Coronary CT angiography in percutaneous coronary intervention

H.S. Hecht
Lenox Hill Heart and Vascular Institute, New York, NY, USA.

Multidetector CT has become the non-invasive modality of choice for coronary imaging.

Pre-acquired coronary CT angiography can facilitate and guide interventions.

Lenox Hill Heart and Vascular Institute of New York is among the leading cardiovascular care programs in the United States, providing a continuum of progressive care from diagnosis to treatment and recovery. As a major center of coronary and percutaneous intervention, it has been a pioneer in the integration of coronary computed tomographic angiography (CCTA) into the catheterization laboratory.

**Background**

Selective invasive coronary angiography (ICA) is the gold standard for the detection of coronary artery disease. However, in addition to being invasive in nature, it has well documented shortcomings [1, 2]. Because of its insufficient sampling, the three-dimensional coronary tree is viewed and displayed in limited two-dimensional standard angiographic views. These views are subjectively chosen, causing significant intra- and inter-observer variability [3]. As a result, lesions are either missed or underestimated [4], resulting in incorrect stent selection (diameter and length) and inaccurate placements.

Some of these shortcomings are addressed by rotational angiography [5], in which data is collected via pre-defined isocentric arcs of the C-arm for each of the coronary arteries, thereby presenting the user with a panoramic view of the anatomy. However, like invasive coronary angiography, it is also a lumenogram, depicting planar projections of the contrast-filled lumen, rather than the vessel itself. Important quantitative information such as cross-sectional lumen area, size, distribution and composition of plaque and remodeling of the vessel wall remain unavailable [1].

Intravascular ultrasound (IVUS) addresses all the above shortcomings. With its ability to provide cross-sectional imaging of both the coronary lumen and the wall, it enables:

- measurement of the minimum luminal area along with the minimum luminal diameter
- plaque quantification and characterization
- identification of vessel wall remodeling.

However, in addition to being invasive in nature, IVUS is limited to the more proximal and mid coronary segments and the cost limits its routine use.

Technical advances have enabled multidetector CT to become the non-invasive modality of choice for coronary imaging. Recent clinical literature has supported the power of CCTA using 64-slice multidetector CT scanners in the detection and ruling out of significant (> 50%) coronary artery disease, with an average negative predictive value of 98% on a per-patient basis [6-8]. With the capability of acquiring 3D data volumes (thus providing an infinite number of viewing angles) along with its tomographic nature, it shares many of the advantages of IVUS and thus has the potential to enhance the practice of percutaneous coronary intervention in the catheterization laboratory by providing data which was difficult to obtain by invasive coronary angiography [9, 10].

The following sections demonstrate some unique applications of CCTA in percutaneous coronary intervention (PCI), while at the same time avoiding the pitfalls of ICA. Specific clinical scenarios, such as left main and ostial disease and detection of diffuse narrowing, are presented. In addition, the examples demonstrate the power of pre-acquired CCTA data in facilitating and guiding successful intervention for chronic total occlusions.

All CCTA scans were performed on a Brilliance 64 Multidetector CT scanner (Philips Healthcare, Cleveland, Ohio, USA), employing advanced cardiac gating algorithms [11], adaptive cardiac reconstruction techniques [12] and dose-saving technologies (DoseRight Cardiac, Philips Healthcare, Cleveland Ohio, USA) to reduce radiation.

All CCTA images were generated by advanced post-processing applications (Comprehensive Cardiac Analysis and CT TrueView) on a dedicated CT workstation (Brilliance Workspace, Philips Healthcare, Cleveland, Ohio, USA).
recent work has shown the usefulness of non-invasive coronary CTA in the assessment of left main artery lesions [16].

Figure 1 demonstrates the important role played by coronary CTA in the detection of left main artery stenosis. A 62 year old male with atypical chest pain underwent retrospectively-gated helical CCTA. By using ECG-triggered dose modulation (DoseRight Cardiac, Philips Healthcare, Cleveland), radiation dose savings of 42% were achieved, resulting in an effective radiation dose of 8 mSv.

