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Coronary CT Angiography as an Alternative to Invasive Coronary Angiography

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1. Introduction

X-ray computed tomography (CT) was first invented in 1972 and its ability to obtain cross sectional images has proven to be a major advance in the field of medicine, garnering the Nobel Prize in medicine for Sir Godfrey Newbold Hounsfield and Allan McLeod Cormack in 1979. Since then, numerous advances have been made with the introduction of high quality scanners and new imaging protocols to enhance the quality of the images and reduce the amount of radiation. Inherent drawbacks of conventional CT imaging for cardiac imaging, such as low temporal resolution and the need for ECG gating, prompted the development of electron beam CT (EBCT). Further advances in the scanners have led to the introduction of multi detector CT (MDCT) scanners, which have increased spatial resolution and now utilize sequential imaging acquisition modes and other features to minimize radiation exposure. MDCT scanners for coronary imaging utilize a minimum of 16 slice, and now 64 - 320 slice scanners are widely used to get excellent, high-resolution images of the heart and the coronary arteries.

2. Basics of operation

The coronary CT angiogram (CCTA) is a relatively fast and simple procedure. Adequate patient preparation and co-operation are essential for good image acquisition. Beta-blockers are routinely given to slow the heart rate (Bluemke et al. 2008) in order to eliminate or reduce artifact from motion of the coronary arteries. This chapter deals primarily with the use of coronary CTA as an alternative to invasive angiography and another chapter describes the technical features in more detail. However, in brief, temporal resolution is an important limitation and is determined by the speed of the X-ray gantry (Kapoor and Thompson 2009). MDCT scanners improve this temporal resolution by acquiring a full CT slice in only half a rotation, and recent advances in scanner design have improved the speed of rotation and even added second tube sources in order to improve temporal resolution even more. The 64-slice MSCT instruments are now considered the minimum standard for CT scanners intended for coronary artery imaging. Images are most commonly acquired using prospective gating and only during diastole (for example at 70-80% of the R-R interval) in order to reduce the radiation dosage (Earls et al. 2008). Both spatial resolution and temporal resolution are less with CCTA than conventional invasive coronary

angiography and these limitations must be kept in mind when deciding which test to order. The maximum spatial resolution of MSCT is 0.4 mm, and is determined by the size of the picture elements of the CT detector. Smaller coronary segments frequently are not evaluable with CTA and coronary CTA may be unable to distinguish moderate from severe flow limiting stenosis, because of these limitations of resolution (Kapoor and Thompson 2009).

3. Application of coronary calcium scoring

Non-contrast CT scanning of the coronary arteries is a widely used technique for risk stratification and prognosis for individuals without known coronary artery disease. With this technique, calcium in the form of calcium hydroxyapatite in the artery wall is imaged and quantified in order to provide a rough measure of the presence of coronary atherosclerosis. There is a linear relationship between the amount of coronary calcium and coronary atherosclerosis, that is, the more coronary calcium the higher the likelihood of coronary stenosis (Rumberger et al. 1995), and proportionally prognostic – the higher the calcium score the greater the likelihood of coronary events (O'Rourke et al. 2000). Moehlenkamp and colleagues recently demonstrated that coronary calcium scoring not only adds prognostic value to the Framingham risk model, but also that its value is greater than hsCRP (Moehlenkamp et al. 2003). Also the recent randomized Eisner Trial demonstrated that coronary calcium testing leads to better downstream control of coronary risk factors (Rozanski et al. 2011). Thus, the ability of coronary calcium scoring to non-invasively identify and quantify the amount of coronary calcium is invaluable to diagnose pre-clinical CAD and help to aggressively modify the risk factors. It should be emphasized that coronary CTA, while a very useful tool, is not a particularly appropriate test for patients with chest pain syndromes. CT coronary calcium scoring is performed without the use of iodinated x-ray contrast. In order to perform CT coronary angiography, the focus of this chapter, x-ray contrast is administered.

4. CCTA as an alternative to invasive angiography

While CCTA can sometimes provide images of truly impressive quality, the spatial and temporal resolution are significantly inferior to invasive angiography, and CCTA images are sometimes degraded by artifacts. A recent prospective multicenter-blinded study evaluated the diagnostic performance of 64-multidetector row CCTA compared with invasive coronary angiography (ICA) in patients with chest pain without known CAD who were referred for non-emergent ICA. The data revealed high diagnostic performance at both 50% and 70% stenosis thresholds. In addition, the 99% negative predictive value (NPV) of CCTA at the patient and vessel levels establishes it as a highly effective noninvasive alternative to ICA for the exclusion of obstructive coronary artery stenosis (Budoff et al. 2008). The strength of the CCTA lies in its high negative predictive value. *A good quality negative CCTA without artifacts can rule out the presence of CAD with a great level of confidence.* The high negative predictive value has been consistently demonstrated (Gopalakrishnan et al. 2008; Mowatt et al. 2008; Stein et al. 2008) and it is this population where coronary CTA might well be a substitute for invasive angiography. Figure 1 demonstrates a normal high quality coronary CT angiogram and figure 2 demonstrates one in which the diagnosis of high - grade coronary artery disease was made. In general, coronary CTA is much less accurate in the presence of heavy coronary

calcification and in patients with atrial fibrillation or other irregular cardiac rhythms. Figure 3 is an example of such a non-diagnostic study. Another chapter deals with the accuracy of CTA in greater detail.

