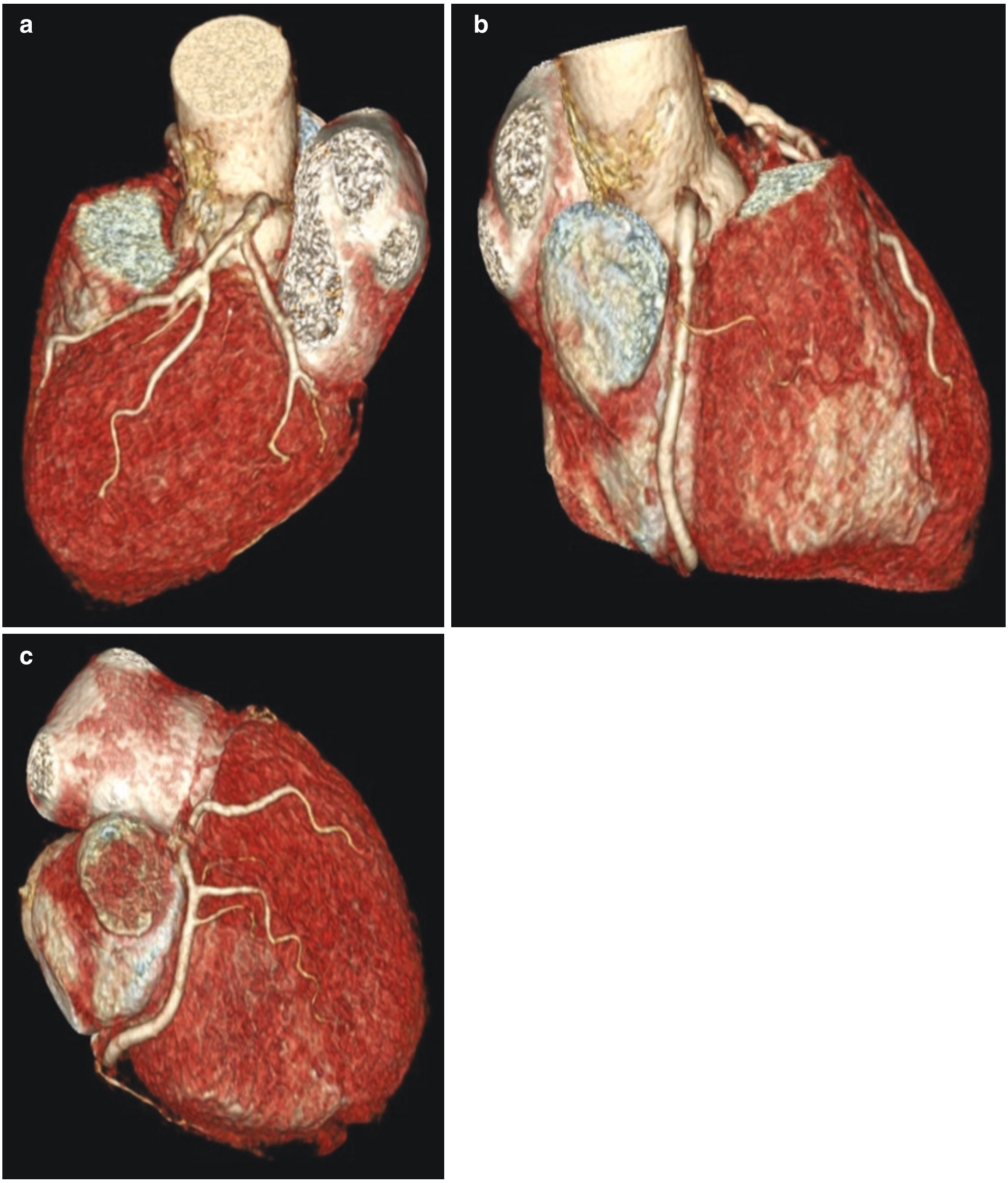

Fig. 1.1 Volumetric reproduction (VR) reconstructed images (**a**–**c**) showed the general overview of heart and coronary arteries. ((**a**) Left anterior descending (LAD) branch and left circumflex artery (LCx) (**b–c**) right coronary artery (RCA))

