

Status of Coronary Calcium Scoring in the Lung Screening Setting

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Heart Disease and Coronary Calcium

- ◆ Coronary artery calcification (CAC) is a very strong predictor of morbidity and mortality in asymptomatic individuals ¹
- ◆ CAC is independently predictive of coronary events over and above traditional cardiac risk factors such as the Framingham Score ^{2,3,4,5}

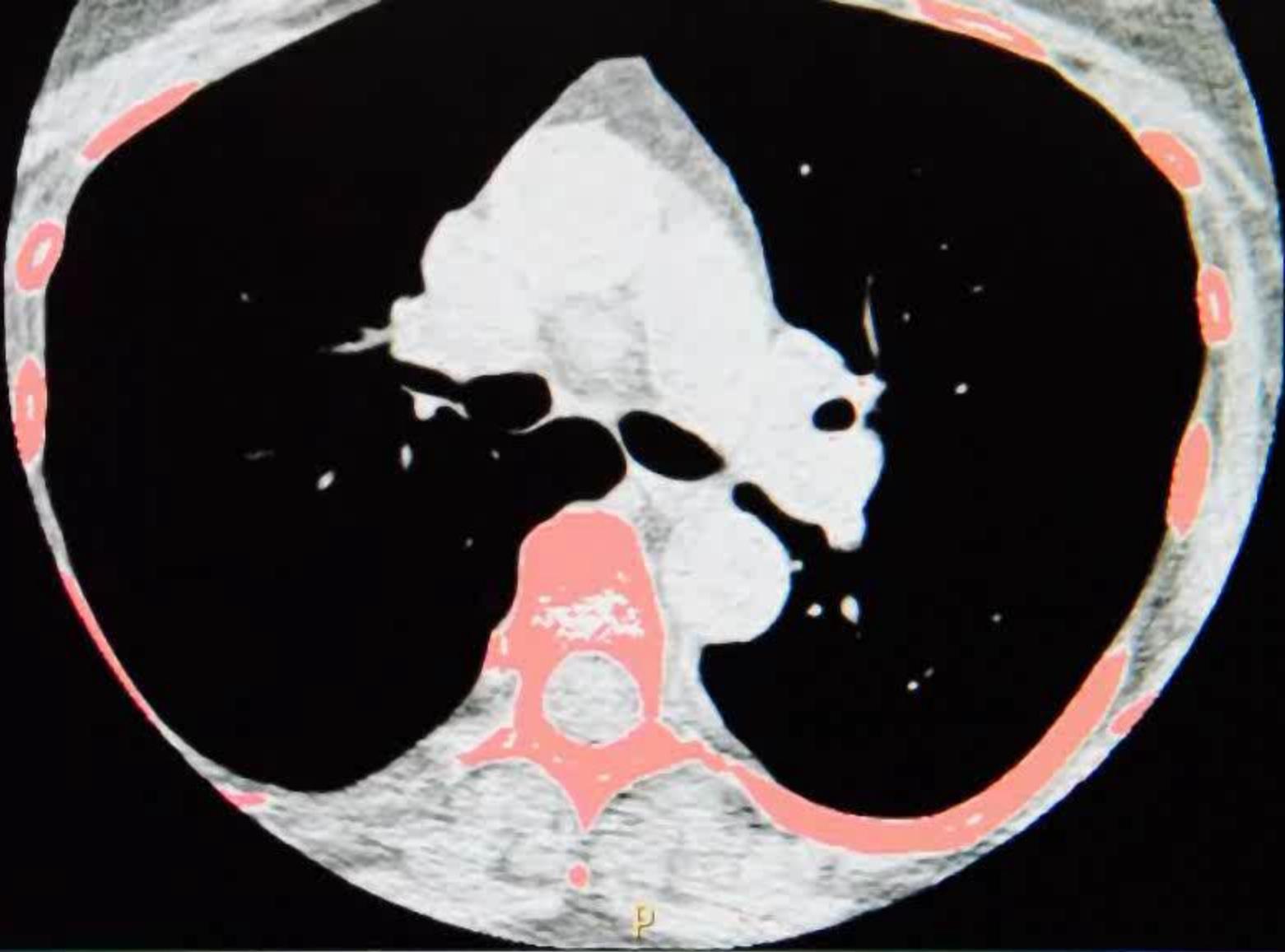
¹ J Am Coll Cardiol 2007;49:378-402.