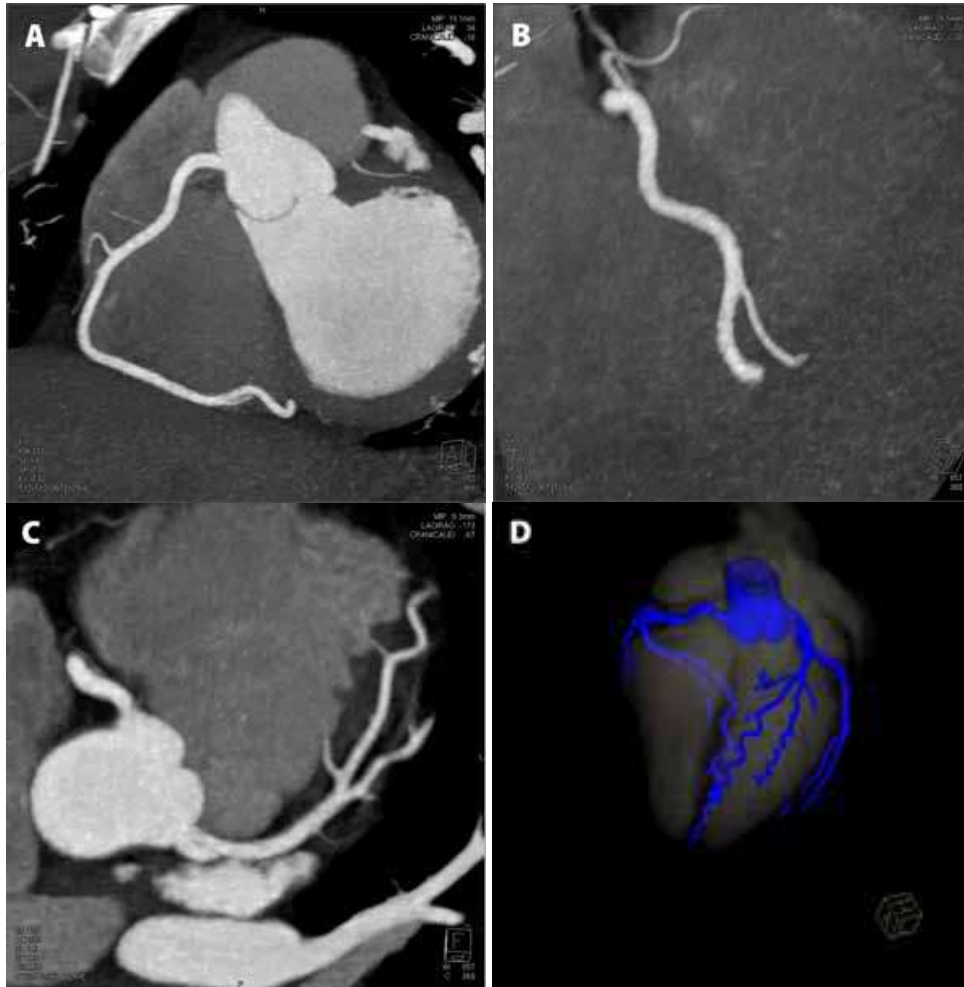


Fig. 1. CT coronary angiogram of a 39 year old male who complained of chest pain (maximum intensity image of the right coronary artery (A and B) and the left coronary artery (C) and reformatted image (D). The study was normal giving a high degree of confidence that coronary artery disease was not present.

Although coronary CTA has limitations, it is much less invasive than invasive coronary angiography and it is an appropriate alternative in selective cases. For example, according to the ACCF/ SCCT/ ACR/ ASNC appropriate use criteria for diagnosing CAD, patients who present with non-acute symptoms and possibly representing an ischemic equivalent, CCTA is considered an appropriate test in those with a low to intermediate probability of CAD whose ECG is uninterpretable and who cannot exercise (Taylor et al. 2010). CCTA is also considered appropriate in patients with a low to intermediate pre-test probability with acute symptoms suggestive of acute coronary syndrome (ACS) with a normal ECG and cardiac biomarkers (Taylor et al. 2010). However, in patients who have obvious severe cardiac ischemia, coronary CTA is not an appropriate alternative to invasive angiography as it will simply delay interventional therapy and add to the x-ray contrast load prior to the needed invasive procedure (Taylor et al. 2010).

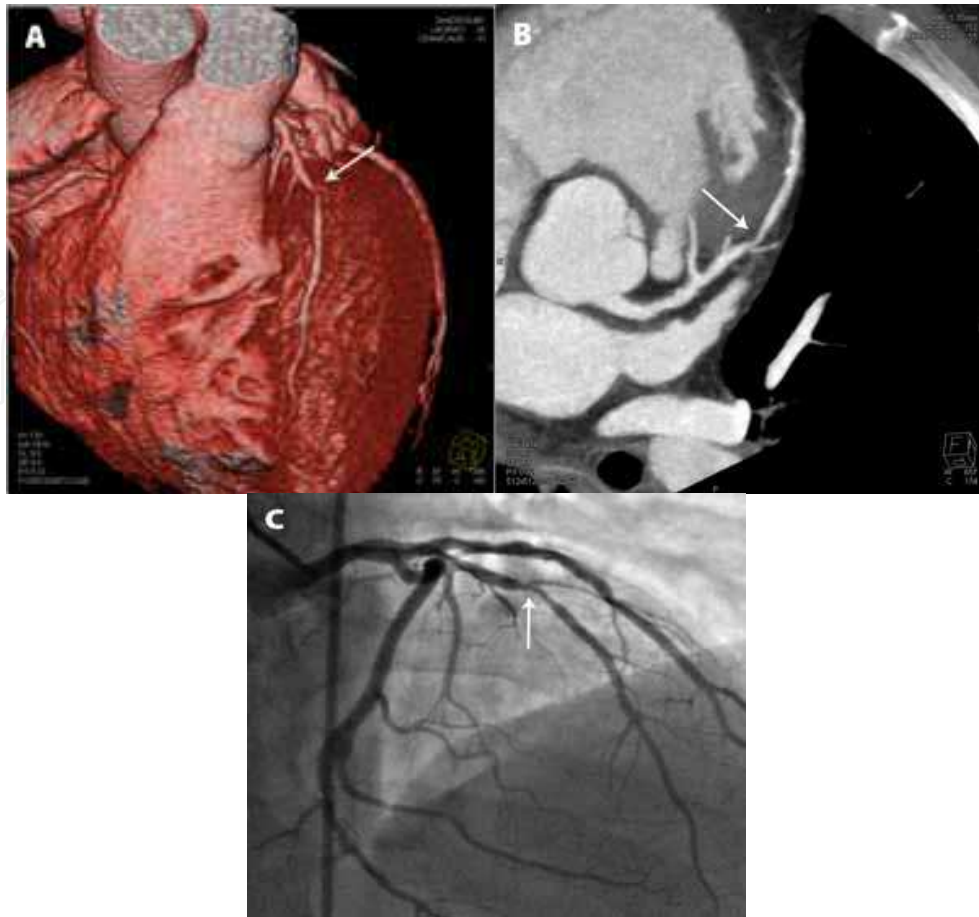


Fig. 2. Volume rendered (A) and maximum intensity projection (B) CT angiogram images from a 48-year-old male demonstrating a high-grade stenosis in the mid segment of the left anterior descending coronary artery. The patient had presented with persistent, intermittent chest pain and a myocardial perfusion image had been equivocal.



Fig. 3. Thin maximum intensity projection (MIP) coronary CT angiogram in a 65-year-old female patient showing the proximal left coronary artery branches. Heavy coronary calcium makes the study non-diagnostic. Image quality is also impaired by insufficient x-ray contrast in the aorta and coronary arteries at the time of acquisition.

