Chapter 1

Coronary Artery Calcium Scoring

After completing this chapter, the learner should be able to:

- Describe atherosclerosis and its effect on the function of the coronary arteries
- Explain how CT calcium scoring is performed and calculated
- Discuss how the results of calcium scoring can impact patient management

INTRODUCTION

Routine screening examinations are a well-accepted practice for detection of medical problems early in the disease process. Annual physical exams, mammograms, and colonoscopy are examples of routine screening exams.

Using CT as a tool for measuring coronary artery calcium (CAC) has become an accepted method of screening for coronary artery disease (CAD). Heart disease remains the leading cause of death in the United States, with about 610,000 people dying from the disease each year. Coronary artery disease is the most common type of heart disease, killing more than 370,000 people annually.[1] Computed tomography has assumed an important role in screening of the asymptomatic patient, allowing for early and effective treatment and potentially reducing the rate of cardiac death.

HEART DISEASE

In the United States, heart disease continues to be the number one killer of Caucasians, African Americans, and Hispanics and is the number two cause of death for Asian Americans.[1] One in four women will die from heart disease, while one in 31 women will die from breast cancer.[2, 3] More women will die from heart disease than all forms of cancer combined. Almost two-thirds of women who die suddenly of coronary heart disease have no previous symptoms.[2] Despite these disturbing facts, only one in five American women believe that heart disease is their greatest health risk.[3]

Heart disease risks are equally as sobering for American men. One in four men will die of heart disease, and about half of the men who die suddenly of coronary heart disease experience no previous symptoms.[4]

About 15% of people who suffer a heart attack will die from it.[5]

High blood pressure, high LDL **cholesterol**, and smoking are the greatest risk factors for developing heart disease, and approximately 50% of Americans have at least one of these three major risks. Other medical conditions or social habits that increase the risk of developing heart disease include diabetes, obesity, poor diet, physical inactivity, and excessive use of alcohol.[1]

Almost half of sudden cardiac deaths occur outside of a hospital, suggesting that many people do not act on early warning signs. Calling 9-1-1, even if the cause of symptoms is not known, is vital since the chance of surviving a cardiac event increases dramatically with immediate emergency treatment. The most common warning signs of a heart attack include pain or discomfort in the chest, jaw, arms, neck, upper back, and upper stomach; shortness of breath; nausea; lightheadedness; and cold sweats.[1]

In addition to these common warning signs, indigestion and extreme fatigue may also be a warning of a “silent” heart attack, which has few if any symptoms.[2]

Clearly, early detection is critical given the high risk of developing heart disease in the United States and the associated high mortality rate.

CT CORONARY ARTERY CALCIUM SCORING

CT coronary artery calcium scoring identifies the presence of calcium in the coronary arteries, a sign of **atherosclerosis** that occurs when **plaque** builds up on the walls of blood vessels **(Figure 1**). Over time, plaque can calcify, resulting in narrowing of the coronary arteries which limits blood flow to the heart (**ischemia**) and can ultimately cause **necrosis** of the heart muscle **(Figure 2)**.[6]

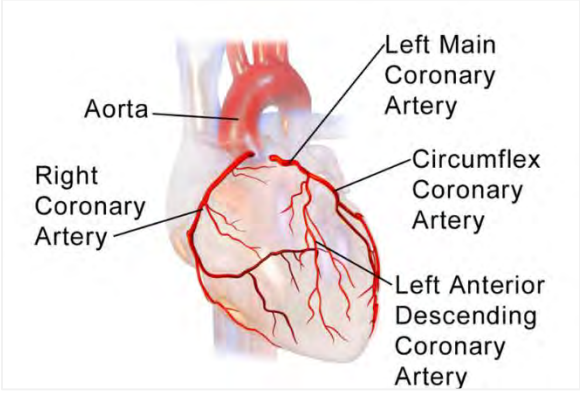

Figure 1. The three main coronary arteries are the right coronary artery, left anterior descending artery, and circumflex artery.

Courtesy of Bruce Blaus, Wikimedia.

Plaque is made of several substances found in the blood, including fat, cholesterol, and calcium. Plaque formation can be fatty, mixed, or calcified.

The presence of calcified plaque is an excellent predictor of future risk of heart attack.

Soft plaques, also known as fatty or vulnerable plaques, are usually caused by inflammation and may be buried in the wall of the artery. Soft plaques can cause arterial narrowing, in part due to the development of blood clots and inflammation, increasing the risk of rupture and sudden heart attack.