² J Am Coll Cardiol 2005, 46: 158-165.

³ Am J Epidemiol 2005, 162: 421-429.

⁴ J Am Coll Cardiol 2005;46:804-814.

⁵ Circulation 2003, 107: 2571-2576.



Scoring Results : Agatston Score Protocol

Total Coronaries

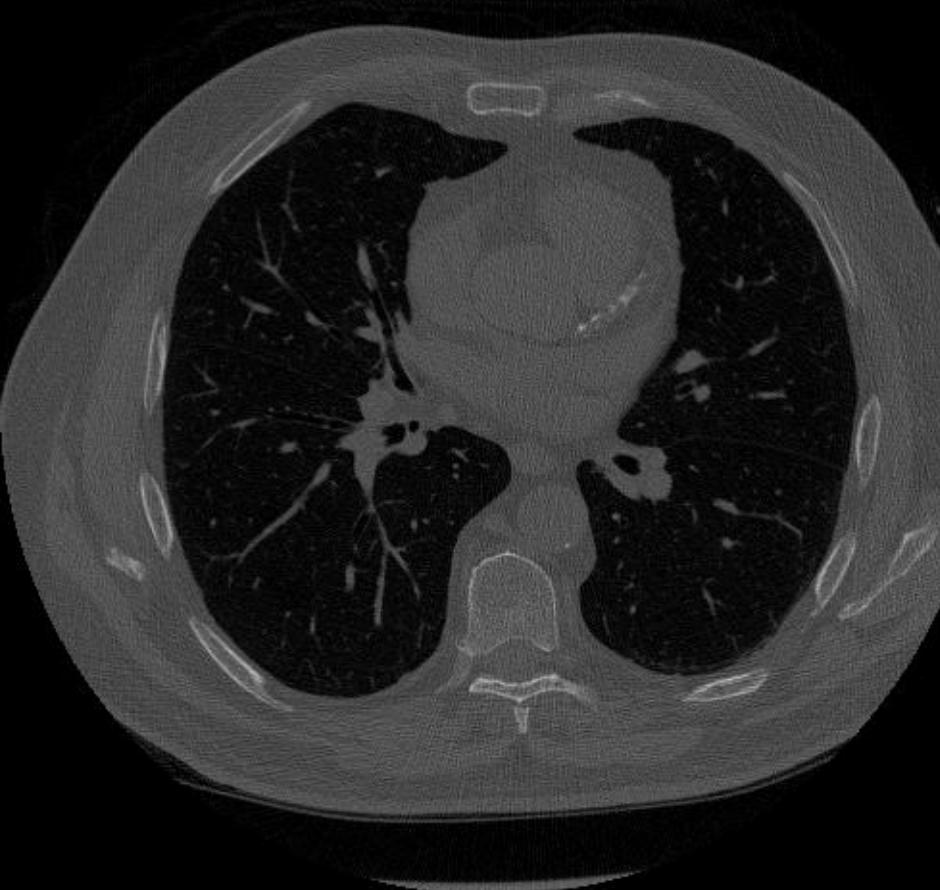
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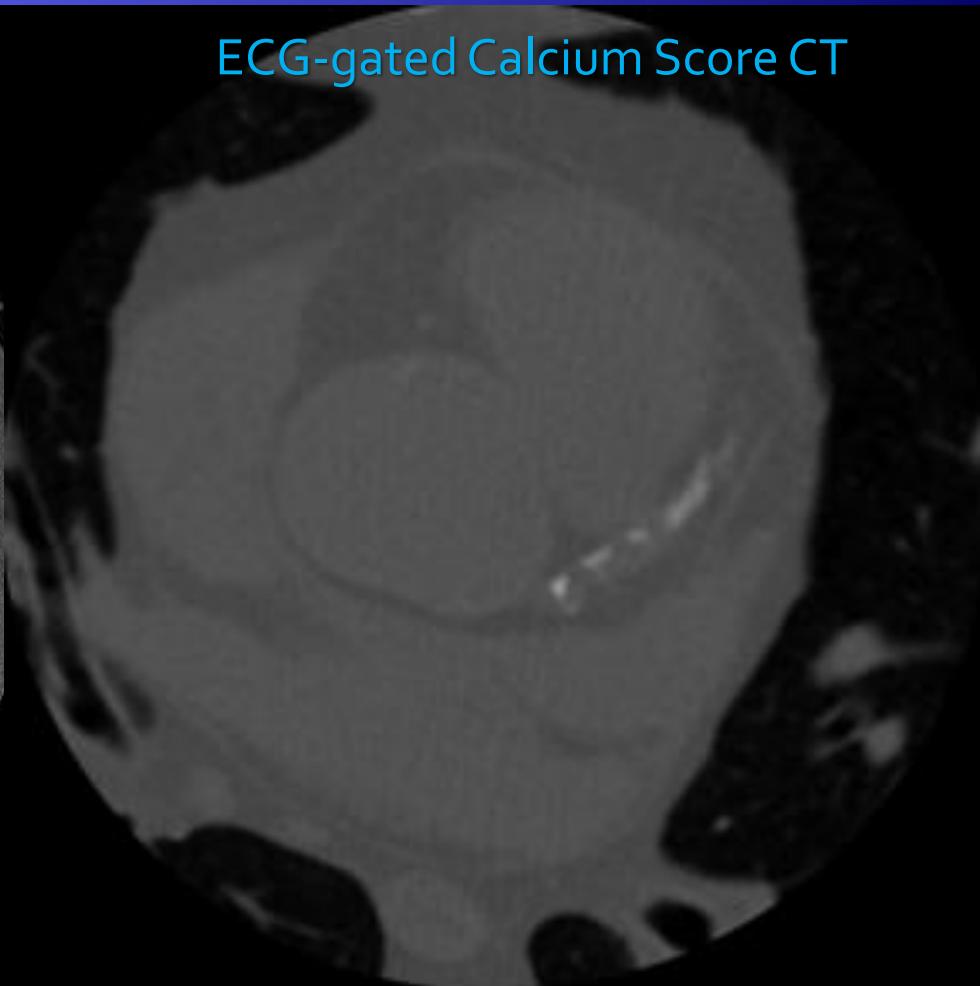
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Combined Lung and Cardiac Screening