Another category of patients in whom CCTA is used as an alternative to invasive angiography are those with an equivocal or low probability stress tests whose symptoms suggestive of angina persist despite low probability scans. These patients are often referred for cardiac catheterization, but CCTA is a less invasive test that can rule out obstructive CAD as a cause for their symptoms. The high negative predictive value of CCTA allows the clinician to confidently reassure the patient without invasive testing. This same rationale applies to those patients with suspected coronary artery disease who are scheduled to undergo non-cardiac surgeries. When applied to the appropriate subset of patients, i.e. those with relatively low pre-test probability of CAD, CCTA can prove to be the final test to confidently rule out the presence of CAD and these patients benefit from avoiding the higher cost and potential complications of invasive coronary angiography.

4.1 Etiology of cardiomyopathy

When patients present with a new diagnosis of heart failure / cardiomyopathy, further diagnostic evaluation is warranted. Coronary artery disease is the most common cause of cardiomyopathy and differentiating ischemic from non-ischemic etiology has important therapeutic and prognostic implications. In particular, since ischemic cardiomyopathy has the potential for improvement from revascularization, it is very important that the etiology be established. Treatment guidelines for patients with a new diagnosis of cardiomyopathy prominently feature the use of invasive coronary angiography, and it is considered the gold standard for establishing the diagnosis of cardiomyopathy of coronary artery disease. While myocardial perfusion imaging has some value in this population, there are important limitations in this group such as lower diagnostic accuracy and difficulty in performing stress in some of them. Also, while regional wall motion abnormalities identified by two dimensional echocardiography or radionuclide angiography have been proposed to be specific for coronary artery stenosis induced ischemia and infarction(Budoff et al. 1998), subsequent studies have shown similar abnormalities with dilated cardiomyopathies, not related to coronary artery disease(Andreini et al. 2007). With the use coronary CT angiogram, however, a diagnosis either in favor of or against coronary artery disease can be made fairly easily. Patients with acute congestive heart failure may not be suitable for CCTA immediately because of tachycardia and the need to avoid x-ray contrast. However, once the heart failure is compensated, coronary CTA can be performed and the accuracy in this setting has been established. One study that demonstrated excellent sensitivity (89%) and negative predictive value (99%), suggests that it could be used in patients with a cardiomyopathy to identify the etiology(Garcia et al. 2006). Also, a direct comparison with coronary angiography revealed excellent accuracy of the MDCT in correctly diagnosing the etiology of cardiomyopathy, ischemic or non-ischemic(Andreini et al. 2009). There are obvious advantages to non-invasively ruling in or out coronary artery disease in this group of patients. The ACC/ ASNC/ AHA consider it appropriate to evaluate for CAD in new onset HF and no prior diagnosis of CAD and reduced LVEF(Taylor et al. 2010).

4.2 Utilization prior to electrophysiology procedure

Atrial fibrillation is a common arrhythmia and is associated with significant morbidity. The options available for the treatment of atrial fibrillation, especially in symptomatic

individuals, include anti-arrhythmia drug therapy, surgery, and catheter based approaches. The use of radio frequency ablation to isolate the pulmonary veins is a growing therapy for atrial fibrillation and has emerged as an important alternative to conventional treatments. The majority of the atrial fibrillation foci appear to arise around the pulmonary veins and successful pulmonary vein isolation (PVI) can prove to be a permanent cure for atrial fibrillation. Coronary CT angiography is a key diagnostic tool in managing patients being considered for PVI (Cronin et al. 2004). For one, the presence of significant coronary artery disease has implications for adjunctive medical therapy since Vaughan-Williams class 1C drugs such as flecainide are contraindicated in patients with CAD. Coronary CTA can diagnose coronary artery disease in these patients. Essential components for a successful pulmonary vein isolation procedure include accurate anatomical mapping of the pulmonary veins. This is important because the pulmonary vein anatomy is variable, and common ostia and extra pulmonary veins are common. The knowledge of this anatomy is helpful to avoid pulmonary vein stenosis and necessary to avoid missing potential areas contributing to atrial fibrillation (Jongbloed et al. 2005). MDCT provides excellent visualization of the origins of the pulmonary veins, the diameter of the ostia, course of the pulmonary veins, presence of dual ostia and presence of additional supernumary veins (Schwartzman et al. 2003). The distance of the esophagus from the left atrium is also an important parameter that can also easily be measured. Another important pre-requisite for the procedure is the absence of a left atrial appendage thrombus, a finding not uncommon in patients with atrial fibrillation. CT angiography allows for excellent visualization of the entire left atrium and the appendage and can be used to identify the presence or absence of a thrombus. Invasive angiography is not ordinarily needed in patients being evaluated for pulmonary vein isolation for treatment of atrial fibrillation; the exception being those with signs of ischemia who may need revascularization as part of the management strategy.

4.3 Coronary anomalies

The incidence of coronary anomalies in the general population is about 1% (Yamanaka and Hobbs 1990). A coronary anomaly can be defined as a pattern that is not routinely encountered in the general population. Coronary anomalies account for about 12% of the deaths in U.S high school and college athletes (Van Camp et al. 1995). The American Heart Association's (AHA) committee on sudden death attributed 19% of the deaths in athletes to coronary anomalies. Invasive coronary angiography is often used to diagnose coronary anomalies and they are routinely found unexpectedly when angiograms are performed for other reasons, but ICA has inherent limitations to accurately study coronary anomalies because of its two dimensional display and the non-visualization of adjacent vascular structures. Computed tomography angiography, however, is inherently three dimensional and is ideal for providing extensive information about the spatial anatomy of the coronary artery, including the origin, course, presence of an intra-myocardial path as well as the relationship to the surrounding structures. The sensitivity of the CCTA in diagnosing coronary anomalies is nearly 100% (Kacmaz et al. 2008). Figures 4 and 5 demonstrate the superb display of coronary anomalies by CT angiography. Since many patients in whom the diagnosis of a coronary anomaly are made young, it is important to pay particular attention to keeping the radiation dose low in this group. For example, diagnostic tests to rule out a coronary anomaly are frequently ordered in young athletes who have symptoms. The

radiation dose with CCTA is heavily dependent on imaging technique and pristine image quality is not needed for this indication. Thus, lower than standard tube current and tube voltage along with other radiation sparing algorithms should be used for this group of patients. In fact, the origins of the coronary arteries can sometimes be seen quite well with a limited field-of-view, non-contrast CT at a very low radiation dose and such an exam should be considered.

