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REVIEW

CT coronary angiography of chronic total occlusions of the coronary arteries: how to recognize and evaluate and usefulness for planning percutaneous coronary interventions

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Abstract Chronic total occlusions (CTO) of the coronary arteries are a common finding. A CTO can be underdiagnosed on CT coronary angiography (CTCA) as a high grade stenosis, because of the presence of retrograde collaterals which allow opacification of the vessel distal to the stenosis, or can be missed completely, especially if another adjacent opacified artery is mistaken for occluded artery. CTOs are considered as Type C or high risk lesions with a higher restenosis rate and increased technical failure rate by percutaneous coronary intervention (PCI). CTCA can help identify features that most influence current success rates of PCI such as marked calcifications at the stump, severe tortuosity of the proximal vessel, long length of the occluded segment as well location of the vessel distal to the occlusion, which often may not be well seen on conventional angiography. Identification of these features and displaying the 3D information as the best angiographic projection that demonstrates the length and orientation of the CTO, either as hard copy images or transmitted direct to the angiographic catheter lab for data fusion, allows strategic preprocedural planning and scheduling of the PCI. Myocardial viability of the affected area of the occluded segment is a major factor that influences whether PCI for CTO is attempted but is not currently readily available by cardiac CT. Contrast enhanced cardiac MR imaging is still the gold standard for this and may need to be performed prior to PCI.

Keywords CT coronary angiography · Chronic total occlusion · Percutaneous cardiac intervention · Coronary revascularization

Abbreviations

CAG	Conventional coronary angiography
CTCA	CT coronary angiography
CTO	Chronic total occlusion
DES	Drug eluting stent
IVUS	Intravascular ultrasound
LAD	Left anterior descending artery
MACE	Major adverse coronary event
MI	Myocardial infarction
MPR	Multiplanar reconstructions
MIP	Maximum intensity projection
RCA	Right coronary artery
PCI	Percutaneous coronary intervention
QCA	Quantitative coronary angiography
TIMI	thrombolysis in myocardial infarction

Introduction

The ability of CT coronary angiography (CTCA) to diagnose and detect coronary stenosis (≥50%

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stenosis) with high sensitivity as well as high specificity compared to quantitative coronary angiography (QCA) has been well documented in recent years [1–3]. All the previous reports have used a threshold of ≥50% minimal luminal diameter narrowing at the site of the stenosis (the so-called binary cut-off) in order to define clinically significant coronary stenosis. However, in daily clinical practice, the detection of significant coronary stenosis is not sufficient and CTCA is less successful for quantitative assessment compared to QCA; moreover, there is still considerable standard deviation associated with CTCA [4–6]. A multi-tiered or graded method of reporting different categories is usually used by most readers of CTCA scans. The use of a multi-tiered reporting system based on visual assessments has been recently validated [7], and this study also showed that a stenosis of ≤50% on CTCA can be considered virtually exclusive of a ≥70% stenosis on conventional coronary angiography (CAG). Many readers reporting CTCA scans would report a stenosis of >70–75% as high-grade stenosis with another category for chronic total occlusion (CTO) if the diameter of the stenosis was 100%. However, there are some pitfalls associated with the diagnosis of CTOs on CTCA, as it not only depends on the observed degree of stenosis present at the site of the lesion but because the vessel distal to the CTO is often visualized or opacified with contrast due to retrograde collateral flow, the diagnosis of CTO may be underestimated or missed.

Definition of CTO and clinical relevance

Chronic total occlusions of the coronary arteries is defined as the obstruction of the native coronary artery with no luminal continuity and interruption of antegrade blood flow as assessed by coronary angiography with thrombolysis in myocardial infarction (TIMI) grade zero flow with total flow occlusion, or TIMI grade one flow, with minimal contrast penetration through the lesion without distal vessel opacification, and occlusion period of more than 3 months estimated from the clinical events or proven by previous angiography [8].

Incidence of CTO is quite high in patients undergoing CAG and can be seen in more than one-third of patients [9]. CTO was found in 52% of patients with significant (≥70% diameter stenosis) coronary artery disease in another study [10]. CTOs are most prevalent in the right coronary artery (RCA), followed by the left anterior descending artery (LAD), and are least common in the circumflex artery; they increase with advancing patient age [11]. Clinically, most CTO patients who undergo PCI also tend to be symptomatic with stable or progressive angina; unstable angina is seen in <20% of patients with CTO, and asymptomatic conditions are observed in only about 11–15% patients, who are usually managed medically [12].

Percutaneous coronary intervention of CTO remains a major challenge for interventional cardiologists; it is a complex procedure with a variable success rate of 55–80% in most experienced centres, but high success rates only in a few luminary sites [13]. The rationale for performing PCI in patients with CTO includes relief of symptoms, especially angina; improvement of regional and global LV ejection function, especially if the initial ejection fraction is <60%; reduction of arrhythmias; and reduced need for bypass surgery. It has also been recently shown that there is improved myocardial blood flow and contractility after PCI, which can be evaluated by cardiac MR (CMR) after PCI [14].