Ungated Lung Screening CT



ECG-gated Calcium Score CT



CAC during lung screening CT

- ◆ Agatston CAC scores derived from low dose lung CT correlate well with ECG gated CAC CT ($\text{Kappa} = 0.89$)¹
- ◆ CAC is predictive of death from cardiovascular disease after adjusting for sex, age, pack years of smoking²

¹Wu MT, et al. AJR Am J Roentgenol 2008;190:923-8.

²Shemesh J, et al. Radiology 2010;257:541-8.

CAC during lung screening CT

- ◆ CAC is a better predictor of cardiovascular events and all-cause mortality than FEV₁ and emphysema extent¹
- ◆ CAC is an independent predictor of all-cause mortality and cardiovascular events²

¹Sverzellati N, et al. Radiology 2012;262:460-467.

²Jacobs PC, et al. AJR Am J Roentgenol 2012;198:505-11.

CAC during lung screening CT

TABLE 2: Annualized Event Rates for All-Cause Mortality, Fatal and Nonfatal Cardiovascular Disease (CVD) Events and Fatal and Nonfatal Coronary Heart Disease (CHD) Events According to Coronary Artery Calcium (CAC) Risk Categories

CAC Risk Category ^a	All-Cause Mortality (n = 56)	CVD Endpoint ^b (n = 127)	CHD Endpoint ^b (n = 61)
0	0.08 (2)	0.7 (10)	0.3 (4)
1–100	0.2 (8)	1.5 (27)	0.4 (8)
101–1000	0.6 (22)	1.7 (32)	1.0 (18)
> 1000	1.1 (24)	6.1 (58)	3.2 (31)