The exam revealed significant distal left main artery stenosis in the curved multi-planar reformatting (MPR) view (Figure 1a). A straightened lumen view (Figure 1b) was used to generate a cross-sectional view (Figure 1c) providing valuable quantitative information (minimum lumen area of 5 mm²). Two-dimensional cardiac angiography failed to demonstrate any significant disease (Figure 1d). However, a significant stenosis was detected on IVUS (Figure 1e) with a minimum lumen area of 5.4 mm², confirming the findings in CCTA. A retrospective analysis of the cardiac angiography images revealed a linear ridge of calcified plaque (Figure 1d, white arrows) corresponding to the true outer border of the vessel. The CCTA data was crucial to the correct diagnosis and surgery was recommended.

**Clinical applications**

**Left main artery disease**
Significant left main artery disease is defined as a stenosis of over 50% in diameter with a minimum lumen area of less than 6.0 mm². Left main artery lesions are difficult to assess using the standard limited projections of invasive coronary angiography. Since a clearly normal reference area may not be readily identifiable and the minimum lumen area cannot generally be measured without IVUS, the findings can be misleading. Additionally, vessel foreshortening and overlap with the left circumflex and left anterior descending (LAD) artery also contribute to this problem [13, 14].

While IVUS is the preferred modality for assessing the severity of left main artery lesions [1, 15], recent work has shown the usefulness of non-invasive coronary CTA in the assessment of left main artery lesions [16].

**Ostial disease and the route to the stenosis**
Ostial and proximal disease, particularly the bifurcation of the left main artery into left anterior descending (LAD) artery and the left circumflex artery, present unique problems. The presence of a stenosis in this region could be obscured by the overlap of the vessels. Using the standard viewing angles in the ICA, this area is sometimes poorly visualized and requires additional angiographic views for further examination. Passage of percutaneous intervention hardware through diseased left main artery areas en route to the lesion may create significant lesions where none previously existed.

CCTA not only has the ability to provide unlimited 360° of data to examine this area, but can also clearly delineate the path to the lesion, thereby guiding the treatment plan. For instance, CCTA can provide knowledge of any distal left main artery disease present in the path proximal to the stenosis that could be missed on interventional coronary angiography. Any calcification present in the left main artery is easily detected on CTA, potentially altering the treatment plan if found to be extensive.
increase of the maximum lumen area from 2.8 to 8.3 mm² (Figure 2d).

The operator was aware of the moderate distal left main artery disease noted on the CCTA prior to the procedure (Figure 2g, left) and confirmed by IVUS, but the small caliber distal vessel suggested percutaneous intervention rather than coronary artery bypass graft surgery. Symptoms disappeared following percutaneous intervention but returned after four months;
documented a decrease of the left main artery MLA from 6.7 to 2.6 mm², and patency of the ostial stent (Figure 2g). Trauma from the percutaneous intervention undoubtedly caused the subsequent left main artery disease; similar insult to the ostial LAD during the first stent implantation was the likely etiology of the ostial disease, which was angiographically inapparent.

**Diffuse disease**

The diffuse nature of coronary artery disease poses problems in interventional coronary angiography, causing it to underestimate the degree of stenosis when there is no nearby “normal” reference segment. Under these conditions, segments with diffuse disease could appear on invasive coronary angiography as a normal artery of a small caliber.

In contrast, IVUS and CCTA are immune from this problem; they depict the vessel wall as well as the lumen and provide measures of maximum lumen area. Accurately assessing the degrees of positive and negative remodeling may be crucial in choosing the ideal strategy and appropriate size of the device.

**Procedure planning using CTA**

Having prior knowledge of the complexity of the vascular system, e.g. the course, tortuosity, size and the length of the vessels, can be of enormous benefit to a diagnostic and therapeutic procedure. Modeling techniques have recently been developed that extract information from 2D invasive coronary angiography projections to generate a 3D arterial model [17, 18]. From the model, optimal viewing angles for a coronary artery segment of interest can be visually displayed to the user in the form of a color map. The availability of this information has positive implications for interventional procedures, making them safer and more efficient.

CCTA, with its IVUS-like advantages, is an obvious fit for the above model [19]. As before, a CT-based 3D tree can provide identical information. If a pre-procedural CCTA has

---

**Figure 3. Diffuse disease in the left anterior descending artery in a 64-year-old male.**

Figure 3a. CMPR from CCTA showing disease from the ostium to the stent.