In addition, there is good evidence of improved long term 5- and 10-year survival with reduced mortality rates, lower incidence of myocardial infarction (MI), and improved tolerance to future coronary events [15, 16]. Looking at the 10-year survival based on CTO location, those that do best have CTO of LAD successfully treated followed by RCA. There is no long-term survival advantage for successfully treated CTO of left circumflex [17].

Percutaneous coronary intervention of CTO is a high-risk procedure with 80% of failures related to guidewire crossing. Complications include dissection, perforation, and impairment of ipsilateral collaterals to the distal bed. The major adverse coronary event (MACE) rate with a successful PCI of CTO is about 2–2.5% but can exceed 5% [13]. Moreover, note that an unsuccessful CTO procedure is not risk free—failed PCI is associated with MACE rate of about 5.6% compared with successful PCI–MACE rate of 2.5% [18].

Thus, correct patient selection for PCI is paramount due to the increased risks, but conservative treatment of a CTO may not always be the best option, and preprocedure viability imaging seems to be an important factor in taking the decision on PCI [19]. Essentially, PCI for CTO is warranted when the occluded vessel is responsible for the patient's symptoms, the myocardium supplied by the occluded artery is viable, the likelihood of success is moderate to high (>60%), and the anticipated major-complication rate is low [13]. Assessment of myocardial viability, e.g., by using contrast-enhanced cardiac magnetic resonance (CMR) imaging performed prior to PCI for CTO may help in identifying the patients who will benefit from PCI [19].

Diagnosis of CTO on CTCA

To diagnose a high-grade coronary artery stenosis on CTCA when reading the scans, one should look for a marked decrease in the diameter of the contrast-filled lumen, at the site of the lesion, and the site of stenosis should also show the presence of a coronary plaque. Using axial scans and oblique multiplanar reconstructions (MPRs) as the main tools on the workstation, one can estimate or measure the maximum degree of stenosis at the level of the lesion (minimal luminal diameter); compare this to a reference site, either proximal or distal to the stenosis; and get the percentage stenosis estimation [20]. The use of dedicated software-analysis tools may also be helpful, especially when calcifications are present.

To diagnose a CTO, one should look for complete lack of opacification of the lumen of the artery, especially in the cross-sectional views (Fig. 1). There is usually opacification of the vessel lumen distal to the site of occlusion due to retrograde collateral flow of contrast, which results in contrast opacifying the lumen, distal to the occlusion (Fig. 1). This is due to the relatively long time that has transpired between intravenous injection of contrast and the time required for the scan acquisition ($\sim$20–30 s). If there is no contrast opacification of the distal vessel beyond the occlusion, then one should suspect that the occlusion is not a chronic one but may be subacute or acute occlusion as filling of the distal vessels from retrograde collaterals is usually expected (Fig. 2). 3D-VR images are also helpful to aid in the diagnosis of a CTO as a CTO can usually be easily recognized on 3D images (Fig. 3). Note that it is also difficult to differentiate between a subtotal or severe high-grade stenosis (99%) and total (100%) stenosis on CT (Fig. 3). Both total and subtotal occlusions appear as complete interruption of contrast-enhanced lumen on CTCA. A recent study examined the parameters on CTCA that may allow differentiation between the two and concluded that this was not reliably possible due to the limited spatial resolution of CTCA. Total occlusions were found to be associated with more calcification and more marked reduction of contrast density over the lesion and tended to be >9 mm in length [21].