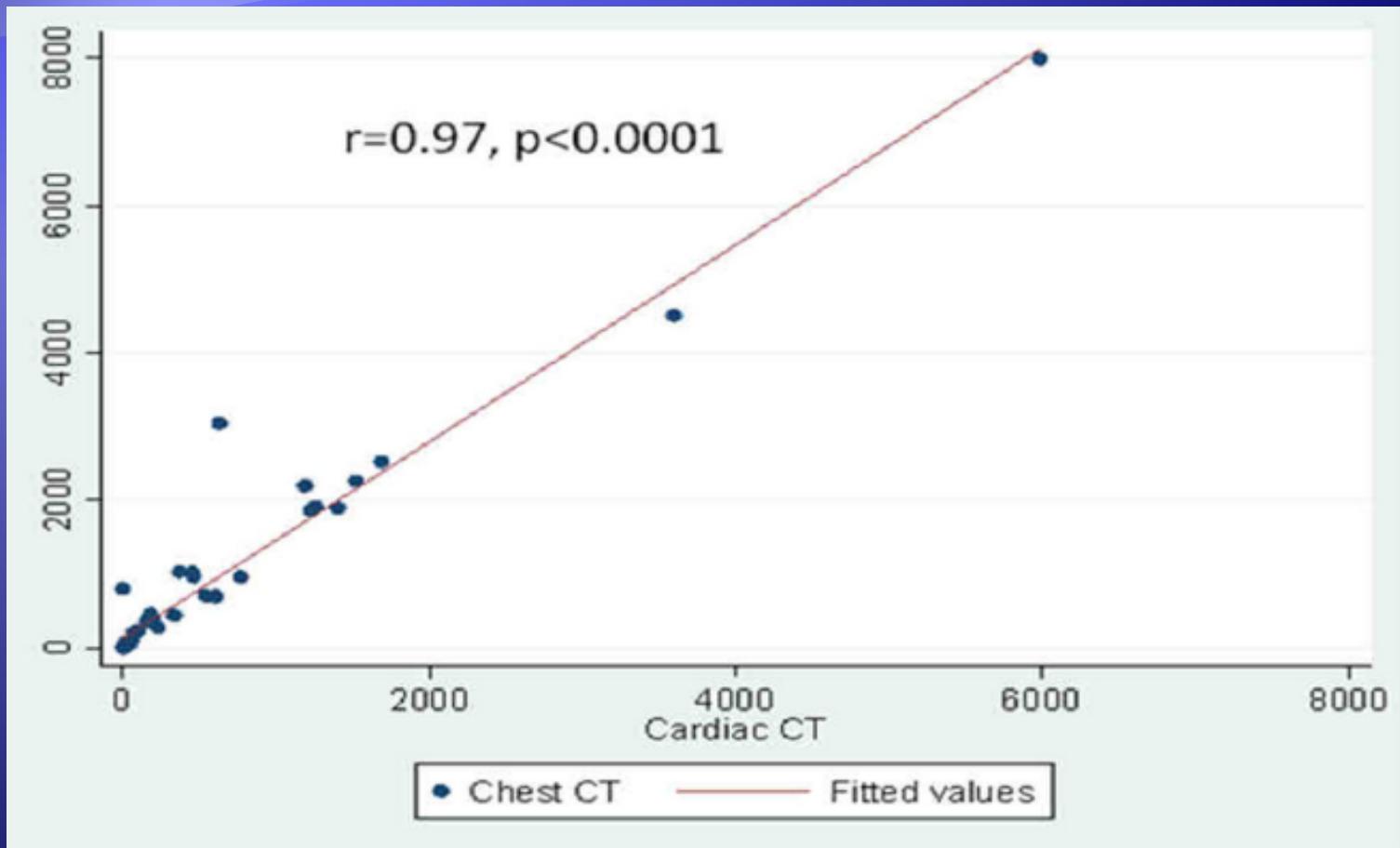
Note—Data are percentage annualized event rate (no. of cases). Annualized event rates were calculated as follows: $100\% \times [\text{no. of total events} / (\sum \text{person-days subcohort} \times 1/0.107)] \times 365$. The \sum person-days of the subcohort was weighted by the inverse of the sampling fraction (~ 11%) for the subcohort (1/0.107).

^aMedian follow-up per case-group was 21.5 months for all-cause mortality, 9.5 months for CVD events, and 9.8 months for CHD events.