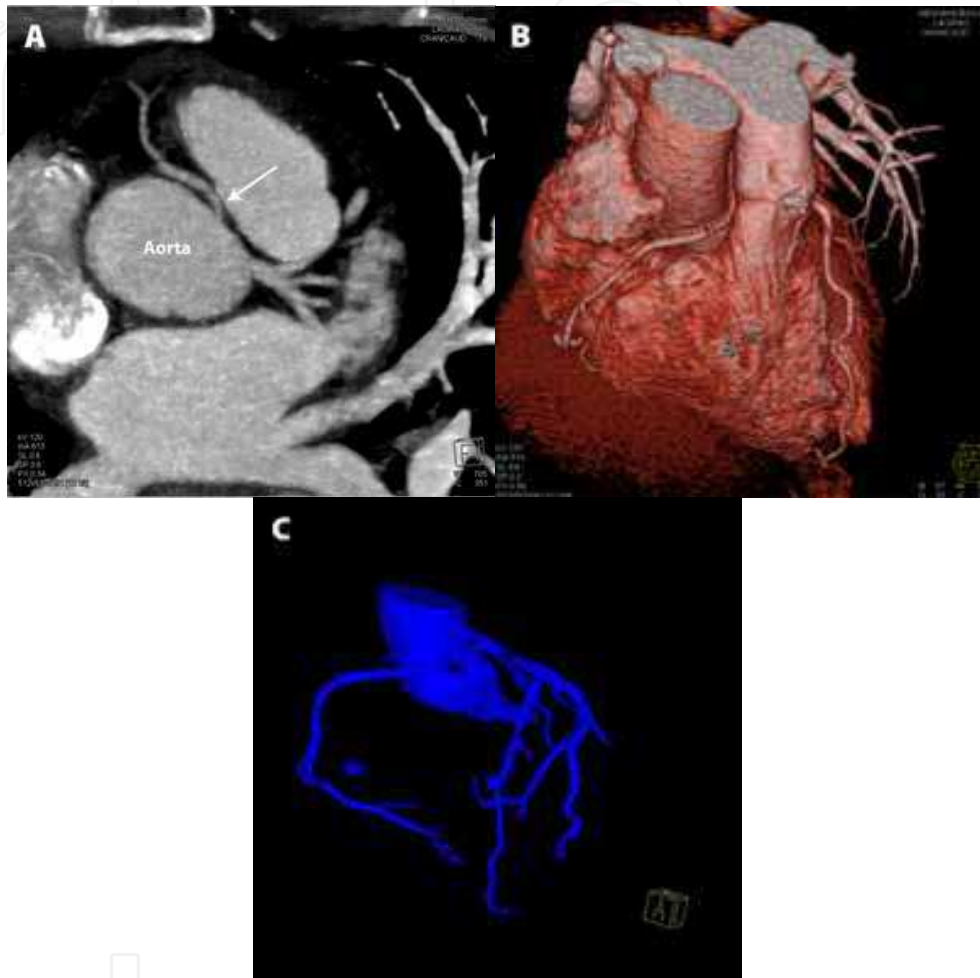


Fig. 4. CT angiogram maximum intensity projection (A), volume rendered (B) and reformatted image (C) from a 55 year old female with chest pain and problems during a coronary angiogram. The right coronary artery arises from the left coronary cusp (arrow) and courses between the aorta and the main pulmonary artery

4.4 Evaluation of left main coronary artery stent patency

The conventional treatment of left main coronary artery (LMCA) stenosis is coronary artery bypass graft surgery. However recent advances in percutaneous coronary intervention (PCI) have prompted utilization of stents to treat LMCA stenosis. The rate of angiographic restenosis on follow up studies varies from 22% to 40% (Silvestri et al. 2000; Park et al. 2003), although the use of drug eluting stents (DES) has markedly reduced the incidence of in-stent restenosis. However, because of the potential dire consequences of re-stenosis in the left main coronary artery, surveillance angiography is usually recommended 2-6 months after

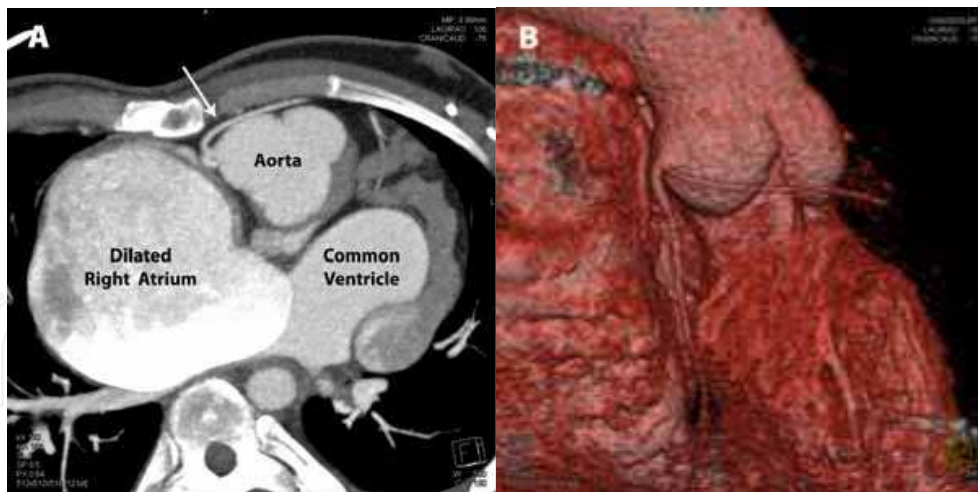


Fig. 5. Complex congenital heart disease in a 22-year-old male patient being considered for surgical intervention. The patient previously had a modified Fontan operation for a large ventricular septal defect and transposition of the great arteries. He developed a giant right atrium and very difficult atrial arrhythmia. Oblique maximum intensity projection (A) and volume rendered (B) CT coronary angiogram images also demonstrate anomalous coronary arteries (arrow) arising from the same coronary cusp to the right and posteriorly to the sternum.

intervention to this segment. Several studies have proposed CCTA as an alternative non-invasive modality to assess ISR in this patient group. Blooming artifacts caused by the stent struts are a major hindrance in the accurate CTA evaluation of ISR in other vessels (Mahnken et al. 2004), (Cademartiri et al. 2007). However LMCA stents tend to be large, usually with a diameter greater than 3.5mm. Also the left main segment is less prone to motion artifact on CT than other segments, and evaluation of stents in the LMCA is more accurate with CCTA than in other locations. One study prospectively evaluated the accuracy of stent patency in

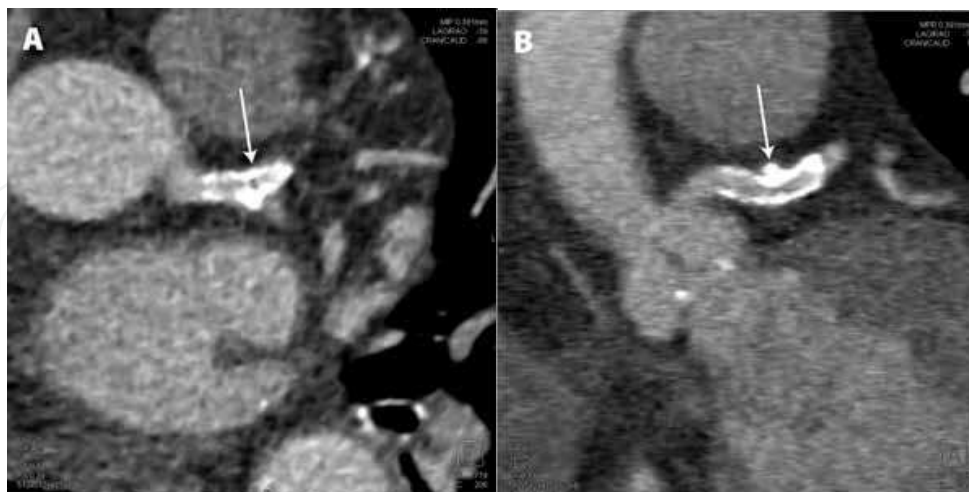


Fig. 6. Thin MIP oblique projections from a coronary CT angiogram in a patient with a stent in the left main coronary artery (arrow). Although there is suboptimal image quality related to artifact from the metallic struts and coronary calcium in this case, the stent appears to be patent. Coronary CT angiography is considered to be accurate in determining the patency of large stents, which have been placed in the left main coronary artery segment.

the LMCA by CCTA and compared it to conventional coronary angiography and intravascular ultrasound (Van Mieghem et al. 2006). In this study of 70 patients the sensitivity, specificity, accuracy, positive predictive value and negative predictive value of identifying ISR (defined as >50% narrowing) in LMCA stents was 100%, 97%, 98%, 86% and 100% respectively. The accuracy was lower (83%) for LMCA bifurcation stents. Conventional angiography identified 14% of the patients having ISR, which were also identified by CCTA. The 2010 appropriateness use criteria (AUC) consider it appropriate to use CCTA in asymptomatic patients for the assessment of left main coronary stent with a stent diameter greater than 3mm. The accuracy of CCTA in detecting in-stent restenosis depends on the type of stent and the complexity of the lesion and these should be taken into account before considering this modality for evaluating ISR (figure 6). Coronary CT angiography, and even non-contrast gated CT scans, can also be useful as an alternative or adjunct to invasive angiography if there is a question of mal-positioning of a left main stent (figure 7).



Fig. 7. Non-contrast CT of the heart demonstrating a mal-positioned stent in the left main coronary artery (arrow) that extrudes approximately 5 mm into the aorta. Invasive coronary angiography had been planned, but was deferred because of concerns that the stent might become dislodged.

5. Coronary CT angiography as complementary to invasive angiography

As discussed, coronary CT angiography is less invasive, although has lower resolution than invasive angiography. However, it is inherently three - dimensional and therefore provides diagnostic content which is different from and which can be complementary to the information derived from invasive angiography.

5.1 Defining coronary anatomy prior to CTO-PCI

Chronic total occlusions (CTOs) of coronary arteries are complex lesions present in approximately 30% of patients undergoing coronary angiography (Grantham et al. 2009). CTOs are defined, as lesions present for at least 3 months with grade 0 to 1 Thrombolysis in Myocardial Infarction (TIMI) flow on angiography. CCTA is being increasingly used as a

non-invasive modality to accurately define the characteristics of the CTO to assist in the interventional procedure.

There are several advantages to performing a CCTA prior to planned revascularization of a CTO. The length of the occluded segment, which is an important predictor of success of revascularization, can be easily obtained (Mollet et al. 2005). The course of the artery, occlusion length, collateral circulation, degree of calcium are important variables that can be obtained by CCTA, all of which assist in planning the procedure that translates into shorter procedure times. Foreshortening of the vessel and limited visualization of the distal vessel in the absence of collateral filling are important shortcomings of invasive coronary angiography, which are easily fixed by CCTA. It can also define bends and angles inside the occluded segment that prove to be extremely helpful to the operator to navigate the wire safely and successfully through the occlusion to the distal vessel. The degree of calcification also has an adverse effect on the success of the procedure. One study showed that the distribution of calcium within the lumen is an independent predictor of failed percutaneous revascularization of CTO (Soon et al. 2007). The ability of CCTA to characterize the distribution of calcium within the lesion is important in predicting the likelihood of PCI success. Cross-sectional calcification, which can only reliably be detected on CCTA, was noted to be more important than the length of calcium deposits in one study (Soon et al. 2007). CCTA information can be utilized to plan the strategy of CTO-PCI. In the evaluation of a CTO, the CT angiogram is able to provide complementary data to that of conventional angiography that may be relevant to the success of the CTO recanalization (figure 8).



Fig. 8. Chronic total occlusion (CTO) of the right coronary artery (arrows) is seen with measurements of the occlusion length on MIP images of a coronary CT angiogram. The patient subsequently underwent PCI of the CTO. Knowledge of the occlusion length and the morphology of the occluded segment were felt to have been helpful in planning the interventional procedure.

5.2 CT angiography for coronary bypass grafts

Many coronary bypass grafts ultimately fail and the standard of care for assessing patients post aorto - coronary bypass has been invasive coronary angiography. Traditionally, this method has been used somewhat liberally, as these patients already have known significant

CAD and, in the presence of symptoms, a negative non-invasive functional study may not be completely reassuring. CCTA has been shown to be a useful alternative in evaluating bypass grafts. The location and patency of grafts can be established with very high accuracy and the conduit can be visualized in a three dimensional fashion (Malagutti et al. 2007). Stenoses in the proximal anastomotic site and the body of vein grafts are accurately displayed with CCTA. However, distal anastomotic sites and especially the coronary artery just beyond the anastomosis are sometimes not easily discerned. Current CT technology is still limited in the presence of significant coronary calcifications and these patients often have heavy coronary calcifications. Metallic clips also sometimes obscure the distal anastomosis site. When patients are being considered for repeat coronary artery bypass surgery, potential injury to patent internal mammary artery bypass grafts can contribute to the hazard of the procedure. Sometimes this injury occurs during the median sternotomy if the bypass graft is adherent to the posterior sternum and inadvertently cut. This occurrence can lead to death or major morbidity. CT angiography can very effectively display the course of bypass grafts relative to the sternum and is considered highly appropriate in this patient population. It is considered to be a useful tool for planning these operations and helpful in avoiding this complication (figure 9).



Fig. 9. Modified lateral and axial views of coronary CT angiogram MIP images were obtained in a patient scheduled for repeat coronary bypass surgery. The previously placed left internal mammary artery graft (arrows) is patent and seen to be located immediately posterior and to the right of the midline of the sternum. Based on the results of the examination, the planned approach to the subsequent sternotomy was modified in order to avoid injury to the bypass

5.3 Coronary aneurysms

Coronary artery aneurysms and ectasia are characterized by an abnormal dilatation of a coronary artery. Morgagni in 1761 first described a coronary artery aneurysm (Falsetti and Carrol 1976). Coronary artery aneurysms are defined as coronary artery segments that have a diameter that exceeds the diameter of normal adjacent coronary segments or the diameter of the patient's largest coronary vessel by 1.5 times and involves less than 50% of the total length of the vessel (Pahlavan and Niroomand 2006). The various etiologies of aneurysms include coronary atherosclerosis (50%), followed by congenital (17%) and infectious causes

(10%)(Pahlavan and Niroomand 2006). The pathogenesis is related to the underlying cause, but a pre-requisite to aneurysm formation is the presence of an abnormal tunica media in the vessel wall that results in enlargement and remodeling of an arterial segment(Diaz-Zamudio et al. 2009). Percutaneous intervention, especially with stents, has also been shown to be a cause for the development of aneurysms(Aoki et al. 2008). The diagnostic approach to coronary aneurysms depends on the clinical scenario, and coronary CT angiography is a useful adjunct to diagnose, evaluate, and follow up these coronary artery abnormalities. Figures 10-12 demonstrate close agreement between invasive assessment and CT angiography in 3 patients with coronary aneurysms and figure 13 demonstrates it in one with a saphenous vein graft pseudoaneurysm. While the natural history of these conditions is not well described and follow up algorithms are not worked out, coronary aneurysms appear to be displayed in accurate detail using CT angiography.

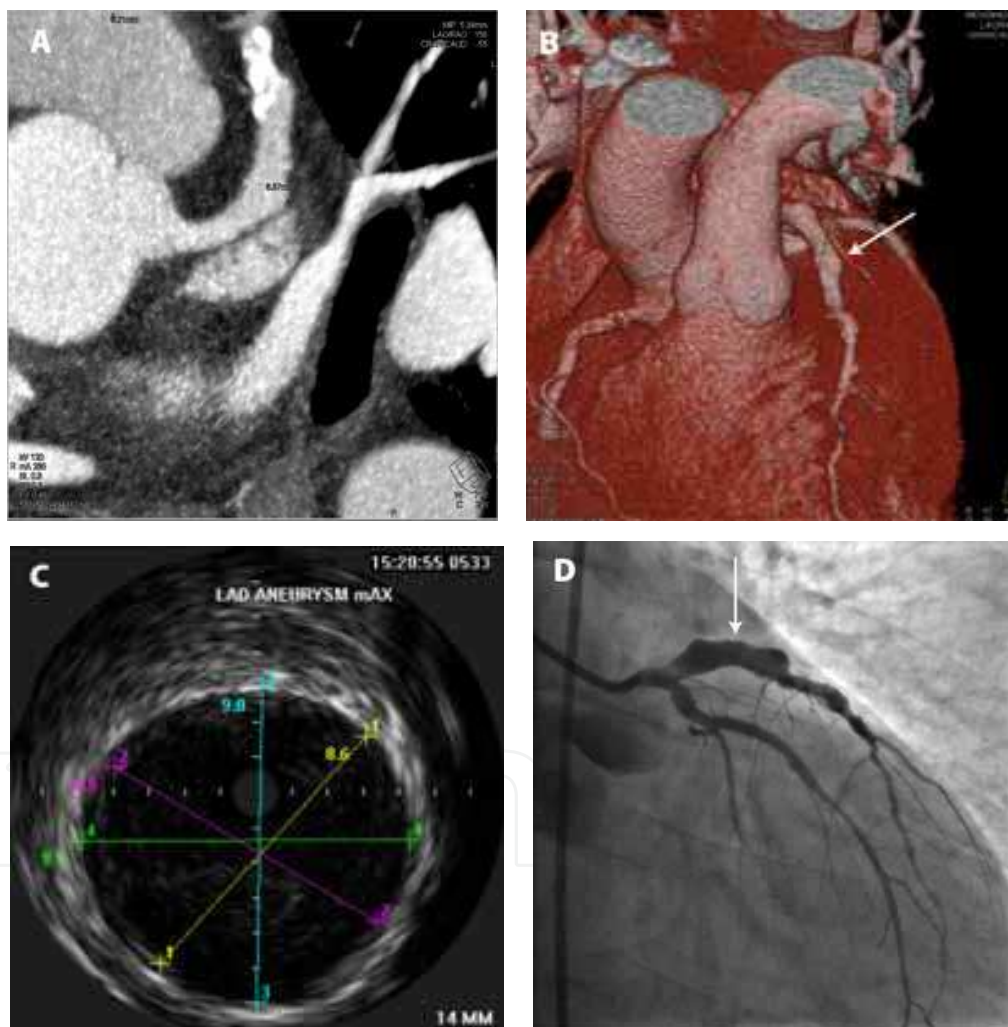


Fig. 10. Aneurysmal dilation of the proximal segments of the left anterior descending artery in a male patient who had recurrent coronary emboli. The aneurysmal segment is seen on oblique maximum intensity projection (A) and volume rendered (B) CT angiogram as well as on intravascular ultrasound (C) and right anterior oblique projection invasive coronary angiogram (D). The appearance and diameter of the dilated segment agrees closely on the three modalities.

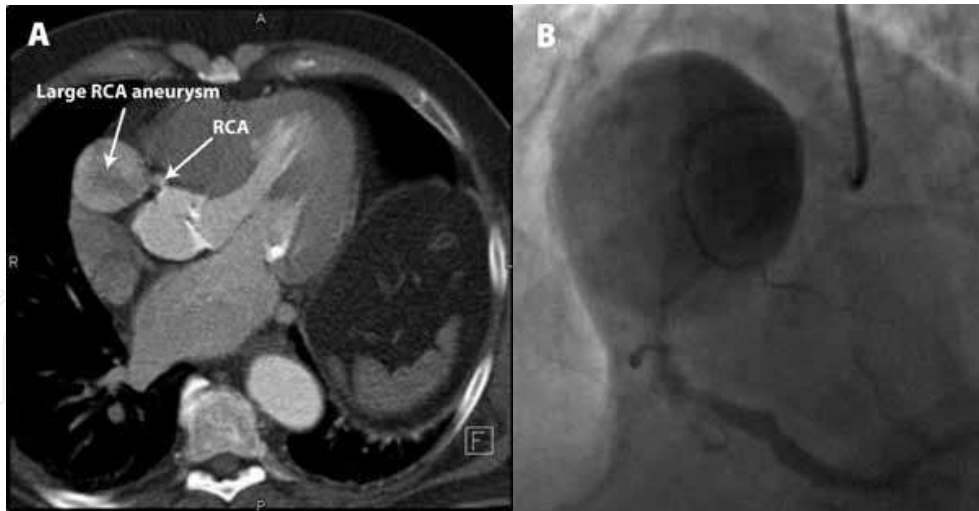


Fig. 11. Huge right coronary artery aneurysm seen on axial view MIP coronary CT angiogram (A) and on invasive coronary angiogram (B).

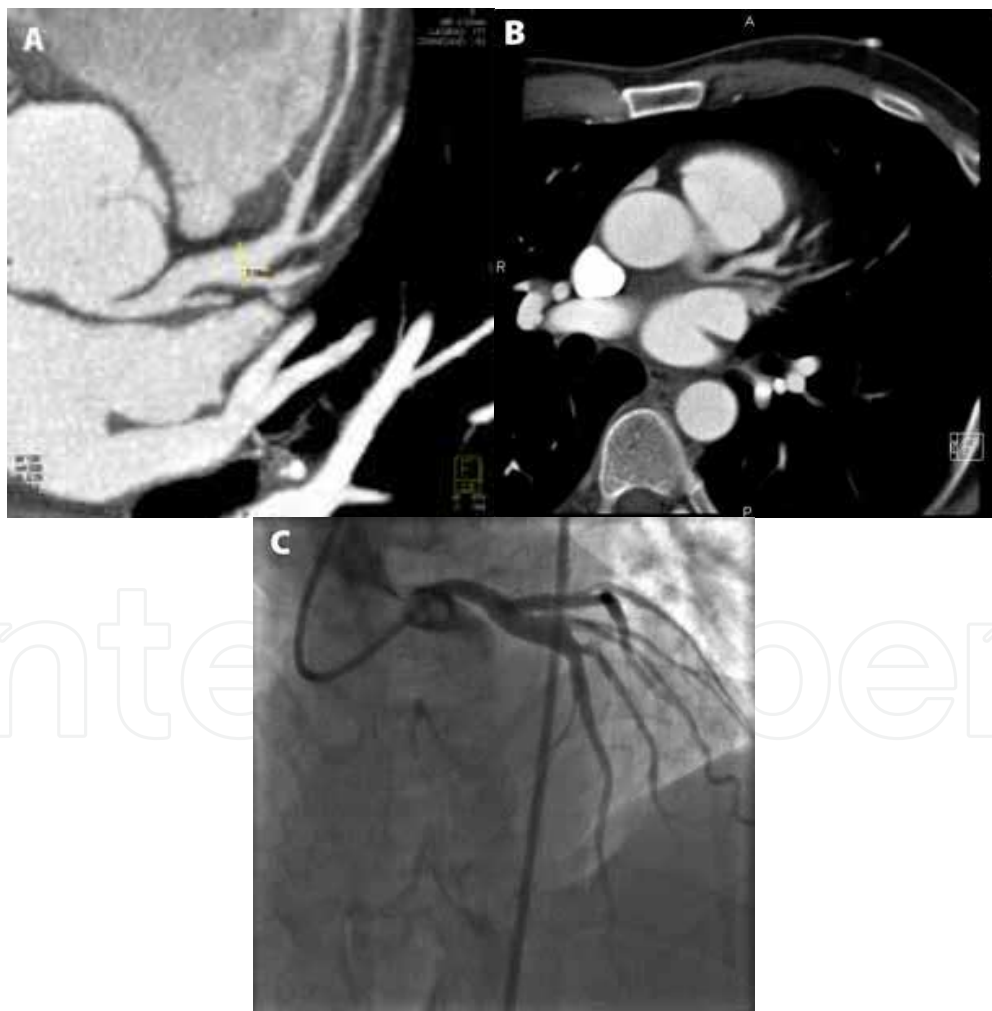


Fig. 12. Coronary CT angiogram MIP (A) and MPR (B) views and invasive coronary angiogram RAO projection showing aneurysmal dilation of the left anterior descending coronary artery.

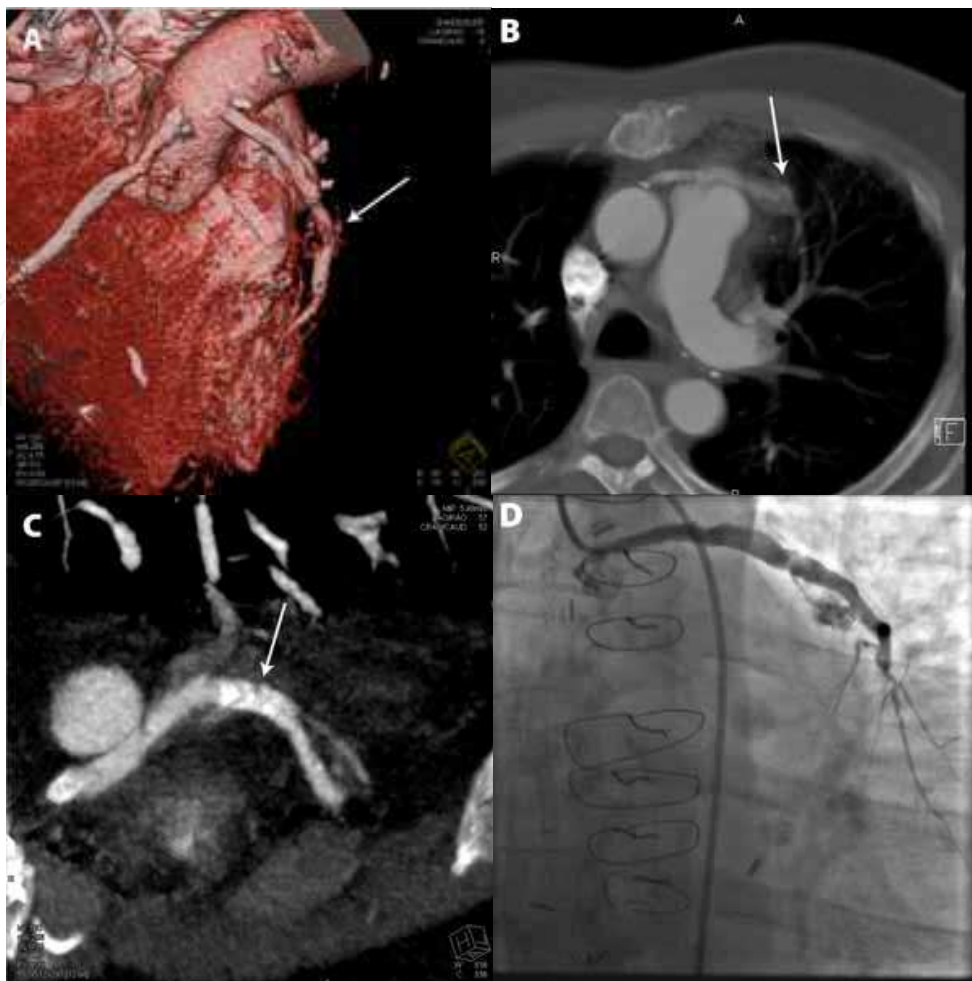


Fig. 13. Saphenous vein bypass graft which developed dissection and contained rupture / pseudoaneurysm post percutaneous intervention. The appearances on CT angiogram by volume rendered image (A), MPR (B), and oblique MIP (C) agreed closely with those on invasive coronary angiogram (D).

6. Prognostic implications of CCTA

CCTA has proven to be an excellent technique to diagnose CAD and is increasingly being used as a first line modality in low risk populations. Several prior diagnostic techniques used in the detection of CAD have proven to provide important prognostic information. CCTA, although a relatively newer imaging technique, has also been shown in recent studies to provide important prognostic information (Ostrom et al. 2008). In a recent report by Gaemperli and colleagues, patients without coronary atherosclerosis on CTA had an excellent prognosis where as the risk for cardiac events increased significantly in the presence of coronary plaques or obstructive lesions. The event rates in the first year were reported to be 34% and 59%, respectively (Gaemperli et al. 2008). There was a strong positive correlation between the extent of coronary atherosclerosis (i.e., the number of segments with coronary plaques) and an adverse cardiac outcome. The presence of three or more coronary plaques was the cut-off providing the highest accuracy to predict future cardiac events. Another study revealed the 1st-year event rate for patients with abnormal coronary arteries to be 30% compared to 0% in patients with normal coronary arteries emphasizing the importance of evaluation of coronary

plaque burden (Gaemperli et al. 2008). Recent angiographic and IVUS derived evidence suggests that assessing plaque phenotype is important in detecting vulnerable plaque (Stone et al. 2011). CCTA's can be used to evaluate the coronary lumen and vessel wall and provide information on obstructive lesions as well as non-stenotic plaques. The burden of atherosclerotic disease determined by CCTA was associated with all-cause mortality among patients with suspected CAD referred for evaluation in an ambulatory setting (Ostrom et al. 2008). CTA demonstrating the presence of luminal obstruction or non-obstructive, non-calcified plaque is a useful noninvasive modality that accurately predicts all-cause mortality with incremental benefit over traditional risk factor assessment and CACS.

7. Other applications of CTA in lieu of invasive angiography

In addition to the above common conditions, there are other, less frequent states when the relatively non-invasive nature of CTA makes it preferable to invasive angiography. For example, occasional patients have very challenging arterial access problems for direct angiography and noninvasively imaging the coronary arteries or bypass graft anatomy might be preferable, even if it would not otherwise be the approach of choice. Also, other patients in whom invasive angiography is risky, such as those with aortic valve endocarditis or heavy aortic atherosclerosis, might also benefit from the less invasive alternative. In these cases, the potential hazard of the invasive procedure is large enough to alter the decision.

8. Conclusion

Coronary CT angiography is an excellent non-invasive diagnostic modality that can be utilized to study in detail the coronary anatomy. It can sometimes supplant traditional invasive coronary angiography, especially in patients in whom the need for coronary intervention is felt to be unlikely. Its excellent negative predictive value makes it a useful, less invasive tool for ruling out coronary artery disease in patients who are at the lower risk of the spectrum for the presence of coronary atherosclerosis. The inherently three dimensional nature also makes coronary CT angiography useful for patients with coronary anomalies and in selected patients who have already had coronary angiography, such as those scheduled to undergo repeat coronary bypass surgery intervention for chronic coronary total occlusions, or those with incomplete procedures. While there has been considerable improvement in the temporal and spatial resolution of the CCTA, it is still inferior to invasive coronary angiography in these aspects and direct invasive angiography is usually needed to make detailed revascularization decisions.

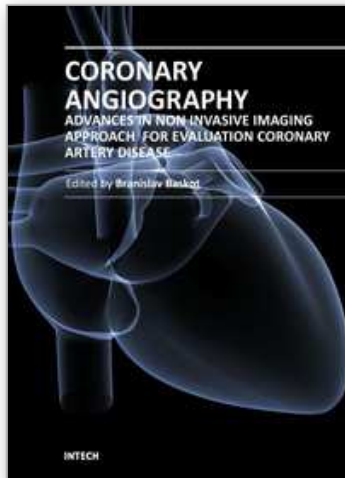
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Coronary Angiography - Advances in Noninvasive Imaging Approach for Evaluation of Coronary Artery Disease

Edited by Prof. Baskot Branislav

ISBN 978-953-307-675-1

Hard cover, 414 pages

Publisher InTech

Published online 15, September, 2011

Published in print edition September, 2011

In the intervening 10 years tremendous advances in the field of cardiac computed tomography have occurred. We now can legitimately claim that computed tomography angiography (CTA) of the coronary arteries is available. In the evaluation of patients with suspected coronary artery disease (CAD), many guidelines today consider CTA an alternative to stress testing. The use of CTA in primary prevention patients is more controversial in considering diagnostic test interpretation in populations with a low prevalence to disease. However the nuclear technique most frequently used by cardiologists is myocardial perfusion imaging (MPI). The combination of a nuclear camera with CTA allows for the attainment of coronary anatomic, cardiac function and MPI from one piece of equipment. PET/SPECT cameras can now assess perfusion, function, and metabolism. Assessing cardiac viability is now fairly routine with these enhancements to cardiac imaging. This issue is full of important information that every cardiologist needs to now.

How to reference

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Seshu C. Rao and Randall C. Thompson (2011). Coronary CT Angiography as an Alternative to Invasive Coronary Angiography, *Coronary Angiography - Advances in Noninvasive Imaging Approach for Evaluation of Coronary Artery Disease*, Prof. Baskot Branislav (Ed.), ISBN: 978-953-307-675-1, InTech, Available from: <http://www.intechopen.com/books/coronary-angiography-advances-in-noninvasive-imaging-approach-for-evaluation-of-coronary-artery-disease/coronary-ct-angiography-as-an-alternative-to-invasive-coronary-angiography>

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