# CARDIAC COMPUTED TOMOGRAPHY: TECHNOLOGY IN RAPID EVOLUTION

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## INTRODUCTION

**From resting electrocardiogram (ECG) to stress ECG, stress echocardiography, and nuclear perfusion imaging , noninvasive cardiovascular imaging has significantly improved the clinician's ability to detect coronary artery disease (CAD). Yet, the holy grail of assessing CAD has been the direct visualization of the coronary arteries. Today, invasive cardiac catheterization and intravascular ultrasound remain the gold standards for detecting coronary stenosis and atherosclerotic plaques. These invasive procedures, however, carry significant costs and procedural risks. Therefore, the development of noninvasive imaging techniques capable of evaluating the coronary anatomy would have a huge impact in managing patients with suspected CAD or at risk of developing CAD.**

**Until now, noninvasive imaging of the coronary arteries has been a challenge. The coronary vessels are small and move with the cardiac cycle and with respiration, so any noninvasive technique would need to have tremendously high spatial and temporal resolution to obtain accurate images of the coronary tree. Over the past decade, hardware and software technological advances in computed tomography (CT) have met these challenges. Single-slice scanners with inadequate resolution for cardiac application have given way to the current generation multislice (up to 320-slice) scanners with submillimeter and almost heart-freezing temporal resolution, enabling accurate noninvasive assessment of coronary arteries.**

## HISTORY OF CT (FIGURE 1): THE BEATLES CONNECTION

In 1895, William Roentgen (a German physicist) discovered the X-ray and was awarded the Nobel Prize for physics in 1901. In 1963, Allan Cormack (a Souch African-born physicist) devised the machemacical principles of reconstruction for cross-sectional imaging and measuring the tissue-densicy distribution within che body, laying the foundation for computerized axial tomography. Interestingly, just one year earlier, che Beatles had signed with EMI Records, a company chat would later develop the first CT scanner - funded, at least in part, by revenue from Beatles' records sales, which had almost doubled EMI's profits. In 1971, Godfrey Hounsfield, an electrical engineer with EMI, developed the firsc clinical CT scanner (Mark I), which acquired a single cross-sectional image of the head in five minutes using a single X-ray source and a single detector. Three years later, the second generation of CT scanners was introduced, followed by the third generation in 1977. The combination of the Bearles' success and the genius of Godfrey Hounsfield had changed the face of modern medicine. Along with Allan Cormack, Godfrey Hounsfield was awarded the Nobel Prize in Physiology or Medicine in 1979. In his acceptance speech, Godfrey predicted that one of the promising fields for CT would be the detection of coronary artery disease.[1]

