Interpretation of Cardiac CT in Patients with Ischemic Heart Disease: Fresh Case, Post-stenting, Post-surgical Bypass and Beyond

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To comprehensively evaluate a cardiac CT for ischemic heart disease, four types of patient should be evaluated with different considerations. They are fresh case, post endovascular revascularization, post coronary artery bypass operation and others. We will share the corresponding diagnostic algorithms in this essay. With the ability of comprehensive evaluation, MDCT could play a great role in the clinical care of ischemic heart disease patients.

Comprehensive evaluation of cardiac CT, including coronary artery, myocardium, left ventricular wall motion and viability, for ischemic heart disease patients is very important in clinical practice. [1] In this article, we will introduce the interpretation algorithm with examples to emphasize the key points of the comprehensive evaluation. The four groups of ischemic heart disease patients will be discussed separately: fresh case, post endovascular revascularization, post coronary artery bypass graft operation (CABG), and conditions presented resembling ischemic heart disease.

Fresh case
This group of patients is frequently encountered in hospitals other than cardiovascular specialized centers. They are also the most studied group in the literature. [2, 3] Clinically, we can evaluate the coronary event risk using calcium score, which is particularly useful in future follow-up, and then directly assess the coronary arteries in the following CT coronary angiography exam. If coronary stenoses are found, the issues which might relate to endovascular revascularization should be particularly noticed, such as whether involving bifurcation, if there’s acute or chronic total occlusion, and if there’s collateral formation. Then we match these lesions with their supplying myocardium to evaluate the myocardial impact of these lesions. [1] The affected myocardial condition should be further classified as functioning, hibernating or infarcted to decide if revascularization is worth doing. Also, for patients with severe coronary artery disease, the left ventricular thrombus and aneurysm formation are of particular importance (Fig. 1). [1]
Post endovascular revascularization

For patients who have received only balloon dilatation, the interpretation is similar to fresh case. Attention should be paid if restenosis occurs and if the ventricular function was restored after revascularization.

However, the condition would become much more complex if a coronary stent is placed, because stent imaging is still the weak point of multi-detector row CT (MDCT) [4-7]. Even though many studies show intra-stent restenosis can be diagnosed by MDCT with good accuracy [4-6], in clinical practice, it is mostly related to stent diameter, location and stent composition.[8] Still, a lot of stents implanted make lumen assessment impossible. [8] Generally, if the lumen can be visualized, the evaluation of intra-stent restenosis is possible by differentiating the width of intimal hyperplasia and patent lumen. [4-8] However, if the lumen is mostly partial-volumed by the stent structure, evaluation becomes impossible. Our recommendation for stent imaging is: (1) choose the most quiescent phase for the stent, (2) reconstruct a new set of image using high-resolution kernel designed for stent with the field of view focused on the stent to make the best use of the spatial resolution. [7] (3) use multiplanar reformation and proper window width/level to visualize the intra-stent con-

Figure 1. A 91-year-old male with chest tightness. a. Multiplanar reformatted image shows a large plaque over the proximal left anterior descending artery with 80% luminal stenosis (arrow). b. Short-axis view at diastole shows normal perfusion over the left ventricular myocardium. c. Short-axis view at systole shows good contractility of left ventricular myocardium. For interpreting contractility, the extent of myocardial thickening and myocardial moving distance should both be evaluated. In this case, the thickness and motion are both good. d. Short-axis view at delayed phase shows normal washout pattern of left ventricular myocardium, indicating viable myocardium. Thus, in this case, percutaneous coronary intervention over proximal left anterior descending artery is suggested to prevent further myocardial infarction and preserve the good left ventricular function.
Cardiac CT for ischemic heart disease

Figure 2. A 55-year-old male post coronary stent placement with recurrent chest pain. 

a. Multiplanar reformatted image based on the axial images reconstructed with routine soft kernel (Filter B, Brilliance 40, Philips). The critical stenoses over pre-stent segment (arrow) and intra-stent segment (arrowhead) are demonstrated with blurred border. Figure 2a, 2b and 2c’s window width/level are set the same, as 850/435, for comparison. 

b. Multiplanar reformatted image based on the axial images reconstructed with sharp kernel (Filter D, Brilliance 40, Philips) but with same whole-heart-coverage field of view. The critical stenosis over pre-stent segment (arrow) and intra-stent segment (arrowhead) are demonstrated with sharper plaque border. 

c. Multiplanar reformatted image based on the axial images reconstructed with sharp kernel (Filter D, Brilliance 40, Philips) and with small field of view focused on the stent. The critical stenoses over pre-stent segment (arrow) and intra-stent segment (arrowhead) are demonstrated even better. These serial images illustrate the importance of using sharp kernel and small field of view; both approaches increase the spatial resolution. There are many studies emphasizing the importance of using sharper kernel. In our experience, using smaller field of view is almost equally important.

dition (Fig. 2). If the stent still can’t be ‘see through’ with this approach, we will mention ‘the intra-stent lumen can’t be evaluated’ on the report rather than proceed on other guesswork.