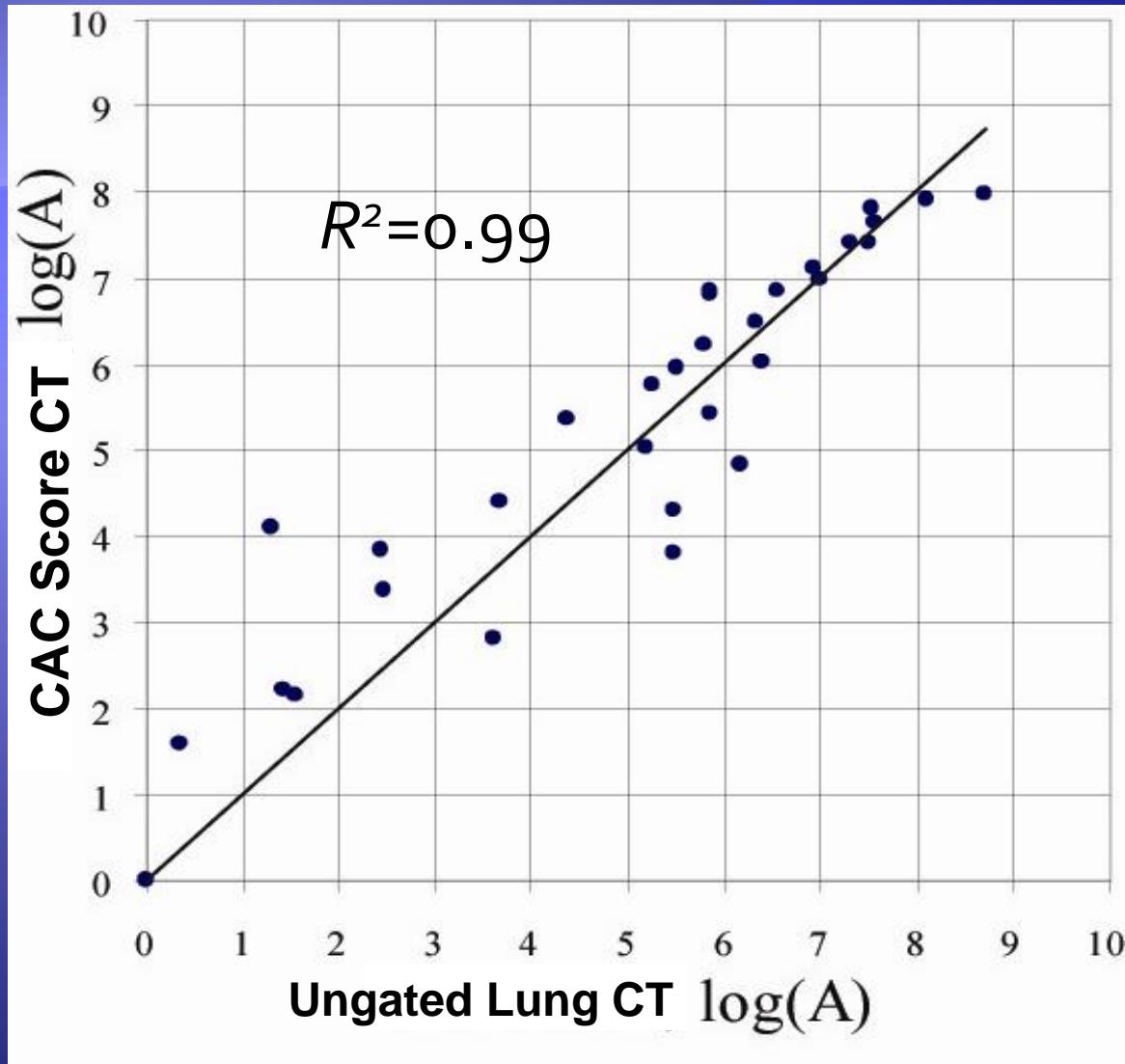
^bCVD endpoint (n = 127) consists of 10 fatal events (myocardial infarction, n = 5; stroke, n = 3; aortic aneurysm, n = 1; and peripheral arterial occlusive disease, n = 1) and 117 nonfatal events (myocardial infarction, n = 13; angina pectoris, n = 43; aortic valve stenosis, n = 24; stroke, n = 14; aortic aneurysm, n = 12; and peripheral arterial occlusive disease, n = 11). Of these 127 events, all fatal and nonfatal myocardial infarctions (n = 18) and angina pectoris (n = 43) events were included in the CHD endpoint (n = 61).

