Learning Objectives

1. To describe methods of coronary calcium quantification with CT
2. To discuss the clinical significance of the presence and severity of coronary calcium on CT

Scoring Methods

1. Agatston score
2. Volume score
3. Mass
4. Coverage score
5. Ordinal score
6. Visual “score”

Coronary Calcium Scoring: Software

130 HU

Voxel CT attenuation threshold > 130 HU:
CT pixel appears bright white

Anatomy-independent:
Software does not identify coronary arteries

Etiology-independent:
White represents potential calcium
DDx includes metal and image noise

130 HU

---AND---

3 contiguous voxels
1.0 mm³: approximate volume

Software only semi-automated
Software identifies all pixels that meet threshold criteria
Manually select only those pixels that are coronary arterial
**Agatston score**

3 voxels / 1.0 mm³ / 130 HU

Weighting factor based on peak CT density of calcific plaque

<table>
<thead>
<tr>
<th>Attenuation</th>
<th>Weighting factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>131-200 HU</td>
<td>1</td>
</tr>
<tr>
<td>201-300 HU</td>
<td>2</td>
</tr>
<tr>
<td>301-400 HU</td>
<td>3</td>
</tr>
<tr>
<td>≥ 401 HU</td>
<td>4</td>
</tr>
</tbody>
</table>

**Volume score**

Volume score = $\sum (\text{area} \cdot \text{increment})$

No weighting factor

Calibration using a standardized phantom

Lack of reference data for large populations

**Mass**

Mass = $\sum (\text{volume} \cdot \text{calibration factor} \cdot \mu)$

Calibration factor: from a standardized phantom

$\mu$ = mean CT density

Mass = mg of calcium hydroxyapatite

Lack of reference data for large populations

**Example of Coronary Calcium Software:**

*Agatston Score, Volume Score, and Mass*

**Multiethnic Study of Atherosclerosis (MESA)**

*Spatial distribution of coronary calcium*

Coronary Calcium Coverage Score (CCCS)

3 voxels / 1.0 mm$^3$ / 130 HU

$$\text{CCCS} = \left( \frac{\# \text{5mm coronary segments + calcium}}{\text{total \# segments}} \right) \times 100$$

CCCS = % segments calcified

MESA CCCS

Increased mortality rates proportional to number of calcified segments.
Higher mortality rates (statistically significant) for left main coronary lesions.


Total [Agatston] coronary artery calcium score remains the preferred metric to refine risk prediction in nearly all patients.

Bansal S and Blumenthal RS. JACC: Cardiovascular Imaging 2008; 1: 70-72.

Significance of Coronary Artery Calcium (CAC)

Framingham and other similar risk stratification schemes deal with 2 unknowns:
- Likelihood of coronary atherosclerosis
- Future risk of coronary events

Coronary calcium
- IS NOT a risk factor for atherosclerosis
- IS atherosclerosis
- IS a risk factor for future coronary events

Significance of CAC

CAC cannot identify vulnerable plaque

CAC may identify the vulnerable patient


Risk-Adjusted All-Cause Survival

Comparison of FRS and CAC scores for Predicting Mortality

MESA

10-fold risk for calcium score > 300

Doubling of calcium score: 15 – 40% increase of coronary event risk


Interpretation of Agatston scores

1. Absolute value of score
2. Relative score: Percentile based on age and gender percentiles (EBT)
3. Relative score: Percentile based on age, gender, and race/ethnicity (MESA)

Total Agatston Calcium Score: Absolute Value

<table>
<thead>
<tr>
<th>Score</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No identifiable atherosclerotic plaque</td>
</tr>
<tr>
<td>1-10</td>
<td>Minimal atherosclerotic plaque burden</td>
</tr>
<tr>
<td>11-100</td>
<td>Mild atherosclerotic plaque burden</td>
</tr>
<tr>
<td>101-400</td>
<td>Moderate atherosclerotic plaque burden</td>
</tr>
<tr>
<td>&gt;400</td>
<td>Severe atherosclerotic plaque burden</td>
</tr>
</tbody>
</table>

Used in 10-year coronary event risk prediction

Coronary Calcium on CT

- Minimal (CCS=2)
- Mild (CCS=81)
- Moderate (CCS=329)
- Severe (CCS=2323)