Calcified or hard plaques tend to be more stable and are less likely to rupture. The presence of calcified plaque is an excellent predictor of cardiac disease.[7]

It is important to note that while cardiac CT for calcium scoring readily identifies calcified plaques, soft plaques will not be seen as visualization of soft plaques requires the use of an iodinated contrast agent. The administration of iodinated contrast would obscure any calcium, making it impossible to score. The extent of calcified plaque correlates with the overall plaque burden of the patient, that is, if a patient has a significant amount of calcified plaque, they will likely have a significant amount of soft plaque.[6,8]

While plaque can form anywhere in the body, causing atherosclerosis and limited blood flow, plaque often accumulates in the coronary arteries.[1,2]

Coronary calcium scoring using CT can play a vital role in the management of both asymptomatic patients who are at intermediate risk for a cardiac event and low-risk patients with a family history of premature coronary heart disease.[9]

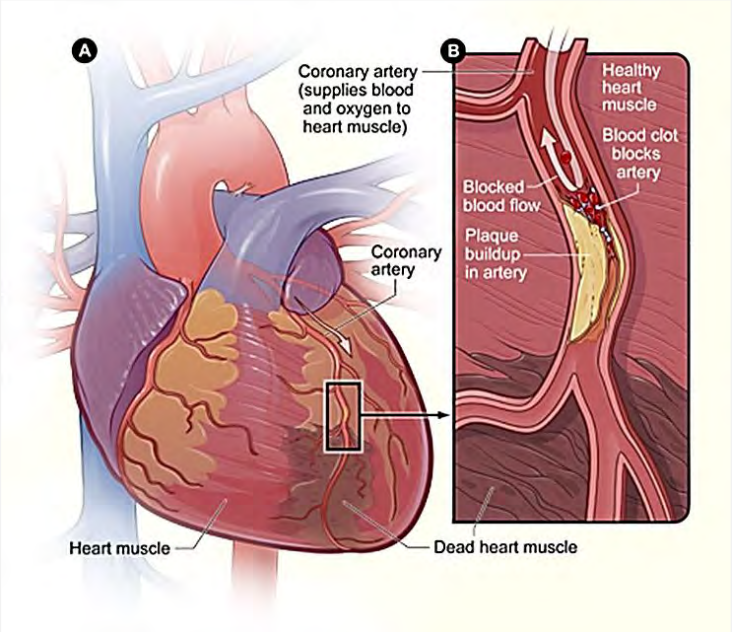

Figure 2. Plaque build-up in a coronary artery, leading to clot formation and heart attack.

Courtesy of National Heart Lung Blood Institute (NIH).

How is CT Coronary Artery Calcium Scoring Performed?

Calcium scoring CT is a fast and non-invasive imaging exam that does not require the use of contrast media. To limit motion **artifact** caused by movement of the heart, ECG leads are placed and synced to the CT scanner. Data are collected using **cardiac gating,** which allows image acquisition during the **diastolic** phase of the cardiac cycle when the heart is at rest. Images are sent to a workstation and evaluated for the presence of coronary calcification (**Figure 3**).

Multi-detector and Electron Beam CT Scanners

Multi-detector CT (MDCT) scanners are most commonly used for calcium scoring; however, electron-beam CT (EBCT) was the first technique used for quantification of coronary artery calcification. Instead of conventional CT where the X-ray source point moves along a circle in space around the object to be imaged, the X-ray tube in EBCT is large and stationary and partially surrounds the imaging circle. The electron beam sweeps along a tungsten anode in the tube, tracing a large circular arc on the inner surface of the tube. Because the beam is swept electronically, EBCT is capable of rapid scan times.