ECG Gated CAC CT vs. Ungated Regular Dose Chest CT

Ungated Regular Dose Chest CT

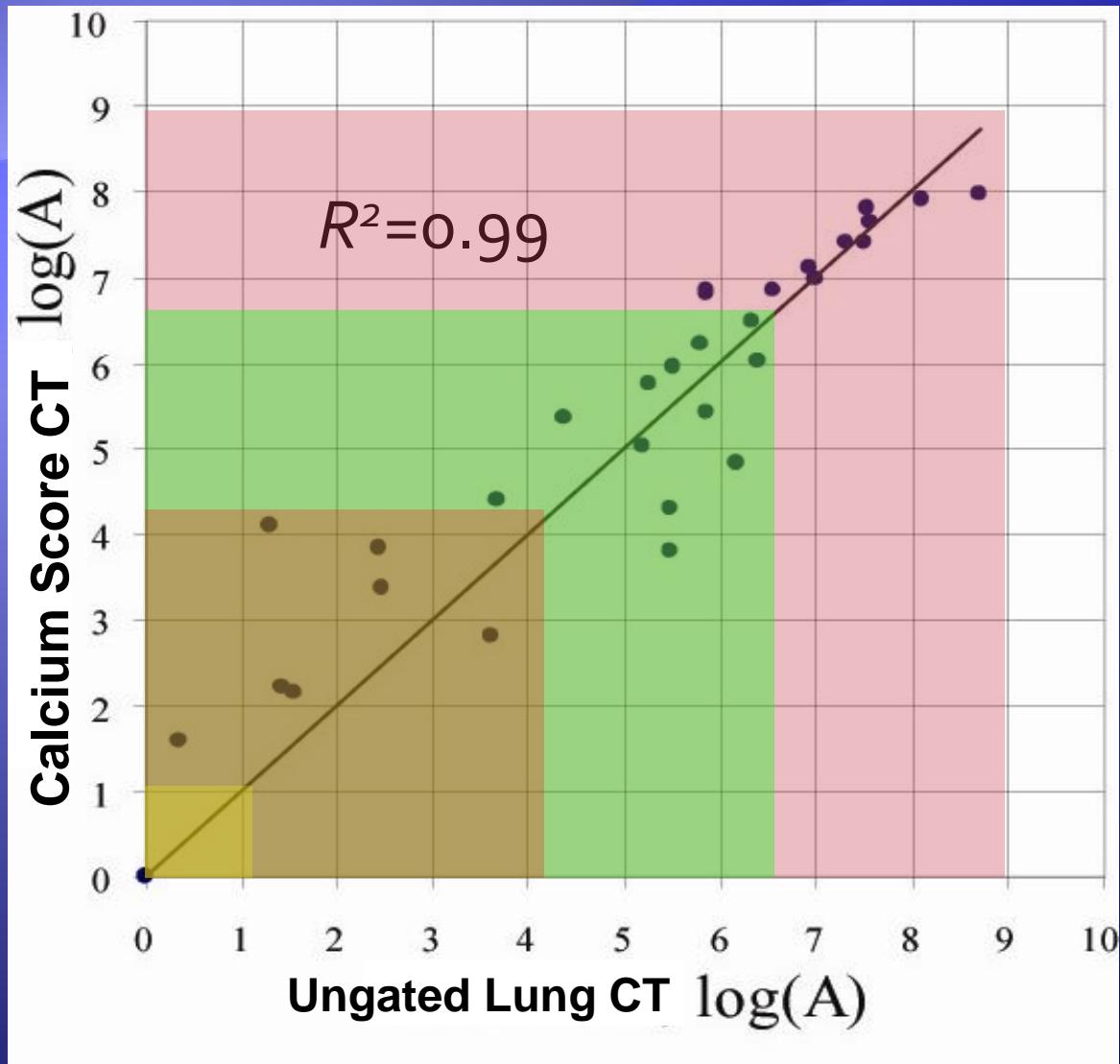


ECG-gated CAC score CT vs. Ungated lung screen CT

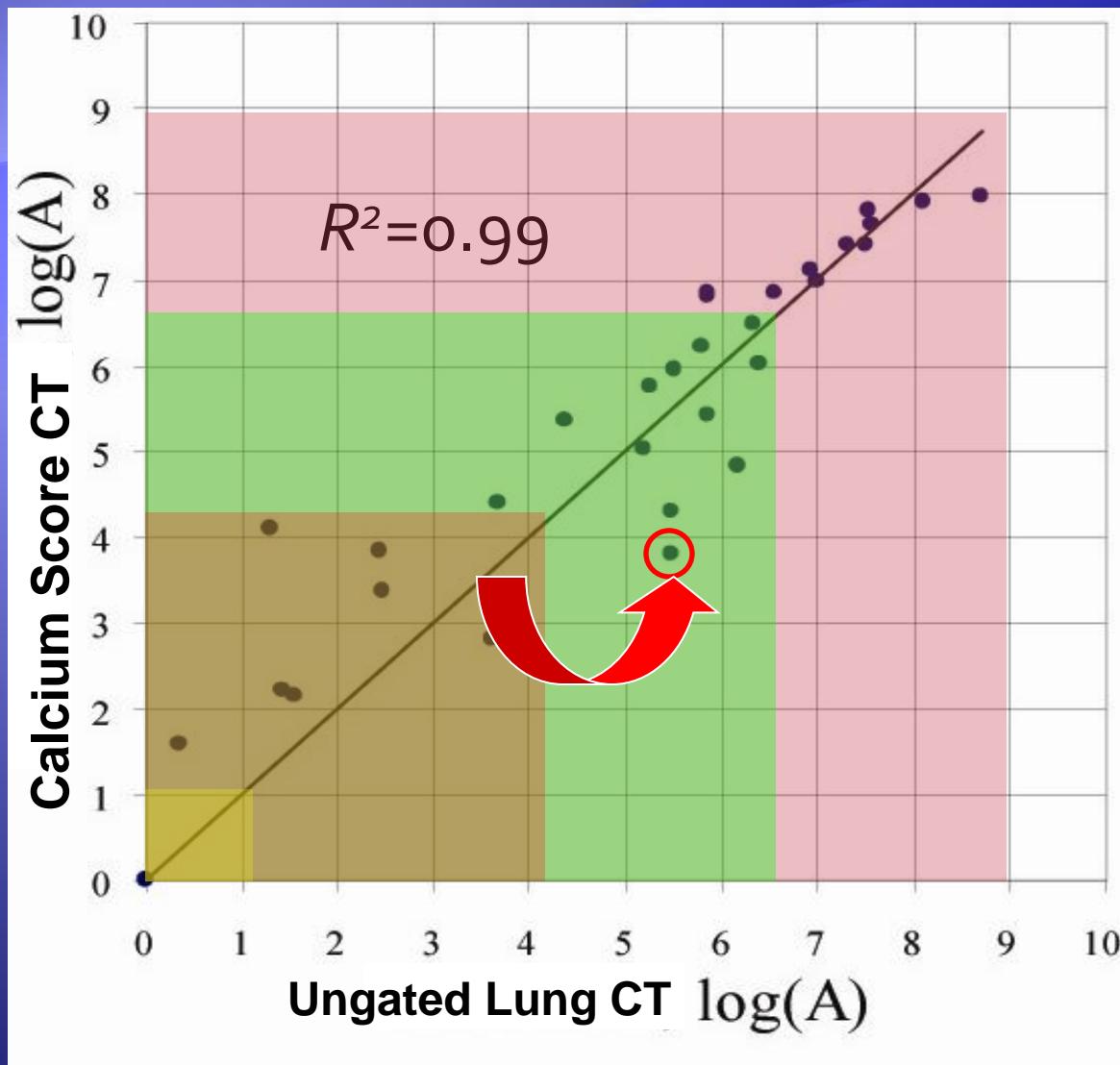


Analysis courtesy of Drs. Anthony Reeves, Alberto Biancardi, and Sergei Fotin

ECG-gated CAC score CT vs. Ungated lung screen CT

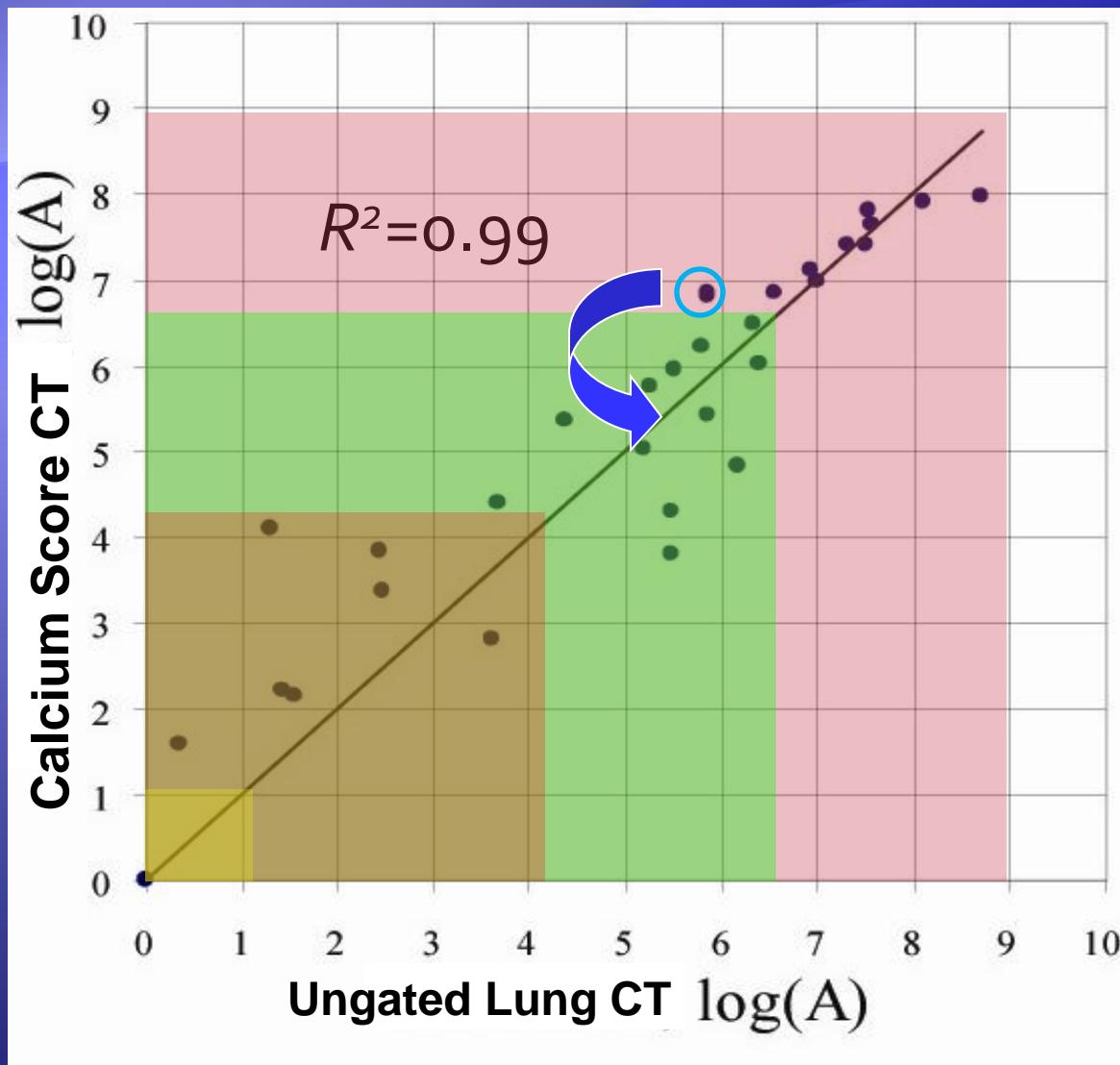


ECG-gated CAC score CT vs. Ungated lung screen CT



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ECG-gated CAC score CT vs. Ungated lung screen CT



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ECG-gated CAC score CT vs. Ungated lung screen CT