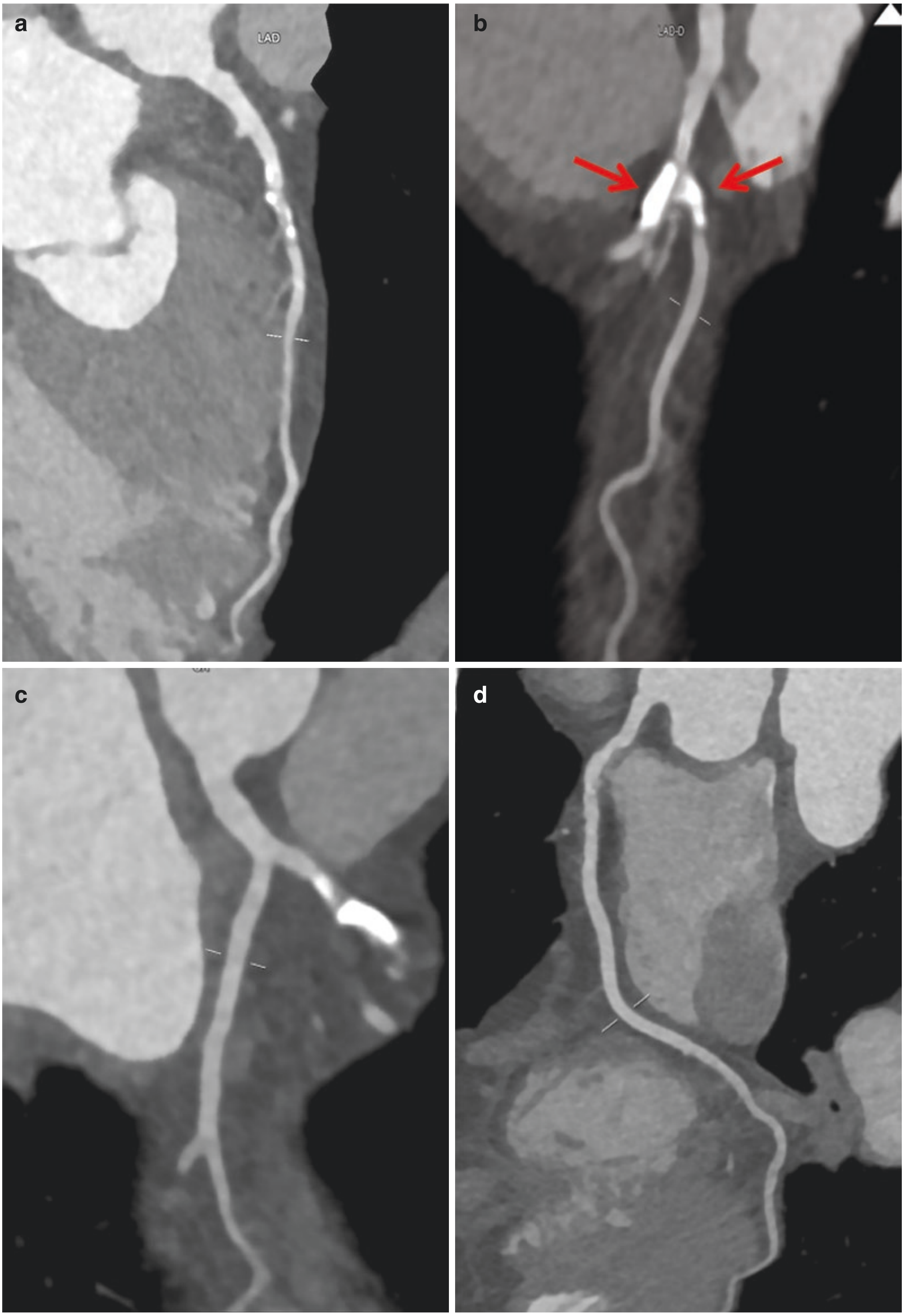

Fig. 1.2 Curved multi-planar reformats (MPR) reconstructed images of the coronary arteries (**a, b**, left anterior descending [LAD] branch and First diagonal branch (D1); (**c**) left circumflex artery [LCx]; (**d**) right coronary artery [RCA]). There were mixed plaques in the proximal segment of LAD and D1. With severe calcification, the stenosis of the lumen was difficult to evaluate accurately

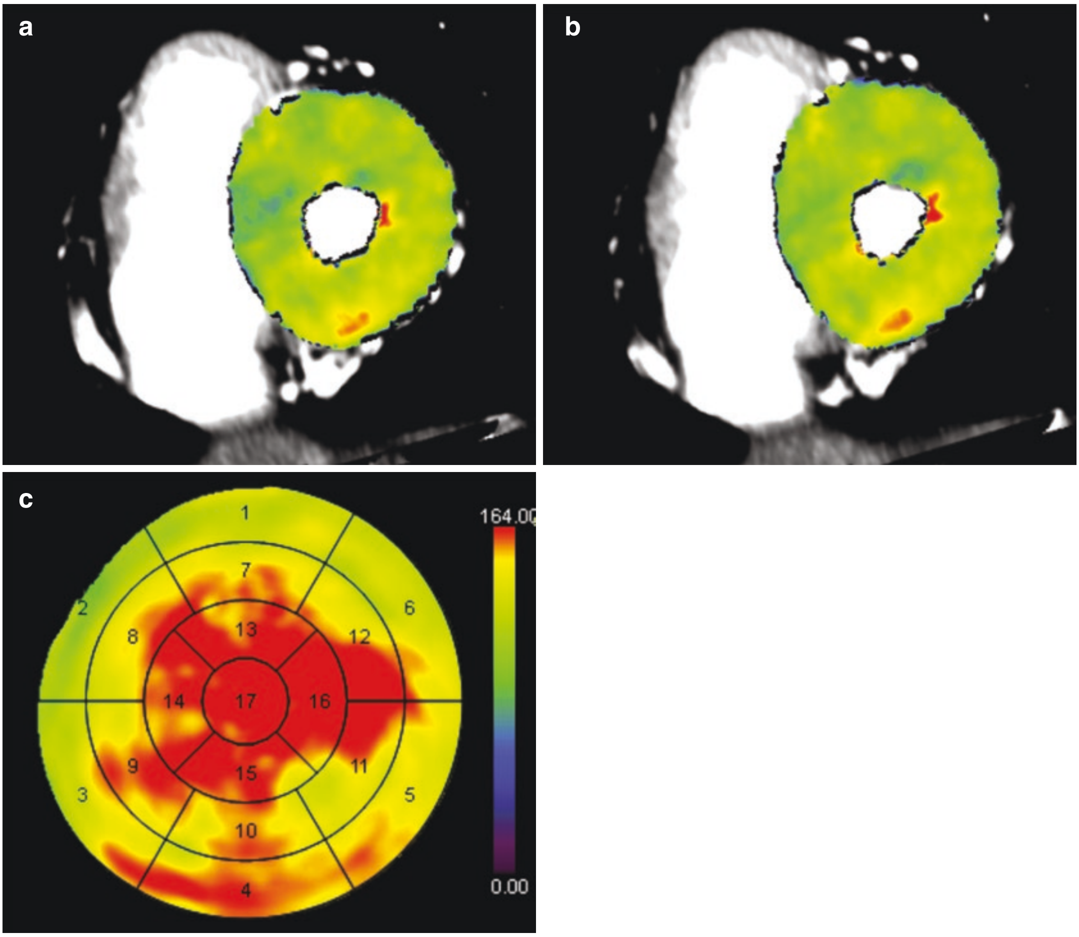

Fig. 1.3 Cardiac CT perfusion imaging of myocardium of short-axis two-chamber view (**a, b**) of left ventricular and myocardial blood flow (MBF) pseudo-color images of Bull-eye polar-map (**c**), both showed the blood perfusion reduction in the anterior wall of left ventricular myocardium

rate method for indicating myocardial ischemia. Based on a relatively long development period, the radionuclide myocardial perfusion and MR myocardial perfusion are most commonly utilized in our clinical practice. Both of them can evaluate the myocardial blood perfusion situation on per-segment, per-vessel, and per-patient basement. Nevertheless, there are still some limitations for these two approaches: the implementation of radionuclide myocardial perfusion is inevitably related to radiation dose, and the sensitivity was relatively inferior to MR perfusion imaging; while MR imaging has some contraindications for patients, like claustrophobia or with recent stent implantation. In the last decade, with the rapid development of CT imaging techniques, myocardial CT perfusion has come into people's vision, and it has been demonstrated as a promising noninvasive diagnostic strategy for myocardial ischemia.

Up to now, the invasive FFR has been regarded as the "gold standard" for diagnosing hemodynamically significant CAD. The FFR also has been regarded as "gold standard" for guiding downstream decision-making to decide if the revascularization is needed or not.

Generally, if the patients received timely and accurate diagnosis and treatment, the ischemia can be reversed and a favorable prognosis could be expected. Otherwise, reversible myocardial

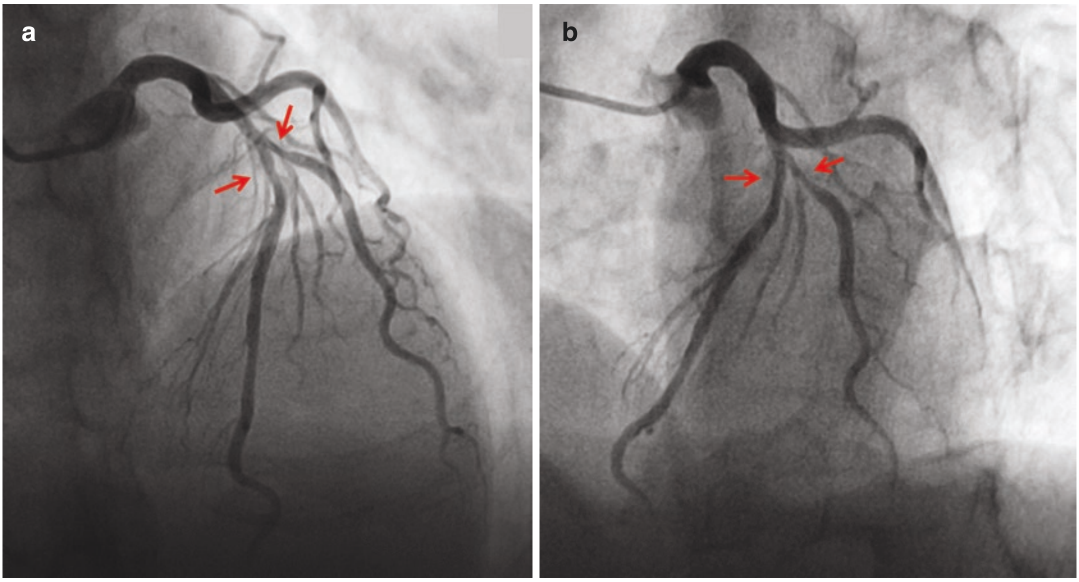

Fig. 1.4 Percutaneous transluminal coronary intervention (PCI) results. Invasive coronary angiography image of LAD and D1, (**a**, **b**, red arrow) with the corresponding FFR results lower than 0.8

ischemia may develop into myocardial infarction, which is irreversible and the prognosis may be poor.

1.3 Current Technical Status and Applications of CT

Radionuclide myocardial perfusion and MR perfusion imaging were most commonly utilized for diagnosing myocardial ischemia in our traditional daily practice. However, during the development of the last few decades, new technologies like single-energy first-pass CT acquisition, dual-energy (DE) CCTA, and myocardial perfusion imaging have become more and more popular as noninvasive medical imaging methods for evaluating hemodynamically significant CAD [1].

The single-energy first-pass CT allows static assessment of myocardial blood pool [2]. Multiple studies have shown that the rest and stress first-pass CT may be able to identify the myocardial ischemia with the reference standard of ICA, single photon emission computed tomography (SPECT), or MR. [3–7] Yet the challenge is a relatively subtle attenuation difference in the areas of perfusion defects.

The dual-energy first-pass CT also has been demonstrated capable of static assessment of myocardial blood pool as single-energy first-pass CT. However, on the basis of energy spectrum analysis, it was more advantaged for quantitatively detecting the myocardial ischemia. DE static first-pass CT makes mapping of iodine distribution possible, which in turn serves as a surrogate for myocardial perfusion [2]. Previous studies have documented enhanced tissue differentiation, along with high image quality and improved accuracy for detection of CAD using DECT imaging [8]. As tissue attenuation profiles obtained at two different energy levels, the disparity in energy-related absorption properties between the two X-ray spectra utilized in DECT allows for one to distinguish materials of sufficiently diverse attenuation profiles. Research has [9] demonstrated that monochromatic DECT imaging at 40 keV exhibited a higher diagnostic performance as compared with material density imaging using iodine-muscle basis pairs for the detection of myocardial ischemia as defined by perfusion defects detected with SPECT.

Comparing to SPECT and MR, with higher temporal and spatial resolution and development of radiation dose reduction, stress dynamic myocardial CT perfusion has emerged as a potential method for evaluation of hemodynamic myocardial ischemia in the clinical application [10]. It can be organized as a preoperative examination to investigate MBF, myocardial blood volume (MBV) and so on. Additional myocardial CT perfusion imaging may be helpful to identify patients with myocardial ischemia in whom coronary revascularization therapy would be beneficial [11]. A systematic review and meta-analysis have shown that stress dynamic myocardial CT perfusion has a high diagnostic accuracy in detecting myocardial ischemia and it may increase significantly at segment level in the combined use of coronary CTA [10]. Lately, a research even showed that single-phase CCTA can be extracted from stress dynamic myocardial CT perfusion for coronary artery stenosis assessment. The image quality and diagnostic value of single-phase CCTA were equivalent to routine CCTA on third-generation dual-source CT, which potentially allows the possibility of "one-stop" cardiac examination for high-risk CAD patients who need myocardial ischemia assessment [12].

As we can expect, myocardial CT perfusion is ready for clinical use for detecting myocardial ischemia caused by obstructive disease. Nevertheless, the clinical utility of CT perfusion to identify ischemia in patients with nonobstructive/microvascular disease still has to be established [11].

Lately, the FFR derived from CT (FFRCT) has shown its potential value for CAD patients with hemodynamically significant stenosis. It offers a noninvasive method for evaluating the borderline stenosis based on computational fluid dynamics calculation [13] or machine learning technology [14]. Both methods outperform the accuracy of coronary CTA and ICA in the detection of flow-limiting stenosis.

Integrating studies of myocardial CT perfusion and FFRCT in the work-up of CAD showed that both of them identify functionally significant CAD with comparable accuracy. Diagnostic performance can be improved by combining these two techniques. A stepwise approach, reserving myocardial CT perfusion for intermediate FFRCT results, also improves diagnostic performance while omitting nearly one-half of the population from myocardial CT perfusion examinations [15].

As we can see, appropriate cardiac CT examination contributes a lot for guiding downstream decision-making of treatment and evaluating clinical prognosis.

1.4 Key Points

- Reversible myocardial ischemia is one of the most clinical conditions in CAD patients.
- Multiple imaging approaches are capable of identifying myocardial ischemia, which is related to the hemodynamically significant coronary stenosis.
- Myocardial perfusion and fractional flow reserve derived from CT are the two most appropriate cardiac CT imaging methods for detecting hemodynamically CAD.

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