Figure 3b. Invasive coronary angiography showing only a mild narrowing.

Figure 3c. Straightened MPR of the CCTA data.

Figure 3d. Cross-sectional CCTA images (left and right) showing reduced minimum luminal area, confirmed by IVUS (center).
already been performed, valuable information like the appropriate choice of guide wire, catheter, balloon and stent could be made available even before the patient enters the interventional laboratory.

From the information provided by the segmented coronary artery tree from the CTA scan, the model generates a four-quadrant color map showing areas of minimum and maximum foreshortening for a lesion of interest, with each quadrant representing the standard C-arm orientations (LAO-cranial, LAO-caudal, RAO-cranial, RAO-caudal). This CT optimal-view map (CT TrueView) also provides the operator with optimum C-arm orientations that result in minimum foreshortening for the given lesion. This information is extremely useful, not only for planning the procedure but also for ensuring the best possible results for the patient.
The segments of the artery distal to the occluded area are always visible in CCTA.

Without CCTA guidance, flush occlusions present a particularly difficult problem.

only for a single lesion percutaneous intervention, but also for complex, multi-vessel, multi-lesion interventional procedures.

Figure 4 shows CT TrueView displays, with a model of the coronary artery tree in the main viewport. The segment of interest corresponding to the lesion in the right coronary artery (RCA) in this example is shown in yellow. The optimal view map (shown on the left of both figures) represents areas with various degrees of foreshortening, with areas in red indicating increased foreshortening and the green areas representing reduced foreshortening.

Figure 4a shows the orientation of the tree corresponding to a significant foreshortening for the segment of interest (with the location on the color map represented by a small white square in the red area). In contrast, Figure 4b shows the corresponding orientation of the tree with significantly reduced foreshortening (with the white square now located in the green area). In addition, the corresponding C-arm orientations are shown at the bottom. Thus advances in technology such as segmentation and dynamic modeling of the coronary arteries from a CCTA scan provides valuable information, paving the way to a more efficient interventional procedure even in challenging situations, such as stent placement for complex lesions, even in the presence of vessel overlap and bifurcations.

Taking this one step further, a proof-of-concept of an integrated approach linking the already-acquired CCTA data to the C-arm via registration has also been investigated [19]. This approach can provide the operator with a close look at the working view of the anatomy even before the acquisition is made. This integration has important clinical implications in the guidance of percutaneous interventions.

Successful intervention to treat a chronic total occlusion is predicated on the ability to:
• identify the route and course of the totally occluded arterial segment, along with the visualization of the distal vessel beyond the occlusion
• measure its length and diameter
• detect any tortuosity of the vessel proximal to the lesion, and
• identify the nature of plaque within the occlusion, which, if heavily calcified, may be a contraindication to the procedure.

In general, shorter, less calcified chronic total occlusions are easier to open [20]. CCTA is ideally suited to provide all the requisite data. The segments of the artery distal to the occluded area are always visible from CCTA (which is not always the case with interventional coronary angiography) because of the presence of collateral flow, thus providing a more accurate measurement of the length of the occluded segment with minimal foreshortening, no overlap, and a clear course of the vessel. This provides the operator with a good starting point for the procedure, thereby optimizing the success rate while also enabling contrast optimization and reduction of fluoroscopy time and radiation exposure. Lastly, the capability to analyze the types of plaque present makes it possible to decide on the optimum therapeutic interventional strategy.

Figure 5 demonstrates a successful interventional procedure based on a pre-operative CCTA scan. Selective invasive coronary angiography on a symptomatic 65-year-old woman with anterior ischemia showed flush occlusion of the LAD with partial collateral filling from the RCA (Figure 5a). After six months of persistent symptoms, CCTA guided intervention was planned. Curved multi-planar reformating (CMPR) of the CCTA data clearly visualized the occluded LAD segment (Figure 5b, right).