At that cime, cardiovascular imaging

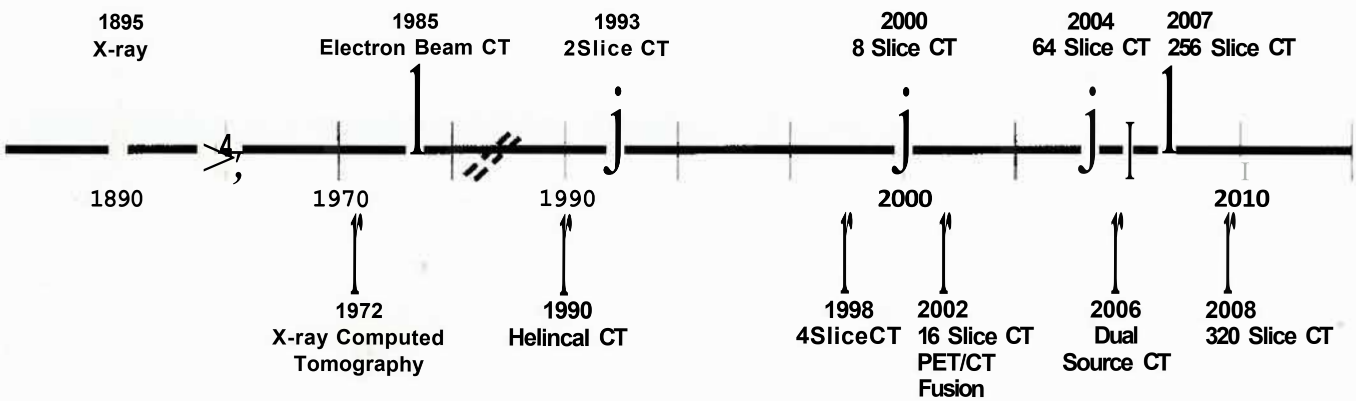


**Figure 1.** Timeline of Cardiac CT Development.

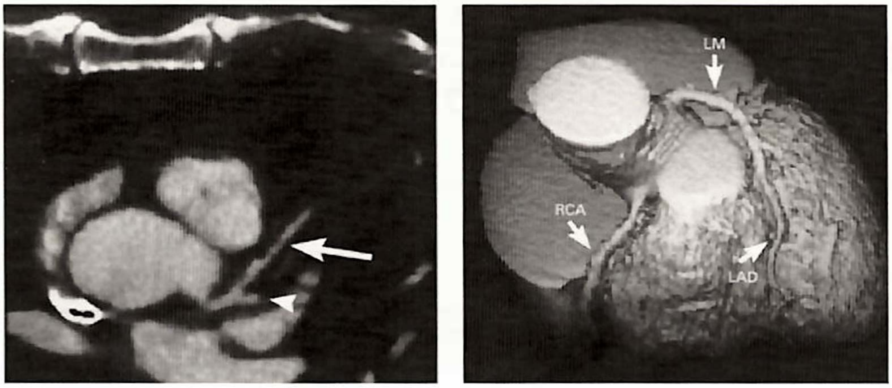


**Figure 2.** Coronary CT angiography with electron-beam computed tomography.

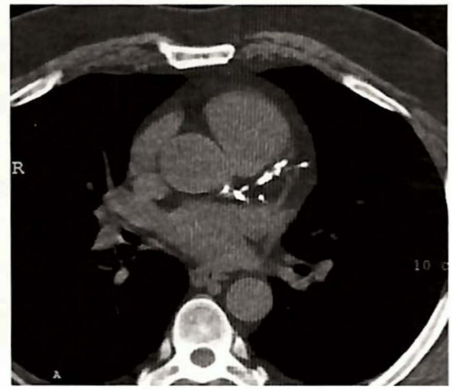


**Figure 3.** Severe extensive coronary calicification seen in noncontrast CT.

was not possible with general-purpose CT scanners due to insufficient spatial and temporal resolution. Initial CT scanners were limited to tomographic sections of the non-mobile brain chat cook several minutes to acquire. Through the pioneering work of Douglas Boyd in the rnid-1970s and early 1980s, electron beam tomography (EBT) was introduced for dedicated cardiac applicacion.2 With nonmechanical control and electronic sweeping of the electron beam, EBT was also called "ultrafast CT" because of its extremely short image-acquisition times of 50-100 ms/image chat virtually froze cardiac motion. Although it allowed functional assessment of cardiac chambers, che major limitations for coronary visualization were the low spatial resolution, signal-to-noise ratio, small coverage, and a relatively long patienc breach-hold. Despite these limitations, in the mid-1990s EBT was first in demonstrating the capacity of CT to obtain "noninvasive coronary angiograms" and assess cardiac volume after injection of an intravenous contrast agent (Figure 2).3 To date, the main application of EBT is the detection and quantification of coronary artery calcification.

The new development in the rnid-1990s generated tremendous interest in better visualizing the coronary tree and fueled the subsequent explosive evolution of new CT technology. In 1989, with the advent of spiral or helical CT systems with subsecond rotation, computed tomography became a widely used vascular imaging modality. The cables of older scanners were replaced by slip-ring technology, allowing faster helical scanning in which the X-ray source and detector continuously rotate around the patienc while the patient table moves through the scanner. However, limitations in spatial and temporal resolution still prohibited the application to cardiac work.

The scan speed was further improved by the fan-shaped radiation beam, larger number, and becter quality of X-ray detectors in what are called multi-detector (or multislice) CT scanners (MDCT). The Elscinc CT Twin developed in 1991 was the first MDCT scanner and had two parallel arrays of X-ray detectors to acquire two slices for each gantry rotation. For the first time, these scanners enabled ECG-correlated multislice acquisition at considerably faster and larger volume coverage and higher spatial and temporal resolution for cardiac applications compared co single-slice scanners. However, the early experience with the MDCT was still unsatisfactory. For the next several years, a "slice wars" among major CT manufacturers fostered major performance advances in cerms of thinner slices (better spacial resolution) and an increased number of slices acquired per rotation - from four to eighc, eight co 16, 16 to 64 in 2003 and now even up to 320 (betcer volume coverage), which enable whole heart imaging in one single cardiac cycle. All these technological advances finally overcame many of CT's prior limitations: CT can now provide ECG-gated acquisition with shore acquisition rime (6-10 seconds), submillimecer spatial resolution (0.5 mm), and adequate temporal resolution (83-220 ms), thus allowing excellent visualization of che coronary arteries.

## ESTABLISHED CLINICAL APPLICATION

There was intense debate regarding che clinical role of cardiac CT in the 1990s. The wealth of clinical daca published in the lase decade has significantly clarified the clinical application of this cechnology.

### Coronary Artery Calcium Scoring (Figure 3)

Calcium scoring detects coronary atherosclerosis at its early stages, well before development ofhemodynamically significant coronary scenosis. Currencly, coronary artery calcium scoring can be performed using EBCT or MDCT (Figure 3). It requires minimal patient preparation and no IV contrast administration, and it subjects patients co very low radiation doses of around 2-3 mSv. The amount of calcium is calculated to what is known as an Agacsron score.[4] Calcium scoring based on age and gender has been shown co be prediccive of obscrucrive disease {>50% stenosis) by invasive coronary angiography in symptomatic populations with suspecced CAD[5] and by the presence of ischemia detected by perfusion imaging.[6] In addition, it has been shown to predict coronary events beyond standard risk factors alone in asymptomatic populations regardless of racial or ethnic identicy.[7] Therefore, calcium score scans are powerful predic-cors of a patient's risk of developing a furnre coronary event. The early detection of atherosclerosis could help the patient and physician determine lifestyle and ocher therapeutic interventions to decrease that risk.