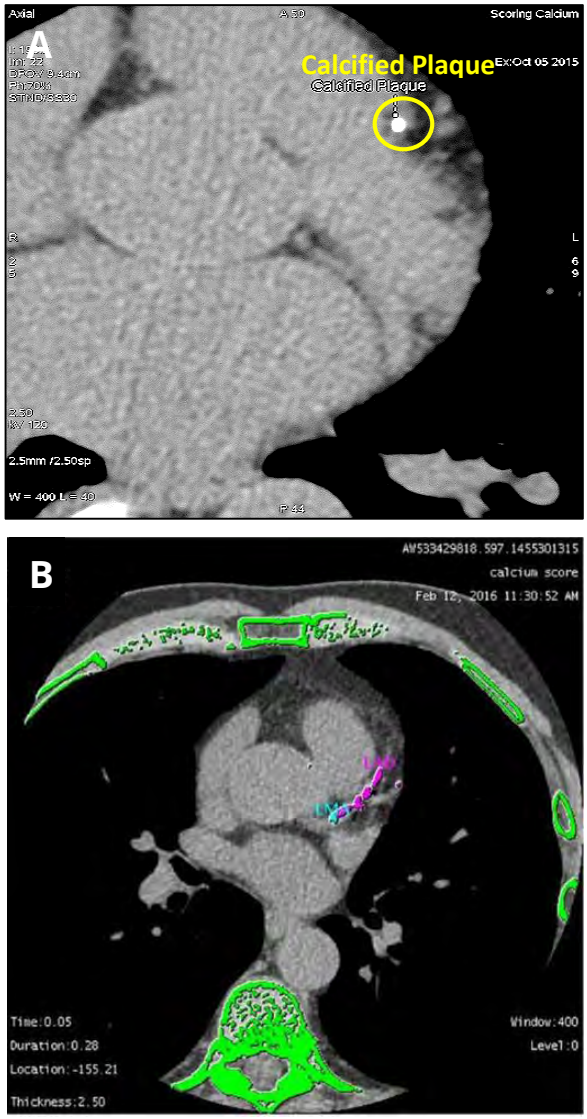

Figure 3. Calcium scoring images for a 69-year-old male; (A) calcified plaque, not scored; (B) calcium scored image; green represents calcium outside the coronary arteries; blue shows calcium in the LT main artery; and purple shows calcium in the LT anterior descending artery.

EBCT utilizes ECG **triggering** during end-diastole to decrease motion artifact. While capable of accurately quantifying coronary calcium, EBCT scanners are quite expensive and not as versatile as MDCT scanners, which can perform a multitude of CT studies beyond the visualization of coronary calcium. As the number of CT detectors has increased, **temporal resolution** has increased, making MDCT a highly reliable option for performing CT for calcium scoring. However, there are trade-offs when comparing these technologies: MDCT produces better **spatial resolution**, while EBCT scans can be performed faster, produce better temporal resolution, and deliver a slightly smaller radiation dose to the patient than does MDCT.[10]

How is the Calcium Score Calculated?

A calcium score is also called an **Agatston score** after noted cardiologist, Dr. Arthur Agatston. After scanning, the CT images are sent to a workstation equipped with specialized software that calculates a calcium score that is interpreted by a qualified radiologist or technologist. Although calcium can be found in other sections of the heart, especially around the valves, only calcifications in the coronary arteries are scored. Each coronary segment — the left main artery (LMA), left anterior descending artery (LAD), left circumflex artery (LCX), right coronary artery (RCA), and their branches — are scored to provide per-segment scores as well as a total score of all coronary segments (**Figure 3 and 4**).

Calcium Scoring Report Template

Patient Name _____ Exam Date _____

Sex ☐ Male ☐Female Diabetes ☐ Yes ☐ No

Age _____ Smoking ☐ Yes ☐ No

Important Information about Your Scan

The following information is based on an analysis of the coronary arteries only. Calcium deposits do not correspond directly to the percentage of narrowing of the arteries. They do correlate directly to the amount of coronary plaque and to the risk of future coronary disease. These calcium deposits usually begin to form years before any symptoms develop. Early detection and modification of risk factors such as smoking and cholesterol intake can slow the progress of coronary artery disease.

A low score suggests a low likelihood of coronary artery disease but does not exclude the possibility of significant coronary artery narrowing. The results should be discussed with your physician, taking into account other risk factors such as age, gender, family history, diabetes, smoking, or high cholesterol levels.

Should you ever experience chest pain, difficulty breathing, discomfort radiating into your neck or arm, or discomfort combined with lightheadedness, sweating, fainting, or nausea, you should seek prompt attention.

Calcium Score Range

0	No evidence of CAD
1 – 10	Minimal evidence of CAD
11 – 100	Mild evidence of CAD
101 – 400	Moderate evidence of CAD
Greater than 400	Extensive evidence of CAD

Score Summary

Your total calcium score is _____.

Ranking

Your score of _____ places you in the ____ percentile rank.

That means ____% of males from ages ___ to ___ will have a higher calcium score than yours.

Coronary Anatomy	Agatston Score
Left main artery	_____
Left anterior descending artery	_____
Left circumflex artery	_____
Right coronary artery	_____
Posterior descending artery	_____
Total	_____

Figure 4. Sample calcium scoring report for the patient.

Peak Density (Hounsfield Units)	Weighted Score
130 – 199 HU	1
200 – 299 HU	2
300 – 399 HU	3
> 400 HU	4

Table 1. Density scoring of calcification in Hounsfield units.