Many studies emphasize the importance of using sharper kernel to visualize the intra-stent condition. However, in our experience, using smaller field of view is almost equally important. Making best use of MDCT’s spatial resolution could help much in stent evaluation (Fig. 2).

Even if the stent can’t be ‘seen-through’, MDCT still plays a role in evaluating other de novo lesions in other coronary segments. Thus, in patients with recurrent chest pain after stent placement, we still consider non-invasive MDCT as the first-line modality but mentioning the potential weakness to the patient before exam.

Post coronary artery bypass graft operation

Patients post coronary bypass graft are probably the most time-consuming in cardiac MDCT evaluation. Many studies have focused on graft imaging using MDCT [9, 10], but MDCT actually can do much more beyond that. In MDCT, we can clearly evaluate the appropriateness of graft planning (Fig. 3), and the results of revascularization (Fig. 4), and identify the cause of patient’s recurrent symptom (Fig. 5) [11] under the surgically created new coronary supply map. Combining with myocardial assessment can let us know if the patient needs further revascularization. If needed, which approach should be suggested, endovascular or surgical? (Fig. 5, 6) A comprehensive approach is very beneficial to patients post coronary bypass graft.

We summarize the interpretation algorithm of patients post coronary bypass graft into five steps: (1) History. What kind of operation did the patient receive? (2) Evaluate the anatomy and patency of grafts, native coronary arteries and anastomoses; (3) Evaluate the left ventricular myocardium and match it with the new coronary supply map; (4) Findings other than CABG; (5) Making diagnosis with treatment suggestion.

First, we have to know what operation the patient received. This can be done either by reviewing the operation history or by reading the post-operative findings on MDCT. This could lead us to pay special attention to the possible post-operative complications. For example, traditional on-pump CABG could have problem of sternal dehiscence [12], off-pump
Figure 3. A 66-year-old male post coronary artery bypass operation with recurrent exertional dyspnea. a. & b. Volume-rendering images demonstrate the patency of the composite arterial U-graft using left internal mammary artery (LIMA) and radial artery (arrows) to anastomose left anterior descending artery (LAD) and a branch (arrowhead) of posterolateral artery of right coronary artery (RCA). However, the whole lateral wall (Lat) can’t be revascularized due to there being no patent coronary artery branch for anastomosis. c. & d. Short axes of diastole (c) and systole (d) of arterial phase shows hypokinesia over the lateral wall myocardium (arrow), which corresponds to the decreased coronary artery supply in the lateral wall. e. Short axis of delayed phase shows normal washout pattern over lateral wall (arrow), hibernating myocardium is considered. Even though there is no CT-visible coronary artery over the lateral wall, the myocardium is not infarcted but only hibernated. The condition is assumed to be previously severe coronary artery disease over circumflex territory but still some invisible intramyocardial collateral vessels supplying the region. In this case, neither percutaneous coronary intervention nor surgical revascularization could be suggested.
coronary artery bypass operation could have problem of immediate patency in inexperienced hands[13,14], robotic assisted off-pump coronary artery bypass operation could have graft failure while passing the lateral wall to the posterior descending artery due to limited space for cardiac manipulation. [15] (Fig. 6) Understanding the possible complications would enhance our interpretation.

Secondly, in vascular evaluation, not only should the graft be assessed, but also the anastomoses and native coronary arteries are important. Since the patient might have only single- or two-vessel disease prior to operation, there would be native coronary arteries not bypassed. The recurrent symptom would probably result from new lesions in the non-bypassed native coronary artery (or arteries) (Fig. 5). If the evaluation is only limited in graft, we will fail to help these patients.