Relative Agatston Calcium Score: Age and Gender Percentiles

<table>
<thead>
<tr>
<th>PERCENTILE</th>
<th>AGE 40-44</th>
<th>45-54</th>
<th>55-64</th>
<th>65-74</th>
<th>75+</th>
</tr>
</thead>
<tbody>
<tr>
<td>MEN</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>25%</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>50%</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td>75%</td>
<td>11</td>
<td>34</td>
<td>110</td>
<td>229</td>
<td>389</td>
</tr>
<tr>
<td>90%</td>
<td>69</td>
<td>151</td>
<td>346</td>
<td>580</td>
<td>933</td>
</tr>
</tbody>
</table>


MESA

Useful for prevention/risk modification strategies

NIH Framingham-based Calculator for Risk of Myocardial Infarction

http://cvdrisk.nhlbi.nih.gov/
Accessed 3/30/15

MESA public website

http://www.mesa-nhlbi.org
Accessed 3/30/15

MESA public website

http://www.mesa-nhlbi.org
Accessed 3/30/15

Downloadable spreadsheet

http://www.biomedcentral.com/content/supplementary/1741-7015-2-31-S1.xls
Accessed 3/30/15


Why revisit coronary calcium?

It is imperative for physicians involved in imaging coronary arteries to understand the importance of coronary calcification as a marker of atherosclerosis.

Opening Plenary Session RSNA 1998

Suggested review for this topic: "Role of Nonenhanced Multidetector CT Coronary Artery Calcium Testing in Asymptomatic and Symptomatic Individuals"

Nasir K and Clouse M. Radiology 2012;264:637-649

Ordinal Coronary Calcium Scoring on Low-Dose CT for Lung Cancer Screening Predictive of Cardiovascular Death

CAC score 0

0 = Absent
1 = Mild: <1/3 length calcified
2 = Moderate: 1/3-2/3 length calcified
3 = Severe: >2/3 length calcified

For each of 4 vessels: LM, LAD, LClv, RCA

Sum:

CAC score >4

ELCAP investigators
Agatston Scoring of Low-Dose CT for Lung Cancer Screening Predicts All-Cause and Cardiovascular Mortality

<table>
<thead>
<tr>
<th>Fatal events</th>
<th>Nonfatal events</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAC Risk Category</td>
<td>All-Cause Mortality</td>
</tr>
<tr>
<td>0</td>
<td>0.01 (2)</td>
</tr>
<tr>
<td>1-100</td>
<td>0.2 (6)</td>
</tr>
<tr>
<td>101-400</td>
<td>0.4 (2)</td>
</tr>
<tr>
<td>&gt;400</td>
<td>1.2 (1)</td>
</tr>
</tbody>
</table>


NELSON Trial

Visual (non-ordinal) Scoring on Low-Dose CT for Lung Cancer Screening

<table>
<thead>
<tr>
<th>Visual Scoring on LDCT:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatal events</td>
</tr>
<tr>
<td>Minimal</td>
</tr>
<tr>
<td>Agatston on ECG CT:</td>
</tr>
<tr>
<td>1-10</td>
</tr>
</tbody>
</table>


Visual Scoring of Coronary Calcium in NLST Predicts All-Cause & Cardiovascular Mortality Risk

<table>
<thead>
<tr>
<th>Total Visual Score (TVS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linear extent of calcification:</td>
</tr>
<tr>
<td>#Image slices with coronary calcium</td>
</tr>
<tr>
<td>Score range: 0-4</td>
</tr>
<tr>
<td>Thickness of calcification:</td>
</tr>
<tr>
<td>#Images &lt; or ≥ 25% vessel diameter calculated</td>
</tr>
<tr>
<td>Score range: 1-3</td>
</tr>
<tr>
<td>TVS = I (linear extent x thickness)</td>
</tr>
<tr>
<td>1-vessel TVS = 0-12</td>
</tr>
<tr>
<td>3-vessel TVS = 0-36</td>
</tr>
</tbody>
</table>


Adding “VALUE” in Radiology

Perhaps we are looking for current missed opportunities that can add even more value that radiologists already provide to patients, providers, and society.

One opportunity may be in coronary calcium scoring in Low-Dose CT for Lung Cancer Screening.

How might we use this information? In addition to CVD risk reduction, imaging evidence of coronary atherosclerosis may serve as an aid to smoking cessation efforts and other behavioral changes.

Patient motivation: Seeing is believing

Effect of patient visualization of CAC on lifestyle behavioral changes

Orakzai, Budoff Am J Cardiol 2008; 101:999-1002.

References