Only plaques having a peak density of at least 130 HU are measured.[11] To determine a calcium score, the peak density of each plaque receives a weighted score based on its size and its highest **Hounsfield unit** (HU) (**Table 1**). The peak density weighted score is then multiplied by the area of the calcification measured in square millimeters (mm^2) to obtain a total calcium score **(Table 2**). For example, a calcified plaque measuring 4 square millimeters with a peak density of 382 HU results in a calcium score of 12:

$$Area\ of\ Calcification\ x\ Peak\ Density\ Weighted\ Score = Total\ Calcium\ Score$$

$$4\ x\ 3 = 12$$

Less frequently used techniques for quantifying the amount of calcium in the coronary arteries are calcium volume and calcium mass. Calcium volume is obtained by multiplying the number of voxels by the voxel volume. Calcium mass is calculated as the product of calcium concentration and calcium volume.[12]

A potential pitfall of calcium scoring with CT is the variability of scoring among different equipment vendors. In a multi-vendor study, follow-up calcium scores performed on scanners from different vendors varied significantly, while tests repeated on the same vendor's scanner showed little variability.[13] Thus, an artificial increase or decrease in a given calcium score may occur if the patient's exams are not performed using scanners from the same manufacturer.

Total Calcium Score	Evidence of CAD
1	No evidence of CAD
1-10	Minimal evidence of CAD
11-100	Mild evidence of CAD
101-400	Moderate evidence of CAD
Over 400	Extensive evidence of CAD

Table 2. Extent of coronary artery disease based on calcium score.

Source: www.radiologyinfo.org

STUDIES OF HEART DISEASE

Framingham Heart Study

In 1948 a large study was performed that included more than 5,200 male and female residents of Framingham, Massachusetts. The United States Public Health Service undertook this large study to help understand why cardiovascular disease had become an epidemic in the 1930s and the number one cause of mortality in the nation by the late 1940s. This famous study — the Framingham Heart Study (FHS) — would become one of the most important research efforts in the measurement of heart disease in American medical history.[14]

In 1971, the children of the original study group and their spouses were recruited for the "Offspring Study," providing the original FHS investigators unique, multi-generational data.[15]

The Framingham Heart Study was the first to identify the risk factors that contribute to the development of cardiovascular disease. Smoking, obesity, and genetic links were found to increase the likelihood of developing heart disease. Investigators also gained an understanding of the attributes of "good" and "bad" cholesterol: HDL or high-density lipoprotein, and LDL or low-density lipoprotein, respectively.

Even today the Framingham Risk Calculator is used to assess a patient's risk for having a cardiovascular event within 10 years. A patient's age, gender, cholesterol levels, smoking history, and blood pressure (and whether it is being treated) are used to calculate that risk.[16]

The Framingham Risk Calculator can found at http://cvdrisk.nhlbi.nih.gov.[17]

Multi-Ethnic Study of Atherosclerosis

The Multi-Ethnic Study of Atherosclerosis (MESA) looked at the risk factors used in the Framingham Heart Study in combination with ethnicity and calcium score to calculate risk for a cardiovascular event within 10 years for multi-ethic patients.

The MESA study took place in six US cities between July 2000 and September 2002 and was comprised of 6,814 people aged 45 to 84 who identified themselves as white, black, Hispanic, or Chinese.

This method of subject enrollment is in contrast to The Framingham Heart Study that included participants who were almost exclusively Caucasian. Each participant in the MESA study was screened for cardiac risk factors and had calcium scoring exams by either EBCT or MDCT.[18]

Researchers in the MESA study observed subjects who reported many conventional risk factors but no evidence of coronary calcium, suggesting that risk factors alone are not a good predictor of a future cardiac event. The MESA study concluded that calcium scoring could be used to further individualize risk beyond that of conventional risk factors to determine the need for a treatment plan. MESA researchers also concluded that calcium scoring was a strong predictor of cardiac risk in all ethnic groups studied.[18]

The MESA Risk Calculator can be found at http://mesa-nhlbi.org/calcium/input.aspx.[19]

The Framingham Risk Calculator is still the most widely used screening tool for quantifying risk of a future cardiac event, with an accuracy estimated to be about 75%.[9] However, because the model was developed using almost exclusively Caucasian participants, the data cannot be extrapolated to other ethnic groups.