**Figure 4.** A 57-year-old male with vague chest discomfort after coronary artery bypass operation. **a.** Volume-rendering image shows patent composite U-graft using left internal mammary artery (LIMA) and radial artery (black arrows). The composite graft is anastomosed with middle left anterior descending artery, first diagonal (D1), first (OM1) and second (OM2) obtuse marginal branches for two-vessel coronary artery disease (left anterior descending and circumflex coronary arteries). However, the native distal left anterior descending coronary artery (D-LAD) and distal first diagonal branch show severe atherosclerotic change with obliterated lumen. The recurrent symptom is considered to be related to the atherosclerotic process of the distal native vessels distal to the graft anastomoses. **b. & c.** Short axis of diastole (b) and systole (c) of arterial phase show good left ventricular wall motion. **d.** Short axis of delayed phase shows normal washout pattern, indicating normal myocardium. Due to patent graft, normal left ventricular wall motion, viable myocardium and the diseased distal coronary arteries can’t be treated; only follow-up is suggested for this patient.
Thirdly, we could match the surgically created new coronary map to the patient’s myocardial condition. Due to the high spatial resolution of MDCT, we can clearly match any coronary artery to the supplying myocardium. [1] Most important is to identify hibernating myocardium [16-19] which could potentially be revascularized [19] and viable and functioning myocardium but with critical stenosis over the supplying vessel. We can restore the function in the former and prevent function loss in the later. The symptoms and prognosis can be improved if we do proper interpretation and suggest proper intervention.

Fourthly, we evaluate the extra-coronary findings using the gated images and reconstructed non-
Figure 6. A 68-year-old male with vague chest tightness after da Vinci robotic assisted coronary bypass graft operation.  

a. The volume-rendering image of the chest wall shows intact skin above the sternum (between arrowheads) and an 8-cm wound (between arrows) over the left anterior chest wall indicating robotic assisted left internal mammary artery harvesting with off-pump minimally invasive direct coronary artery bypass operation. b. & c. The volume-rendering image for the heart shows composite U-graft using left internal mammary artery (LIMA) and radial artery (arrows) to anastomose the left anterior descending artery (LAD), the first obtuse marginal branch and then passing the lateral wall to anastomose with the posterior descending artery (PDA) from the right coronary artery (RCA). The course of the graft could be traced also by the assistance of surgical clips (arrowheads). The distal first obtuse marginal branch (OM1) is occluded, and when the posterior-descending-artery arm of the U-graft passes the lateral wall, the lumen becomes very small and then occluded, causing failure to revascularize the posterior descending artery. Reviewing this case, the surgeon commented the partial graft failure was due to limited space for manipulation while anastomosing the posterior descending artery (PDA). (PLB: posterolateral branch of right coronary artery). d. & e. Short axis of diastole (d) and systole (e) during arterial phase show good left ventricular wall motion. f. Short axis of delayed phase shows normal washout pattern, indicating viable myocardium. Summarizing the above findings, since the proximal right coronary artery lesion (not shown) can’t be treated by percutaneous coronary intervention due to chronic thrombus, re-do of the coronary artery bypass graft for the posterior descending artery is suggested if the patient shows accelerating recurrent typical symptoms.
Figure 7. An 83-year-old male with chest tightness and angiographically proven three-vessel disease. a. & b. Short axis of diastole (a) and systole (b) in arterial phase show generalized hypokinesia of the left ventricle, which could be compatible with three-vessel coronary artery disease. The ejection fraction is only 25.7% by short-axis volume method. The patient then received three-vessel territory surgical revascularization with U-graft. c. & d. After nine months, the patient’s exertional dyspnea didn’t improve. Follow-up MDCT was performed. Volume-rendering image shows patent composite U-graft using left internal mammary artery (LIMA) and radial artery (black arrows) to anastomose with the left anterior descending artery (LAD), first diagonal (D1), first obtuse marginal (OM1), second obtuse marginal (OM2), third obtuse marginal (OM3) branches of circumflex artery and posterior descending artery (PDA) from the right coronary artery (RCA). A complete and good three-vessel territory revascularization was performed. The distal native coronary arteries were also patent. e. & f. Short axis of diastole (e) and systole (f) in arterial phase still show generalized hypokinesia with ejection fraction of only 23.4%. There is no improvement at all for the myocardial motion. For hibernating myocardium (poor motion but normal washout pattern in delayed phase), it is believed that the motion will recover six months after successful revascularization. However, in this patient, the function is not restored. g. The short-axis view of apical level at diastole in arterial phase shows prominent left ventricular trabeculation. The non-compaction (black double arrow)-to-compaction (white double arrow) layer ratio (NC/C ratio) is more than 2. Left ventricular non-compaction is diagnosed. h. Short axis of delayed phase shows normal washout pattern, indicating viable myocardium. Summarizing the patient’s serial MDCT findings, the patient’s poor left ventricular motion is considered to be caused by both coronary artery disease and left ventricular non-compaction. Treating coronary artery disease only can’t reverse the poor function. Thus, for this patient, the suggestion would be medical treatment and follow-up, rather than further intervention.
gated large field of view images to identify other reasons related to the patient’s recurrent symptom. For example, sternal dehiscence [1] and left ventricular non-compaction (Fig. 7).