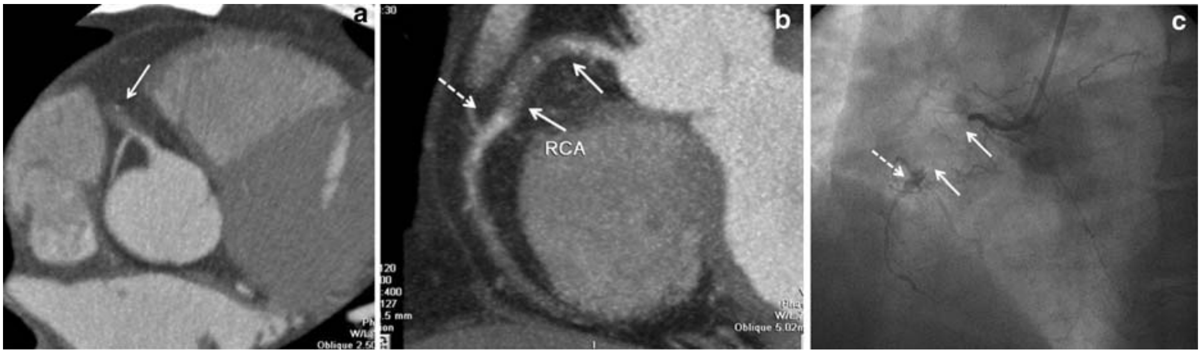

Fig. 1 **a** To recognize a CTO, look for complete absence of a contrast-filled lumen, which suggests a CTO at that level, in this example; the occluded proximal RCA (*arrow*), **b** The lumen of the artery distal to the occlusion is opacified by contrast (*dashed arrow*) due to collateral circulation. The segment of occlusion in the RCA is shown *between arrows*. Moreover, note the poor opacification of the distal vessel. The CTCA suggests PCI will be more difficult because of the absence of any clear stump, moderately long total occlusion, and poor distal vessel quality, **c** CAG shows the segment of occlusion (*between arrows*) corresponding to CTCA findings, and the segment opacified by contrast from the collateral flow (*dashed arrow*). PCI was not successful in the recanalization of the RCA

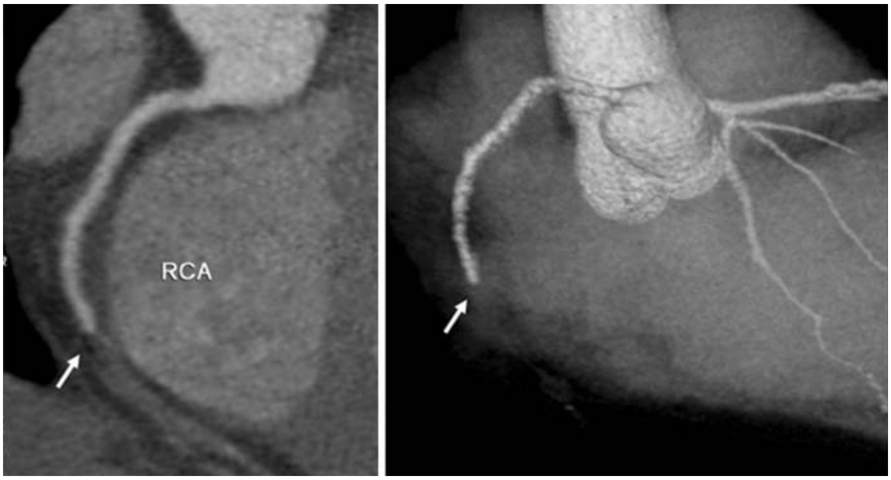

Fig. 2 CTCA images show occlusion of mid RCA near the junction with distal RCA with complete cutoff at the stump of occlusion on the MPR and 3D-MIP images and no visualization of the artery distal to occlusion. This would be a very uncommon finding on CTCA for a CTO, as usually the vessel distal to the occluded segment is opacified by collateral flow. In this case, the duration of the patient's symptoms (chest pain) was for a few weeks, less than 3 months, and this most probably represents sub-acute occlusion and not a chronic occlusion. PCI was successfully performed

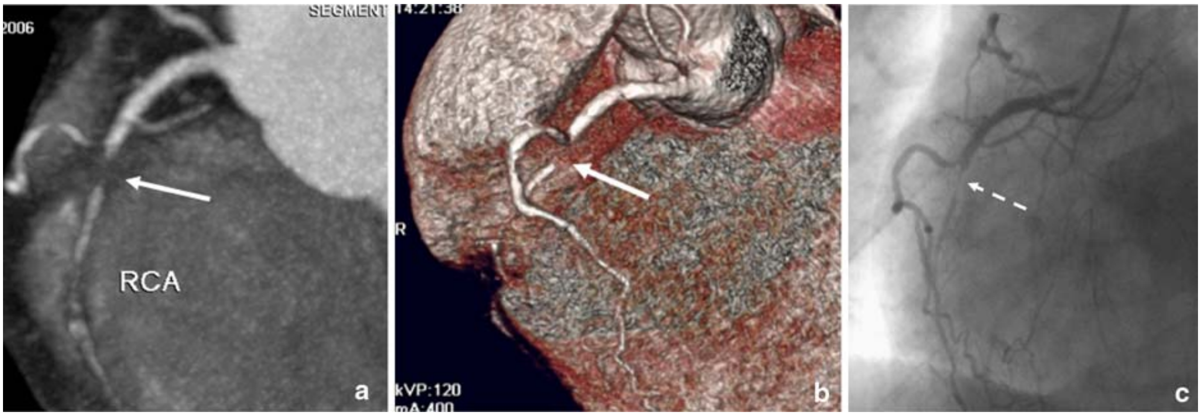

Fig. 3 **a–c** On CTCA, there is a segment in the mid RCA (*arrow*) where the lumen is not opacified with the contrast. The vessel distal to the occluded segment is opacified with contrast. The segment of occlusion is easily recognized on the 3D-VR images. Diagnosis of CTO of mid RCA was made based on CTCA findings, but CAG shows the presence of a subtotal occlusion (98–99% stenosis) (*dashed arrow*). On CTCA, it is usually not possible to differentiate between a total or subtotal occlusion