CALCIUM SCORING AS A SCREENING TOOL

Calcium scoring has been shown to be most beneficial for asymptomatic patients who are assessed to be in the intermediate risk category. Patients who are at low risk may not meet the threshold of benefit versus risk due to both the small amount of radiation received and the low probability of a positive score. Likewise, high-risk patients will likely be treated aggressively regardless of the results of the calcium scoring exam.[20]

Asymptomatic patients who have one or two risk factors or a family history of heart disease may also benefit from undergoing a calcium scoring CT. Developing a course of treatment for these patients and those in the intermediate-risk category can be challenging for clinicians as some studies suggest that **statin therapy**, which aims to lower LDL, and other interventions do not slow the progression of CAC.[9]

The calcium score can be the deciding factor in cases where the decision to treat the patient is not obvious.

Additionally, statins can produce unpleasant side effects such as muscle and joint aches, headache, nausea, and other rare but serious side effects.[21] The calcium score can be the deciding factor in cases where the decision to treat the patient is not obvious.

Total Calcium Score: An Indicator for Risk

Calcium scoring is useful for determining the risk of a cardiac event by providing clinical information in addition to conventional risk factors, eg, systolic blood pressure, cholesterol levels, and smoking history. However, up to 20% of coronary events can occur in patients who do not have any major risk factors. This is where coronary artery calcium scoring can assist in stratifying risk.[11]

Current evidence supports aggressive anti-atherosclerosis treatment for patients with calcium scores greater than 100 regardless of conventional risk factors. Lifestyle modification and treatment include change in diet, administration of statin therapy, or surgery. Untreated patients have shown large increases in calcium scores, while those treated had scores that increased ≤ 10%. Current data show that an increase of greater than 15% in calcium score raises the patient's risk of heart attack by 17%.[13]

Not All Calcium Scores Are Created Equal

Although a patient's calcium score is a reliable indicator of potential cardiac risk, age and gender must also be considered. For example, if a 45-year-old male has a score of 50, his overall calcium score places him in the mild risk category. However, a score of 50 at such a young age is more concerning than for a 60-year-old male with the same calcium score. Likewise, a 60-year-old female with a calcium score of 50 is more concerning than for a male of the same age (**Table 3**).

Age	45-year-old	60-year-old	60-year-old
Gender	Male	Male	Female
Total Calcium Score	50	50	50
Age/Matched %	99th percentile	57th percentile	84th percentile

Table 3. Examples of MESA online calculations including age and gender.

Although all three patients in this example have the same total calcium score, their age/gender matched percentiles vary greatly. For example, if a patient were ranked at the 90th percentile, only 10% of people would be expected to have a higher calcium score. Notice that the 45-year-old male and 60-year-old female have much higher risk percentages than does the 60-year-old male. Current data show that patients who have age/gender matched percentiles above the 75th percentile should undergo extensive risk modification and medical intervention. In fact, patients in the top 25th percentile have an eight times greater risk of cardiac event than those in the lowest 25th percentile.[13]

Interestingly, patients tend to become more serious about embarking on risk modification strategies after having received a positive calcium scoring exam.[22]

Disadvantages of Using CT Calcium Scoring

As mentioned earlier, CT calcium scoring is not advised for all patients due to the small risk of cancer from radiation. Cost is a consideration, too, as the average calcium scoring exam can cost several hundred dollars and often is not covered by health insurance.[9]

RADIATION CONSIDERATIONS

Calcium scores performed on MDCT deliver a slightly increased radiation dose compared to EBCT due to the slightly longer scan time required using MDCT. MDCT average effective radiation doses range from 1.0-1.9 mSv, while EBCT doses range from 0.7-to 1.3 mSv.[9]

Techniques for lowering radiation dose in MDCT include adjustment of scan parameters and use of low-dose equipment with **iterative reconstruction** (IR). Most CT vendors now offer scanners that utilize iterative reconstruction, which consists of passing images through numerous software filters and noise-reducing calculations to reduce radiation dose. Several studies that included scan parameter adjustments and use of IR have reported reduction of radiation doses as much as 30-70%.[22] Carefully following scan protocols that utilize the lowest **mAs** and **kVp** necessary for acquiring diagnostic images will ensure that radiation doses are always as low as possible without compromising diagnostic image quality.

Techniques for lowering radiation dose in MDCT include adjustment of scan parameters and use of low-dose equipment with iterative reconstruction

SUMMARY

Coronary artery calcium scoring CT is an excellent screening tool in the fight against heart disease, as well as an effective predictor of future adverse cardiac events.

Since calcium scoring CT can be costly and does expose the patient to a small amount of radiation, it is not recommended for either a low-risk or high-risk patients. However, asymptomatic patients who have one or two risk factors or a family history of heart disease and patients at intermediate risk may benefit from undergoing a calcium scoring CT.

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