Finally, from the above observations, we can give the patient an appropriate suggestion: conservative treatment, endovascular or surgical revascularization. A qualified cardiac radiologist should play a key role in clinical care by fully exploring the robustness of MDCT.

**Others: conditions presented like ischemic heart disease**

Sometimes, patients present with symptoms like those of ischemic heart disease but actually have another underlying disease. Due to the powerful spatial and temporal resolution of MDCT, we can not only exclude coronary artery disease but also find the correct diagnosis, such as left ventricular non-compaction (Fig. 7), arrhythmogenic right ventricular dysplasia (Fig. 8), leakage of Bentall operation.

**Figure 8.** A 77-year-old male presented as ventricular tachycardia post cardioversion. Arrhythmogenic right ventricular dysplasia is diagnosed with epsilon wave on ECG and right ventricular morphology according to the McKenna criteria. a. Multiplanar reformatted image shows normal coronary artery. Motion artifact is noted over middle right coronary artery (arrow). b. Sagittal view of arterial phase shows focal 4-cm aneurysm (arrows) over the anterior wall of the right ventricular outflow tract. c. Axial image of arterial phase shows intramyocardial fatty infiltration (CT number less than zero) over the right ventricle (arrow). Also notice the fatty infiltration over the right ventricular trabeculation (arrowheads). These foci are considered to be arrhythmogenic in current knowledge. Please also note that the fatty change in the right ventricle evidenced by non-invasive image modality is not a diagnostic criteria currently. d. Axial image of a normal patient with same age shows no fatty infiltration over the right ventricular wall (arrow) and trabeculation (arrowhead).
Figure 9. A 63-year-old male post Bentall operation for two years with typical chest pain. a. Multiplanar reformatted image shows normal coronary arteries. If the evaluation is only limited to the coronary artery, then the patient’s diagnosis will probably never be achieved. (RCA: right coronary artery, LAD: left anterior descending artery, CRX: circumflex artery). b. Multiplanar reformatted image of prosthetic aortic valve (arrowhead) in systole shows good position without suture loosening. Incidentally, a peri-aortic hematoma is found (arrows). (LVOT: left ventricular outflow tract, Ao: aorta, LA: left atrium). c. Multiplanar reformatted image near left main coronary artery (LM) shows a focal defect due to suture loosening of coronary re-implantation results in the hematoma formation. A bidirectional shunt is noted. During systolic phase, the shunt is from the true lumen to the hematoma. During diastole, the shunt is from the hematoma, which could have many microthrombi due to flow stasis, projecting to the left main orifice (arrows). This explains the chest pain symptom of the patient. Re-do Bentall operation was then suggested, but the patient refused. (LVOT: left ventricular outflow tract)
Cardiac CT for ischemic heart disease

(Fig. 9), and lupus microangiopathy [1]. The treatments of these diseases are totally different from those for coronary artery disease. Patients can save time and cost on a negative catheter coronary angiography and quickly receive appropriate treatment such as intracardiac defibrillator implantation, re-do Bentall operation or control of the lupus activity.

**CONCLUSION**

In this essay, we have reviewed the current status and interpretation algorithms (Fig. 10) of MDCT in ischemic heart disease patients. Though most of the studies in the literature are focused on the coronary artery or the graft, exploring the extra-vascular part of the heart also helps much in clinical care. With the ability of whole-heart evaluation, MDCT could play a great role in the clinical care of ischemic heart disease patients.

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缺血性心臟病之多切面電腦斷層判讀：初診患者、支架置放後、外科繞道術後與其他

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在判讀缺血性心臟病患者的多切面電腦斷層時，會遇到四大類的患者，包括：初診病人、支架置放後患者、外科繞道術後患者以及其他，而其評估流程與重點皆有不同，我們將於文中分享之，並提供中文流程圖供讀者臨床使用參考。若能依據評估重點完整判讀，則多切面電腦斷層在各類缺血性心臟病患者的臨床照護上，將能扮演相當重要的角色。