### Noninvasive Coronary CT Angiograms

Currently, most of the coronary computed tomography angiograms {CTA) are performed by widely available 64-slice MDCT systems. They allow effective assessment of stenoses in coronary arteries and coronary artery bypass grafts, ventricular size and function, cardiac strucrnre and masses, pulmonary vein anatomy, coronary arrery plaque, and coronary anomalies (Figure 4). Coronary CTA is now considered an "appropriate" procedure in several selected clinical scenarios, including ruling out coronary disease in symptomatic pacients with intermediace likelihood of coronary artery disease.[8] While numerous comparisons between coronary CTA and invasive angiogra: phy have shown a high accuracy for the detection of "obstructive" coronary artery lesions, che prognoscic implications of coronary CTA are rapidly accumulating as well. Recent daca in 2,538 consecutive patients followed for up to 12 years demonstrated that burden of angiographic disease detected by CTA provides incremental value in predicting all-cause morcalicy in symptomatic patients independent of age, gender, and conventional risk factors.[9]

## LIFE AFTER SLICE WARS: TECHNICAL INNOVATION FOR DEVELOPMENT OF NEW GENERATION SCANNER

In recent years, manufaccurers have taken divergent **paths** in their quest to develop more enhanced coronary imaging approaches.10 The rare of technological advancements leading to improved coronary angiography with MDCT has far exceeded other competing technologies such as electron-beam computed tomography and magnetic resonance imaging. Some of chose advancements including the following:

1) The **dual-detector** CT first introduced in 2006, along with three-dimensional adaptive filtering, enable the dual-source scanner to achieve approximately 75 m/sec temporal resolution. It also could offer important new information about tissue properties by applying **dual-energy imaging** and analyzing the effects of two **X-ray** signals acquired simultaneously. Promising applications include plaque differentiation, virtual precon-crast images, automated bone removal, and iodine maps for perfusion.
2) **New detector materials** to improve further image resolution and noise include garnet-based scintillator material over traditional gadolinium oxysulfide-based materials.
3) **Wide-area detectors** with greater anatomic coverage featuring 320 detector rows and 16 cm of coverage can perform whole-heart imaging in a single heart beat, avoiding the need to reconstruct images from several beats. This would enable the imaging of coronary vessels, cardiac function, and myocardial perfusion in one single study.
4) **Air-bearing gantry** delivers a faster rotation speed of 270 m/sec.
5) **Reducing radiation dosage** by prospective gating: the CT scanner is turned on during a small portion of the cardiac cycle (diastole) and off the rest of the time. New software such as adaptive statistical iterative recon-strucrion (ASIR) could also reduce the dose.
6) SPECT **or** PET/CT three-dimen--**sional fusion** imaging amid provide complementary infurmation on coronary artery anatomy and pathophysiologic lesion severity, directly relating individual myocardial wall territories to the subtending coronary artery.

## CONCLUSION

As cardiac CT technology evolves and more clinical data is accumulated, the clinical applications will continuously expand such as detection and characterization of coronary artery plaques. This powerful noninvasive imaging tech-

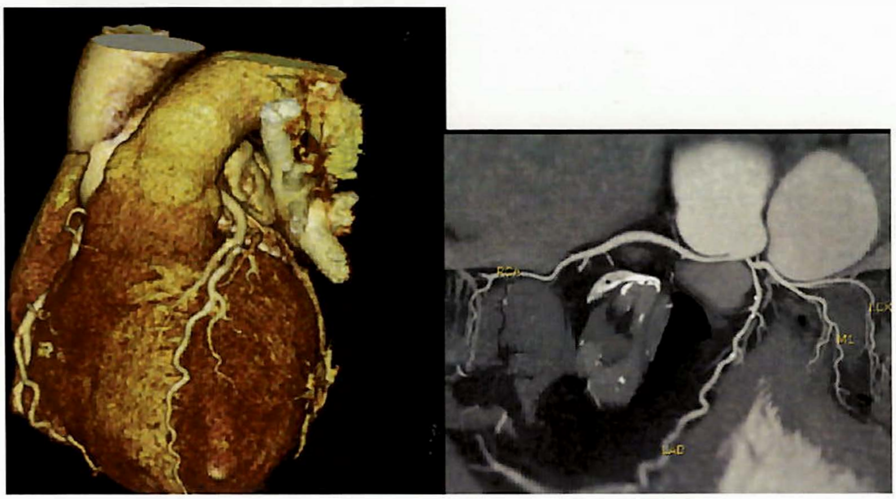

**Figure 4.** Coronary Anomaly by 64 slices MDCT Coronary angiograph.

nique will evencually change the way physicians cradicionally manage patients with suspected coronary artery disease or at risk of developing CAD.

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## ACKNOWLEDGMENTS


*Su Min Chang. M.D. would like to thank Ms. Maria Frias for her expertise in preparing the figures for this article.*