Many new readers of CTCA scans tend to like to use 3D-VR images and the latest software for automatic segmentation of vessels and vessel diameter analysis obtained from various workstation vendors as their primary method of reading scans. These advanced visualization tools should however, not be used as a single method for the detection and grading of coronary artery stenosis [22]. Oblique MPRs have been confirmed as the most accurate of the various post-processing methods of detection for stenosis with CAG as the reference standard [23]. Knowledge of the normal anatomy of the coronary arteries as depicted on CTCA axial scans and 3D is also important. In particular, failure to appreciate the normal anatomy and course of the LAD as it courses along the epicardium in the interventricular groove between the normal left and right ventricles can result in missing a total occlusion of the mid or distal LAD,

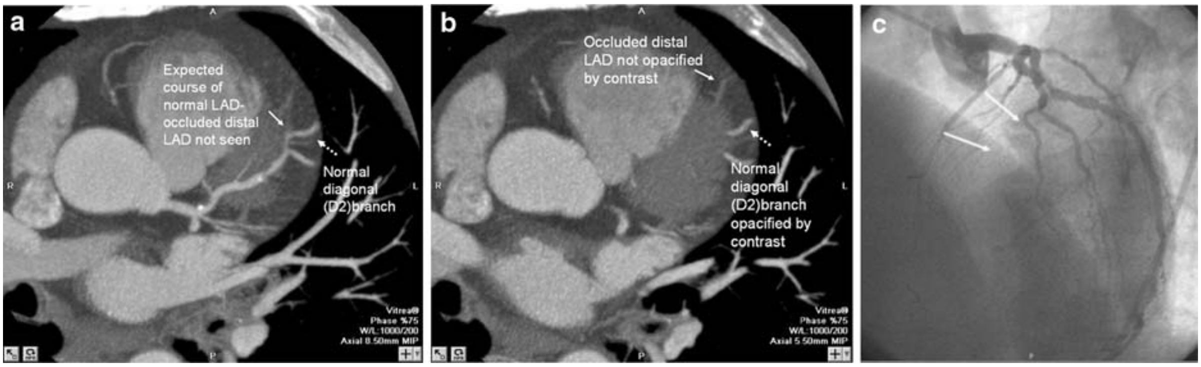

Fig. 4 **a** CTO of the distal LAD missed by the initial reader of the CTCA scan as the vessel-segmentation probe-software tool has been placed in a diagonal branch and not in the LAD. Advanced software tools and 3D-volume-rendered (*VR*) images must not be relied on as standalone tools for analysis. Axial and oblique MPR images must be used for reading scans as the basic tools for detection and quantification of coronary artery stenosis, **b** Axial images showing that the distal LAD is occluded and not opacified with contrast just after the origin of the D2 branch. The contrast opacified D2 branch in its normal course, lateral to the interventricular groove, should not be mistaken for the normal LAD, **c** CAG confirms CTO of distal LAD (*arrows*) after origin of the D2 branch, and successful PCI was performed, although occlusion site is associated with a side branch

as the contrast opacified diagonal branch can be mistaken for a normal contrast-opacified LAD (Fig. 4).

Identifying the types of lesions of coronary stenosis for PCI

The ACC and AHA have a classification system for assessing the morphology of coronary stenotic lesions; this system allows estimation of procedural success in PCI by use of low-risk, medium-risk, and high-risk categories, based on the presence or absence of specific high-risk lesion characteristics (Table 1). High-risk lesions have at least one type-C characteristic while non-high-risk lesions have no type-C lesion characteristics. A CTO is considered as a Type-C lesion. [24, 25] High-risk lesions have higher adverse events after PCI; however, for CTOs, although the risk of restenosis and technical failure is high, the risk of acute complications is not increased.

Success rate of PCI for CTOs

With many new devices and technologies as well as new techniques and methods of crossing CTOs now available, the current success rate of treating CTOs by PCI is generally around 55–80%, with higher success rates (>80%) in some luminary expert centres, especially in Japan [26]. The most common reasons for procedural failure of PCI for CTOs include inability to cross the lesion into the true lumen of the distal vessel with a guide wire (>60%), intimal dissection with creation of a false lumen, contrast extravasation, failure to cross the lesion with a balloon, or failure to dilate adequately [27]. A major reason for increased technical success is the availability of stiffer, more powerful guide wires with greater torque. Tapered-tip wires or wires with hydrophilic coatings are also commonly used.

New and advanced wiring techniques such as anchoring a balloon in a side branch; performing subintimal dissection and using parallel-wire techniques; retrograde collateral crossing after failed antegrade approach using collateral channels that arise from a contra lateral artery; and IVUS-guided wiring to look for the true lumen, are all used now to improve the chances of technical success of PCI of CTOs [26]. Contralateral contrast injections to visualize the distal vessel via collaterals, e.g., into the left main with catheter in RCA for CTO of the RCA, are also often used; these injections are also used to demonstrate the exact length and orientation of the CTO and to allow antegrade approaches or retrograde collateral approaches via intramyocardial or epicardial collaterals [28]. However, not all these new techniques have been widely adopted due to their

Table 1 ACC-AHA characteristics of type-A, type-B, and type-C coronary lesions

Type A lesions (high success rate [>85%]; low risk)
Discrete (<10 mm)
Little or no calcium
Concentric
Less than totally occlusive
Readily accessible
Not ostial in location
Nonangulated segment (<45°)
No major side-branch involvement
Smooth contour
Absence of thrombus
Type B lesions (moderate success [60–85%]; moderate risk)
Tubular (10–20 mm length)
Moderate to heavy calcification
Eccentric
Total occlusions < 3 months old
Moderate tortuosity of the proximal segment
Ostial in location
Moderately angulated (45–90°)
Bifurcation lesion requiring double guidewires
Irregular contour
Some thrombus present
Type C lesions (low success [< 60%]; high risk)
Diffuse (>20 mm length)
Total occlusion >3 months old
Excessive tortuosity of the proximal segment
Inability to protect major side branches
Extremely angulated segment (>90°)
Degenerated vein grafts with friable lesions

Note: The high risk in CTO and vein grafts is for technical failure and increased restenosis, not for acute complications

From Smith et al. [25]

complexity, technical difficulty, long procedure times, and excessive radiation exposure [29].

Once the wire crosses the CTO a low-profile balloon is usually used to follow. If this is not possible, then excimer laser or high-speed rotational atherectomy devices may be helpful for debulking the resistant lesions, especially in the more fibrocalcific lesions that are resistant to balloon dilatation (seen in 2–5% of CTOs) [30]. There are also specialty-guiding catheters that give more support and can be used instead of a laser or atherectomy device for previously difficult, uncrossable lesions.

Angiographic predictors of successful angioplasty of CTO and the value of cardiac CTCA

Traditional clinical and angiographic predictors of procedural success are well known to interventional cardiologists and the adverse factors include CTO >3 months duration, vessel length >1.5 cm, presence of moderate to severe calcium, length > 1.5 cm, TIMI 0 flow, CTO stump not seen or missing or not tapered, presence of antegrade bridging collaterals, tortuosity of vessel proximal to CTO, and presence of side branch at the occlusion site [31, 32]. Currently, with the improved techniques and technology with the newer guide wire and devices, the main predictors of failure are calcifications, marked vessel tortuosity, and long occlusion length [28] (Table 2). The presence of bridging collaterals was previously a major determinant of unsuccessful PCI as these likely represent the chronicity of the CTO lesion, but the availability of newer higher-torque guide wires allows higher success rate of penetrating the occlusion [30].

In a first report on the use of 16-slice CTCA for CTO, it was found that CTCA features of CTO that can be identified as predictors of PCI failure are an occlusion length >1.5 cm and the presence of severe calcifications, while the best angiographic predictor was a CTO lesion with a blunt rather than a tapered stump [33]. While these variables are all well established predictors of CTO failure, and none of the findings are unique to CTCA compared with CAG, it can be difficult to identify all these features on CAG even after careful study prior to PCI, and if CTCA is performed prior to PCI, this information from CTCA allows for adequate preprocedure planning and scheduling (Figs. 5, 6).

CTCA is probably most useful in long, tortuous total occlusions in which there is a need to characterize the path of the lesion and CTCA can be used to accurately identify the route and the course of the CTO segment and allow assessment of the quality of the distal vessel. CTCA also allows the evaluation of the distribution and amount of calcified plaque to help improve the success rate of PCI, as CTCA can identify features not readily seen on CAG [8]. It is not uncommon for the true course and length of an occluded segment to be missed or not seen at the time of CAG. Segments of the totally occluded vessel are often not visualized on CAG; however, they are

Table 2 Current angiographic predictors of PCI failure for CTOs (with availability of newer high-torque, tapered, and hydrophilic guide wires and newer PCI techniques such as balloon-anchor techniques, IVUS-guided retrograde approaches, etc.)–after Tsuchikane et al. [28]

Most important predictors
Severe calcification at the stump of CTO
Tortuosity of the proximal vessel of CTO
Very long occlusion length
Other predictors for less-experienced operators
Absence of antegrade flow and no or poor distal vessel visibility
Long occlusion duration
Presence of antegrade bridging collaterals (reflection of chronicity of the lesion)
Blunt stump occlusion
Presence of side branch at occlusion site

always apparent on CTCA, and their visualization will help facilitate the passage of the guide wire [34]. Visualization of the distal vessel is most important for successful PCI, and it often requires contralateral injections at the beginning of the PCI procedure. It was recently reported that CTCA was able to identify the distal vessel and route for PCI in 68% while CAG was able to show a possible coronary route in only 18% [35].

Morphological characteristics and the length of the occlusion can be assessed by CTCA and additional information such as anatomical landmarks can also be used to guide or refine optimal PCI of the CTOs [36]. The 3D nature of CTCA allows accurate measurements of length that do not suffer from calibration limitations, foreshortening, or absence of collateral filling, as occurs with CAG [33]. CTCA can also be easily used to provide guidance for the location of entrance of ostial or flush occlusions that are often difficult to find at CAG [34].

Currently, the most difficult subsets of successful PCI in CTO lesions are tortuous anatomy before and in the CTO, and severe calcified plaque in the CTO lesion. As CTCA is being used more frequently, a recent report has again shown the ability of CTCA to identify these features and predict the procedural outcome [37] (Table 3). The good ability of CTCA to identify calcifications at the stump of a CTO has also been confirmed in a study where intravascular ultrasound (IVUS) was used as the gold standard

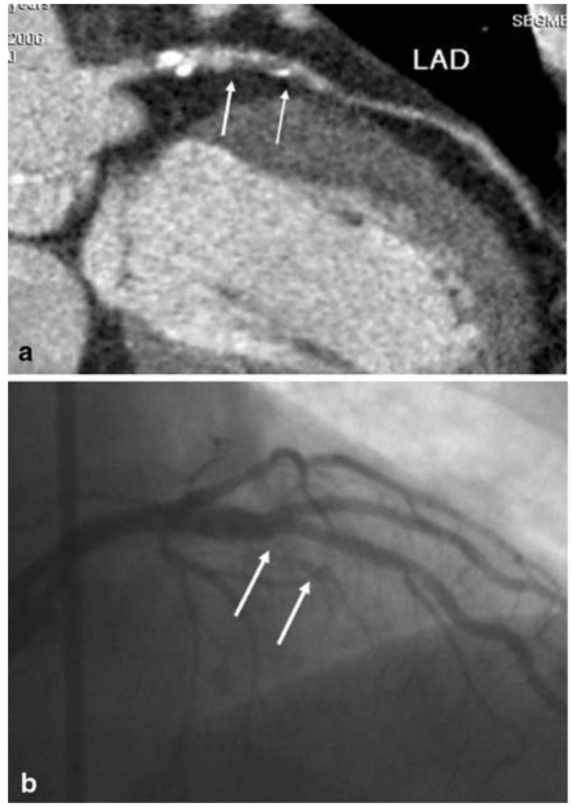

Fig. 5 **a** CTCA shows the segment of CTO in mid LAD (*arrows*). This could be easily misdiagnosed as high-grade stenosis of mid LAD if the lesion was only viewed on MPR images and not in the cross section, which showed no contrast in lumen. Short length of involvement can be easily estimated from the CTCA scan and there is a tapering of the stump of the occlusion, which shows no evidence of calcification. CTCA features predict that PCI should have a high success rate. These findings are confirmed on CAG, and PCI was performed successfully

for detecting the presence of calcification at CTO [38]. CTCA had a significantly higher sensitivity compared to CAG for the detection of calcification; compared with IVUS, the sensitivity of CTCA to detect calcification in CTO was 82% while CAG sensitivity was 66%. CTCA also underestimated the severity of calcification in only 9% while CAG underestimated in 30% [38]. Severe calcifications are associated with more complications, lower success rate, inadequate stent expansion, and higher restenosis rate. Concentric calcification is the hallmark of an undilatable lesion, which usually needs debulking first, and CTCA can identify these easily prior to PCI (Fig. 6).

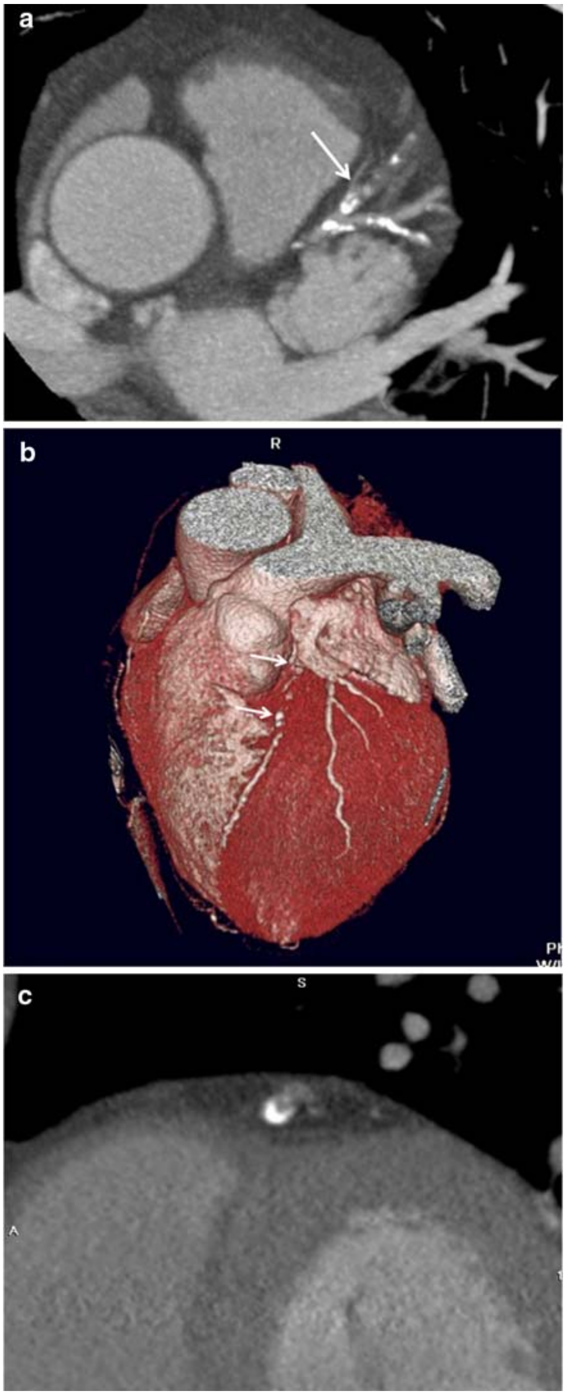

Fig. 6 a–c Axial scan shows calcified plaque at the stump of occlusion and no contrast distal to calcium due to the CTO. On the 3D-VR view, the CTO is easily visualized and the 3D-VR views are helpful to aid the recognition of a CTO on CTCA. On the cross-sectional view, at the stump of the CTO in the mid LAD, there is a severe calcified plaque that is partly concentric, suggesting that the guidewire passage at PCI may be difficult or that the lesion may be undilatable and that the use of a rotational atherectomy device may be needed

3D images from CTCA can be used for road mapping by allowing the determination of the optimal working view angle that best demonstrates the target lesion with least foreshortening, while thin-slab maximum-intensity-projected CTCA images of the target lesion can be used to depict the bends of the complex luminal path, vessel geometry, and occluded segment, and this provides preprocedural information for planning strategies that led to successful complex PCI procedures [39]. The 3D information from the CTCA scan can also be imported directly to the catheterization lab and electronically linked to the C-arm on the angiographic table. This fusion of CTCA images with the catheterization lab is currently only available with one vendor, but it does allow automatic rotation of the CTCA road map to the angiographic C-arm angle with the least foreshortening and overlap of the target lesion, and allows more accurate stent sizing as well as selecting the best approach for the guidewire passage [34].

Identification of bridging collaterals is usually not possible on CTCA, although, as mentioned earlier, the presence of the bridging collaterals is currently less important as a negative predictor of successful PCI. Septal collaterals that can be readily identified on CAG either by antegrade or contralateral injections cannot be identified by CTCA due to their intramyocardial location (Fig. 7). However, collaterals from elsewhere may be visible, e.g., with a mid LAD occlusion; the collateral vessels from the RCA may be seen opacifying the LAD distal to the occluded segment. In one report that compared the ability of CTCA to assess the visibility of collaterals and the grade of collateralization compared to CAG, although the degree of collateralization as assessed by CTCA and CAG showed a close correlation, CTCA could detect only 80% of the collaterals seen at CAG [40]. Therefore, it appears that CTCA is not as useful to identify the collateral vessels associated with a CTO compared to CAG, and it will not replace the need for contralateral injections at time of PCI.

CT assessment of myocardial viability

Selection of suitable CTO cases for PCI is important and most recent reviews have stated that the myocardial territory supplied by the occluded artery

Table 3 CTO features that can be identified by CTCA before PCI to allow preprocedural planning and predict technical difficulties during recanalization

Route and course of CTO segment, as the distal vessel can be well visualized usually. This also allows assessment of the quality of the distal vessel
Length and diameter of the occluded segment without foreshortening. 3D-length measurement of occlusion is possible by CTCA even if retrograde or collateral contrast filling is poor or absent at catheterization
Multiplanar and 3D views allow planning of the best angiographic view of the occlusion trajectory during PCI, i.e., 3D-roadmapping fusion with catheterization laboratory data may be possible
Presence of calcification at the stump of occlusion, especially severe or concentric calcification—this may assist in selection of targeted strategy, e.g., upfront use of ablative technique
Presence of proximal tortuosity at the occlusion site
Presence of blunt occlusion stump or a side branch at the occlusion site
Collaterals or bridging vessels at the occlusion site are not usually visualized by CTCA; septal collaterals cannot be demonstrated by CTCA due to their intramyocardial location

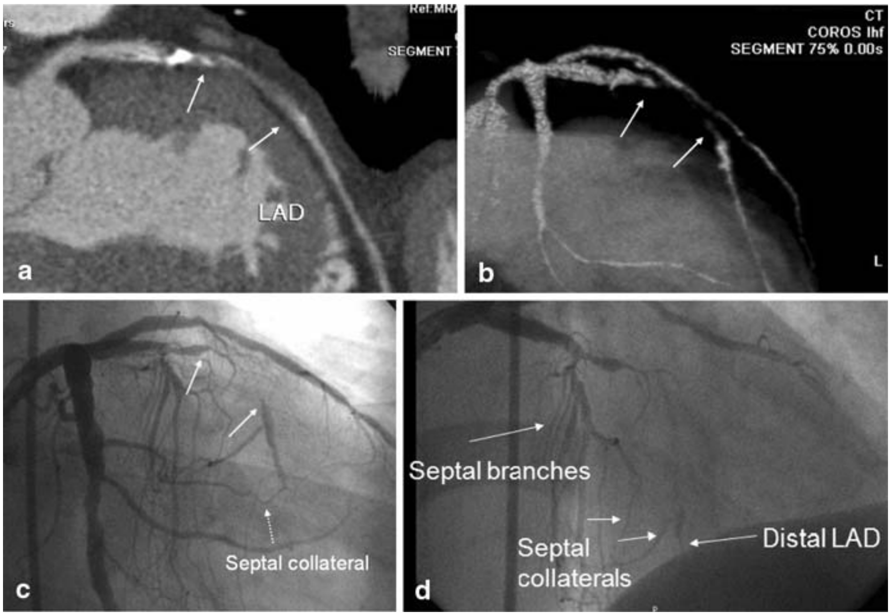

Fig. 7 a–d CTO of mid LAD on the CTCA shows moderate length of occlusion (<2 cm) with tapered stump of occlusion, but no associated calcium at stump (*arrows*). CTCA also shows a straight segment of occlusion with good distal vessel, and these findings predict high likelihood of success at PCI for CTO by antegrade approach. These findings were confirmed at CAG at the time of PCI. Note the presence of septal collaterals at CAG, which cannot be identified on the CTCA due to their intramyocardial location. Visualization of septal collaterals in a CTO is important for the interventionalist if retrograde approach for PCI is being considered

should be viable before PCI is attempted, and that preprocedure myocardial viability imaging is desirable [19, 41]. Myocardial viability can be assessed by stress echocardiography; nuclear-medicine imaging, including PET/CT; contrast-enhanced CMR imaging; and cardiac CT. Myocardial viability can be assessed on CMR and CT from the left ventricular wall thickness, evaluation of myocardial enhancement and perfusion, and by delayed-contrast enhancement [42]. CMR is probably the current gold standard for myocardial-viability assessment [42, 43]. Since myocardial perfusion and myocardial viability can be assessed by using delayed scans, cardiac CT should ideally be used as a comprehensive examination of the heart, not just as a CTCA study [44]. Although using a low-kVp scanning protocol and prospective gating for the delayed scan can be done with a much lower radiation dose, the use of cardiac CT for assessment of myocardial viability is currently not routinely performed in most centres. The availability of the 320-MDCT scanner that allows volume imaging of the entire heart in one heartbeat has the potential for use for assessment of myocardial viability as a part of a routine protocol, but currently these protocols and techniques are still being developed [45].

Conclusion

CT coronary angiography is a useful tool to optimize PCI strategy as it is possible to characterize the length, course, and composition of an occluded artery and allow visualization of the distal runoff and side branches. Moreover, CTCA can serve as a roadmap for the PCI and assist in selection of the appropriate targeted intervention strategy, such as upfront use of ablative techniques for severely calcified CTOs. CTCA also allows preprocedural planning and adequate time scheduling for the PCI and may allow increased success rate for PCI of CTOs as well as reducing PCI procedure time, contrast nephrotoxicity, and radiation dose. Randomized studies will be required to confirm this, but it has been recently shown that CTCA used before PCI does seem to allow better mental power of insight and planning for the interventionalist in the management of CTOs as well as improving and reducing estimation of degree of difficulty of PCI for CTO. A review of the CTCA scans prior to PCI was found to be extremely useful in 80% of CTO cases in this study [35]. As CTCA scans are being performed more often for the assessment of patients with atypical angina and borderline treadmill stress tests, etc., the detection of CTOs by CTCA is also increasing, and all the important characteristics of a CTO can now be assessed prior to a planned PCI.

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