CT TrueView of the left coronary artery and all its branches (Figure 5c) was imported to the catheterization laboratory monitor and electronically linked to the C-arm. The C-arm was rotated, with accompanying automatic update of the CT TrueView map, to the angle predetermined by the CCTA to best demonstrate the origin and course of the occlusion without overlapping branches. Simultaneous injection of the right and left coronary arteries (Figure 5b, left) was performed. With CT TrueView guidance, the guidewire was introduced to the precise origin of the flush occlusion, followed by successful recanalization (Figure 5d), and further stenting of the distal vessel six weeks later. Flush occlusions present a particularly difficult problem; without CCTA guidance, the operator can only guess at the origin of the occlusion, with a subsequent prolonged, often unsuccessful outcome.

Figure 6 is another example of a successful CCTA-guided intervention for treatment of a chronic total occlusion. Selective invasive coronary angiography in a symptomatic 55-year-old man with inferior ischemia showed proximal occlusion of the RCA with a very poorly visualized distal vessel (Figure 6a). A CMPR from the CCTA data showed the occluded segment, with a clear visualization of the distal vessel (Figure 6b), measuring 16.6 mm on the straightened MPR (Figure 6c), with minimal calcified plaque in the mid-portion. CT TrueView
Figure 5. A successful interventional procedure in a 65-year-old woman, based on a pre-operative CCTA scan showing occlusion of the LAD.

Figure 5a. Invasive coronary angiography with simultaneous injection of the left and right coronary arteries.

Figure 5b. CMPR from CCTA shows the occluded segment (right).

Figure 5c. CT TrueView and the optimal view map. The optimum viewing angle was predetermined by CCTA.

Figure 5d. Based on CCTA's guidance, recanalization was performed successfully.

Figure 6. Proximal chronic total occlusion of the right coronary artery in a 55-year-old male, with successful treatment guided by CCTA.

Figure 6a. Invasive coronary angiography.

Figure 6b. Corresponding CMPR from CCTA showing the occlusion and also enhancement of the vessel distal to the CTO via collaterals.

Figure 6c. Straightened MPR from CCTA. The occlusion length measured 16.6 mm.

Figure 6d. The optimal view map of the CT TrueView determined the angle of least foreshortening.

Figure 6e. Corresponding view of the RCA.

Figure 6f. The CTO was successfully treated and stented.
of the RCA was generated (Figure 6d) and imported to the catheterization laboratory monitor. The C-arm was rotated to the CT TrueView determined angle of least foreshortening, thereby showing a good working view of the RCA (Figure 6e). The occlusion was easily opened and stented (Figure 6f). The information about the length of the occlusion, knowledge about the plaque content (minimal calcification) and the course of the distal vessel from the CCTA (missing from the ICA) predicted a successful outcome.

Thus, there is enormous potential for CCTA to enhance diagnostic and therapeutic strategy. Based on our experience, we have developed a CTA-guided percutaneous intervention paradigm at our institution, in which the patient selection for intervention is based on CCTA rather than stress testing [9, 10], with CTA derived measurements helping triage the patients to interventional or medical management. An extension of the integrated approach has also been investigated, wherein an active overlay of CCTA data is “merged” and shown in the background of a fluoroscopic image [19], thereby facilitating safer and more efficient interventional procedures.

Lastly, radiation dose concerns for CCTA are being addressed with the introduction of low-dose prospective acquisition techniques, resulting in radiation dose reductions of more than 80% [21] with image quality comparable to traditional techniques. These low-dose techniques have also been implemented in a newer generation of faster and wide-coverage multidetector CT scanners [22-24]. With these advances, the routine use of CCTA before percutaneous intervention, and consequently a CTA-guided percutaneous intervention paradigm, would direct treatment. Prospective validation studies of the CTA-based percutaneous intervention strategy are currently under way, investigating the safety, efficiency and success of interventional procedures.

Conclusion

The profound impact of CCTA on percutaneous interventions, while still greatly underappreciated, is inevitable. While the role of CCTA in treating chronic total occlusions is well recognized, it is only a matter of time before interventionalists acknowledge the limitations of relying on invasive lumenography in general, and take routine advantage of the plaque delineation and maximum lumen area measurement offered by CCTA. With the greatly decreasing radiation doses associated with prospectively-gated CCTA acquisitions, the routine use of CCTA before percutaneous coronary intervention becomes more attractive and feasible.

References:


