# Minimally Invasive Coronary Angiography Using a Multidetector CT

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Since the beginning of the 19th century, coronary thrombosis has been a known cause of death. In the 20th century, this knowledge led to revolutionary treatment and prevention methods for acute myocardial infarction (AMI)[1]. The selective cineangiocardiography was introduced in 1958, and up to a few years ago was the only test available for coronary anatomical studies, in conjunction with autopsies. The non-invasive tests available were focused on analysis of the coronary function using physical or pharmacologic stress in an attempt to induce myocardial ischemia in order to detect it[2]. The advent of multidetector CTs, work stations with high processing capacity and the acquisition of images with isotropic resolution, made it possible to perform non-invasive coronary anatomical studies *in vivo* that are accurate and reproducible[3].

Heart failure due to atherosclerosis presents two distinct physiopathological mechanisms, culminating in different clinical entities. In the first mechanism, the slow and gradual progression of a stable and angiographically significant plaque leads to luminal stenosis, reducing the distal coronary flow and causing angina pectoris[4,5]. In the second mechanism, the abrupt rupture of an unstable plaque can induce thrombosis almost instantly, causing a coronary occlusion and the development of the so called acute coronary syndromes: unstable angina and acute myocardial infarction (AMI)[6,7]. In this second mechanism, the atherosclerotic plaque is often small with a high lipid content covered by a tenuous fibrous cap and thus the tendency to rupture[8,9]. These are often undetected by conventional invasive angiographies and do not produce any symptoms until they rupture. Since they do not cause a significant luminal obstruction, they may also be undetected by conventional non-invasive methods.

## Technical considerations

Coronary arteries are small vessels (usually with lumen less than 4mm) that originate at the ascending aorta and are distributed throughout the myocardium, creating a complex three dimensional structure. Since they are in close contact with the cardiac muscle they present intense motility. These characteristics make the minimally invasive coronary angiography a superlative endeavor, requiring imaging equipment with high spatial and temporal resolution[10].

In 1998, tomographies that were able to acquire images simultaneously by means of four rows of detectors and a minimum rotation time of 500 msec were introduced. Since then, the strategy adopted to raise the imaging capacity of the tomographies has been to increase the number of slices that can be acquired simultaneously. This in turn has led to the development of machines with more and more rows of detectors.

The key to acquire good quality images resides in the capacity to make tomographic “slices” during the cardiac cycle phase when there is minimal coronary movement: the telediastole. To achieve this, modern multislice tomographies use sophisticated algorithms that are able to produce a “virtual diastole cardiac arrest.” The systolic phase is classically described as the initial third of the cardiac cycle. As the heart rate increases, the systole time, defined on the EKG as the R-T interval, tends to suffer minimal variations. However the diastole, defined as the T-R interval, suffers great fluctuations. Most laboratories use betablockers to maintain low heart rates, enabling sharper images and greater diagnostic precision.

After the patient is adequately positioned and the peripheral venous access puncture is completed, the acquisition phase begins. Initially the patient is asked to inhale and hold their breath for a short period in order to obtain the calcium score. Next, the patient is asked to hold their breath for roughly 20 seconds, which in most cases is enough time to obtain the contrasted images. It should be noted that individuals with large torsos, large cardiac silhouettes or with mammary anastomosis will be required to hold their breath for longer lengths of time. In the case of mammary anastomosis, it is necessary to study the origin of the graft; therefore slices from higher portions of the torso are required, which prolongs the

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acquisition period. An injection of an iodinated contrast agent (approximately 90 ml) is administered at an infusion rate of approximately 4ml/sec. In medical departments that have a double lumen injector pump, frequently a 40 ml bolus of 0.9% saline solution is also infused at a rate of 4ml/sec, immediately following the injection of the contrast agent. The purpose of this last procedure is to reduce the opacification of the cardiac structures located to the right allowing a better visibility of the coronary vascular tree.

Once the images are acquired, the work of the cardiologist/CT technician begins at the workstations for reconstruction, formatting and interpretation. There is considerable variation in image manipulation methods because of the different software packages offered by the various manufacturers. The most common methods include MPR (multiplanar reformation), oblique MPR, curved MPR, MIP (maximum-intensity projection), shaded-surface display and three-dimensional reconstruction (3-D). Considering the large number of settings and projection angles it is important that the images are manipulated so as to visualize the entire vessel volume, taking advantage of the features of each technique[10,11] (fig.1, 2 and 3).

Even though the 3-D images provide a good perception of the coronary tree's spatial distribution anatomy, it is the bidimensional techniques (longitudinal and axial slices) that enable the study of coronary plaque in relation to size, radiological density and estimation of luminal obstruction. For the coronary luminal study it is extremely important to obtain axial slices (cross sections) of the vessel, using the normal portions adjacent to the lesion as a reference (fig.3). Documented consensus of the results obtained in comparative estimations of the degree of luminal stenosis between the various CT techniques and conventional invasive angiographies varies substantially. This fact can be partially explained by the significant variation of analysis protocols supplied by various manufacturers.

## Clinical applicability

The role of a coronary angiotomography is not yet completely defined, however, its diagnostic capability has turned it into a method that is more and more frequently indicated in daily clinical practice[12,13].

The rapid technological evolution of this new technique makes it difficult to safely determine what the real importance of the test will be in altering the history of coronary disease in its widest sense. Likewise, it is important to note that a coronary angiotomography involves new methods and that great improvements are still required and hoped for. Nevertheless, documented

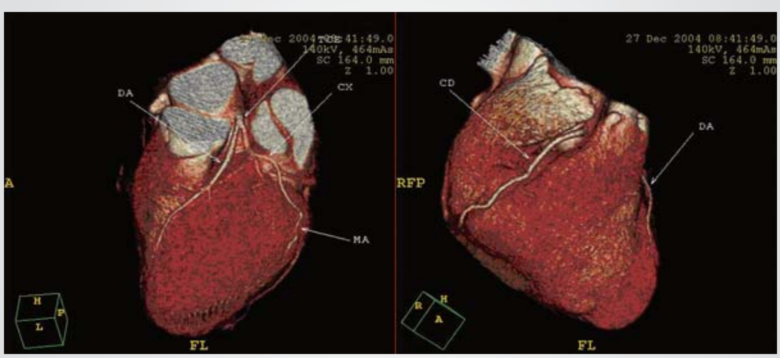


*Fig. 1 – Three-dimensional reconstruction of the coronary tree*

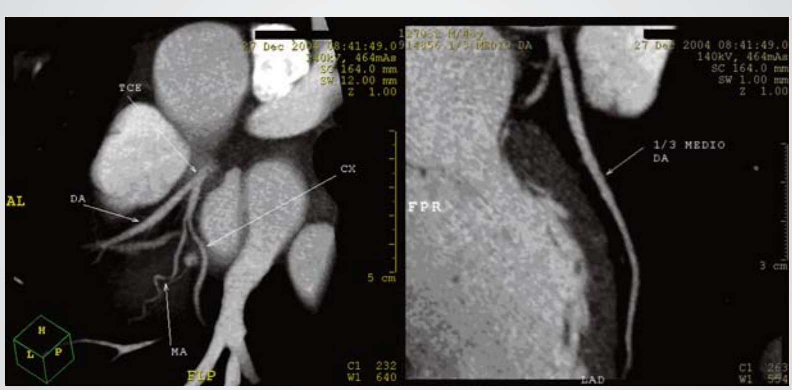


*Fig. 2 – Types of coronary anatomy reconstruction. At the left MIP and at the right curved MIP*

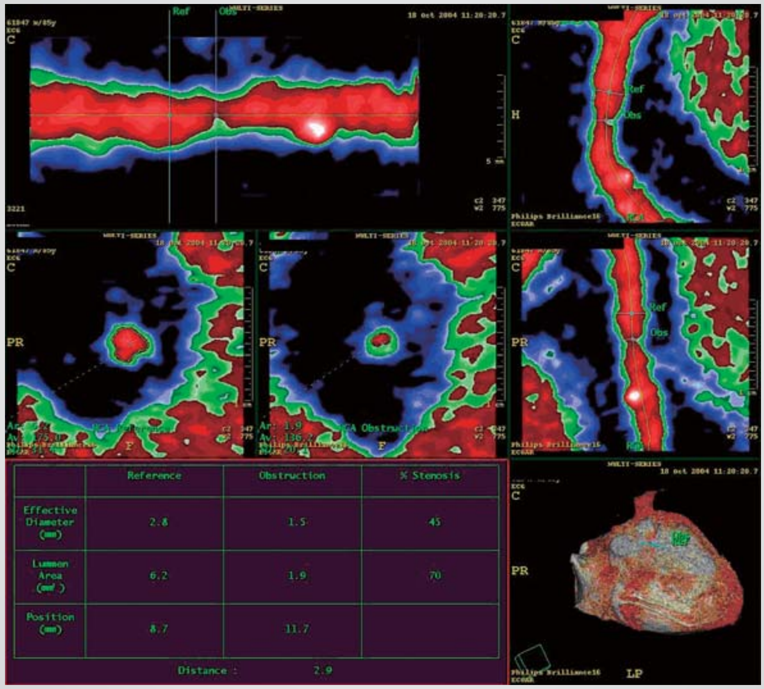


***Fig. 3*** *– Analysis of luminal stenosis. Intracoronary contrast in red, with cross sectional slices to analyze the diameter and area reduction*

data have already specified some of the main indications as follows.

In native coronaries, some authors have documented that the angio-CT is able to not only accurately detect lesions but also to classify the coronary plaque in accordance with its density and calcium content[14]. Schroeder et al[15] compared plaque density recorded by the angio-CT with post-mortem histological findings, determining that high lipid plaques have an average density of 42 ± 22 Hounsfield units (HU), intermediate plaques of 70 ± 21 HU, and calcified plaques of 715 ± 328 HU (fig.4). Unfortunately a precise estimate of the histological characteristics of coronary atherosclerosis plaques remains controversial. Viles-Gonzales et al[16] did not find a dependable relation between the radiological density of the lesion recorded by the angio-CT and the histological findings. Once again, the question is raised regarding the methods used to conduct the test and the results obtained.

The prospects for the angio-CT technique in the case of acute coronary syndromes are promising. Patients with unstable angina present coronary atherosclerosis plaques that are consistently less dense than those found in patients with stable angina[17,18]. Dorgelo et al[19], studying patients diagnosed with acute coronary syndrome, that did not present an elevated ST segment, using CTs with sixteen rows of detectors, obtained an excellent correlation in comparison to a conventional angiography (sensitivity 94%, specificity 96%). In these cases , 45% of the patients were not submitted to a percutaneous intervention as there was no significant obstruction (27%) or surgical revascularization was required (18%).

Mollet et al[20] prospectively studied the entire coronary tree of 128 patients with stable angina in order to detect lesions that would potentially require intervention, finding an excellent correlation with an invasive angiography (sensitivity 92%, specificity 95%, positive predictive value 79%, and negative predictive value 98%).

Various authors[21-28] have studied patients who had undergone surgical revascularization using multislice CTs. The angio-CT technique proved to be precise for the evaluation of various types of anastomosis and coronary artery bypass grafts (fig.5), in various locations, in patients that were asymptomatic or had angina symptoms. Although the reports of these various authors indicate an optimistic future as regards non-invasive anatomical coronary artery bypass graft studies, it is important to note that considering technically inferior tests, there are substantial artifact sources for interpretation errors. As mentioned earlier, mammary anastomosis requires a longer breath hold, which is a difficult task for patients who are demented, elderly or pneumopathic.

The evaluation of stents using multislice CT methods is still a challenge since the increased density of their metallic structure produces artifacts that greatly reduce the visibility of the intraluminal contrast (fig.6). Nevertheless, in some cases, the contrast through the prosthesis could be adequately studied as well as its patency along with the degree of distal artery opacification[29-33].

Other applications include the follow-up of coronary artery remodelling[34,35], detection and graduation of coronary artery aneurisms in individuals with or without

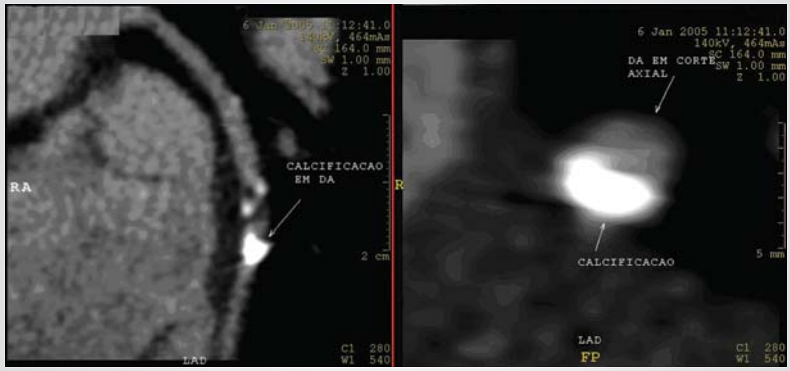


*Fig. 4 – Mixed plaque on the mid third of the anterior descending artery. At the left, observe the longitudinal slice using the curved MIP and at the right the cross section*

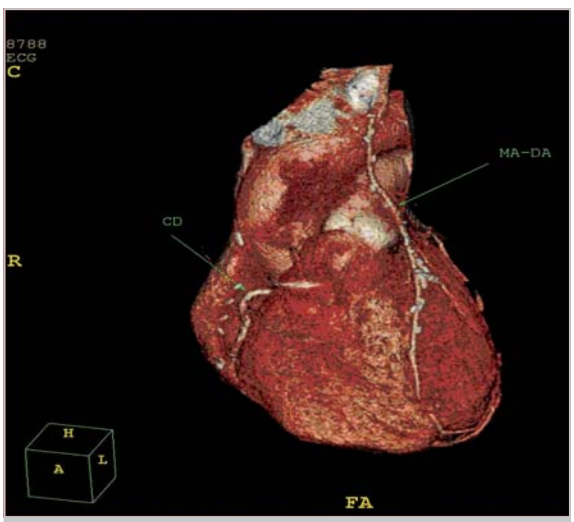


*Fig.5 – Vascular anastomosis. Presence of mammary anastomosis –anterior descending artery*

Kawasaki disease as well as precise detection and characterization of anomalous coronary arteries[36-39].

## Calcium and heart disease

The association between the presence of calcium in the coronaries and atherosclerosis plaques is well established and has been known for almost a century[40]. In rare cases, patients can present Monckeberg calcification in the media layer of the coronary artery and not have atherosclerosis[41,42]. Individuals with calcium-phosphate metabolism alterations can also present accelerated artery calcification[43,44]. Nevertheless, for clinical purposes, coronary calcification represents the existence of atherosclerosis[45].

Data obtained from an electron beam tomography (EBT) allow the formulation of a score that describes the calcification intensity as: low (1-10), moderate (11-100), moderately high (101-399) and high (> 400). The incidence of complications is directly related to the quantification supplied by the score and the absence of tomographically detectable coronary calcification will have an elevated negative predictive value, excluding the possibility of significant atherosclerosis which, for example, is very useful information for a population with atypical precordialgia[45]. Meneghelo et al[46] described the distribution of EBT determined calcium scores for 2,253 Brazilian men between the ages of 22 and 88 years, finding scores higher than zero in 48.8% of the cases, in a pattern that did not follow the Gauss curve.

Recent studies have shown that a multislice CT is at least comparable to a EBT[47,48]. The number of EBTs available in Brazil is extremely limited due to the high cost and low versatility. Since most of the prognostic data were obtained based on prospective studies using an EBT, comparison between the methods remains a controversial issue.

To date, there are no studies available regarding the predictive value of coronary calcification levels based on rigorous prospective studies that have been concluded. Therefore, the real impact of the calcium score still needs to be demonstrated in large population cohorts.

## Diagnostic accuracy

In dealing with studies of angio-CT diagnostic accuracy it is extremely important to emphasize the difficulty of comparison and interpretation since distinct techniques are used. A detailed analysis of the studies reveals diversity in the following variables:

- Algorithms for reconstruction and reconstructed cardiac cycle phases;
- The patient studied;
- Type, volume and flow of the contrast agent injected;
- CT manufacturer;
- Software used for interpretation.

The non-invasive test for coronary visualization requires high temporal and spatial resolution equipment. Since the initial reports in the year 2000[49,50], various authors have contributed to the analysis of coronary stenosis

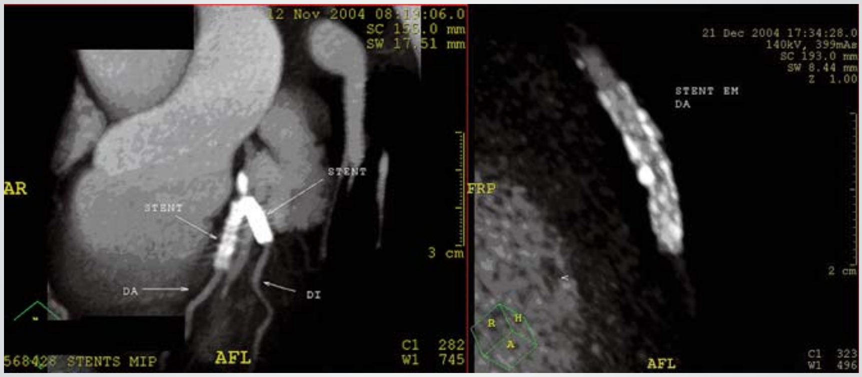


***Fig.6** – Stents. At the left, observe the presence of two stents whose metal structure affects luminal observation. At the right, the contrast within the stent can be seen*

detection accuracy demonstrating that CTs equipped with sixteen rows of detectors, even in the preliminary studies, are superior to the predecessors with four rows of detectors (tab. 1).

Surgical grafts (saphenous vein, mammary and radial arteries) have less movement than native coronaries during the cardiac cycle and is the technique indicated for revascularized patient follow-up (tab. 2).

Along with the development of more modern multislice CTs that include technology with 32, 40 and 64 detectors[60], it is hoped that the image quality will be sharper and that diagnostic accuracy will improve.

## Limitations

As previously mentioned, coronary calcification has been considered as a sign of atherosclerosis. However, luminal evaluation of segments that are severely calcified are affected by the production of arterial light artifacts, similar to those seen in patients with stents.

In order to acquire good quality images, it is desirable to have a cardiac rhythm with a regular R-R interval and a lower heart rate[61,62]. Most laboratories have been using betablockers to obtain heart rates lower than 65 BPM[63]. Of course, the presence of cardiac arrhythmias, especially tachyarrhythmias with a variable R-R interval, such as in the case of atrial fibrillation, often makes it impracticable to conduct the test. Ectopic beats, even isolated, could affect adequate visualization of the coronary segments[64] (fig.7).

The radiation dose to perform the coronary angiotomography is considered high and superior to the dose used in electron beam tomographies and conventional angiographies[65] (tab. 3).

Similar to the classic angiography, the test requires an venous injection of iodinated contrast agent which could cause nephrotoxic and allergic reactions.

**Table 1 – Coronary angio-CT accuracy using tomographs with four and sixteen rows of detectors: preliminary studies with sixteen rows of detectors**

| Author | n | Detectors | Sensitivity | Specificity | No evaluation |
|---|---|---|---|---|---|
| Nieman et al[51] | 31 | 4 | 81% | 97% | 27% |
| Achenbach et al[52] | 64 | 4 | 91% | 84% | 32% |
| Knez et al[53] | 42 | 4 | 78% | 98% | 6% |
| Herzog et al[54] | 42 | 4 | 72% | 92% | - |
| Kopp et al[55] | 102 | 4 | 86-93% | 96-97% | 18% |
| Becker et al[56] | 28 | 4 | 78% | 71% | 11% |
| Nieman et al[57] | 53 | 4 | 82% | 93% | 30% |
| Nieman et al[3] | 59 | 16 | 95% | 86% | 0% |
| Ropers et al[58] | 77 | 16 | 92% | 93% | 12% |

**Table 2 – Angio-CT accuracy in the evaluation of by-passes and coronary anastomosis**

| Author | n patients | n anastom. | Sensitivity | Specificity |
|---|---|---|---|---|
| Burgstahler et al[21] | 10 | 21 | 86% | 100% |
| Ko et al[23] | 39 | 115 | 93.3 % | 99 % |
| Tello et al[22] | 26 | 75 | 97% | 95% |
| Schlosser et al[26] | 48 | 131 | 96% | 95% |
| Rossi et al[59] | 47 | 116 | 100% | 100% |

## Conclusion

At the beginning of the 20th century, anatomical coronary artery studies were performed on autopsy tables. In the second half of the century, the cineangiocardiography offered a gigantic leap in the area of coronary atherosclerosis treatment. Minimally invasive anatomical coronary studies using CTs equipped with multiple detectors began in the year 2000.

The leading qualities of the technique include speed, safety and accurate diagnosis especially related to negative predictive values. The main limitations include arrhythmias during the image acquisition, difficulty for the patient to hold their breath, extensive coronary calcification and the presence of stents.

The main indications for using the technique include diagnosis of anatomical anomalous coronaries, an alternative for patients with a doubtful stress test, atypical chest pain, low calcium score, follow-up for bypass and coronary vascular anastomosis patients, myocardiopathic patients and possibly for pre-operative evaluations.

Currently, development of the multiple detector angiotomography is continually moving forward. The current image quality is not sharp enough to make the method a routine tool for all patients[67,68]. The ability to identify the type of plaque visualized offers new prospects for coronary risk evaluation, however, further investigation in this area is required.


***Fig.7** – Image artifacts. Image at the left showing "steps" produced by respiration during the aquisition phase. At the right, observe the artifact in the third proximal of the circumflex artery due to ventricular ectopics*

**Table 3 – Radiation dose during an angio-CT test**

| | | Multislice CT | | | |
|---|---|---|---|---|---|
| **Dose Organ (mSv)** | **EBT** | **Siemens®** | **Schroder et al[65,66]** | **Achenbach et al[50,52]** | **Invasive angiography** |
| Bone marrow | 2.0 | 14.1 | 11.0 | 10.1 | 2.5 |
| Lungs | 3.9 | 37.6 | 27.9 | 22.7 | 8.1 |
| Thyroid | 0.4 | 2.7 | 3.4 | 1.4 | 0.5 |
| Esophagus | 3.1 | 27.1 | 16.9 | 17.2 | 4.2 |
| Liver | 1.8 | 13.5 | 9.8 | 9.9 | 2.9 |
| Stomach | 2.6 | 18.2 | 9.8 | 9.8 | 1.6 |
| Colon | 1.0 | 1.0 | 0.7 | 0.9 | 0.7 |
| Bladder | 0.3 | 0.4 | 0.3 | 0.3 | 0.3 |
| Breasts | 5.9 | 44.0 | 28.7 | 25.6 | 6.9 |
| Ovaries | 1.5 | 0.6 | 1.4 | 0.9 | 1.1 |
| Testicles | 0.4 | 0.7 | 0.4 | 0.2 | 0.5 |
| Actual dose (mSv) | 0.5 - 2.0 | 10.9 - 13.0 | 7.6 - 9.2 | 6.7 - 8.1 | 2.1 - 2.5 |

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