Low-Dose CT	Calcium-Scoring CT				
	Very Low Risk (0)	Low Risk (> 0–10)	Moderate Risk (> 10–100)	Moderately High Risk (> 100–400)	High Risk (> 400)
Very low risk (0)	66	5			
Low risk (> 0–10)	8	8	4		
Moderate risk (> 10–100)		2	24	2	
Moderately high risk (> 100–400)			1	5	
High risk (> 400)					3

AJR 2008;190:917-922.

Limitations in CAC scoring during lung screening CT

- ◆ ECG-gated CAC score CT:
 - ◆ 12-32% mean interscan variability¹
- ◆ Ungated lung screening CT:
 - ◆ 60-70% mean interscan variability (@ 3 mSv)²
 - ◆ 25% had discordant risk categorization
- ◆ Normal CAC progression = 14-27% per year

¹Budoff MJ, et al. AJR Am J Roentgenol 2009;192:613-617.

²Jacobs PC, et al. AJR Am J Roentgenol 2010;194:1244-1249.

Interscan variability

CAC scores measured using a calibrated stationary phantom during a no-change scenario at 120 kV, 100 mAs, 2.5 mm

	Lesion 1 (5 mm)	Lesion 2 (1 mm)
Scan 1	211	3
Scan 2	250	1
Scan 3	224	3
Scan 4	276	1

Lung versus Cardiac Screening

	Lung Screening CT	Coronary Calcium CT
ECG gating	No	Yes
Scan mode	Helical	Axial
Slice thickness	0.6 mm	2.5 to 3.0 mm
Field of view	45 cm	20 cm
Radiation dose	0.7 mSv (120kV, 15mAs)	0.7 mSv (120kV, 50mAs)
Scan length	Full chest	Cardiac only (40% of chest)

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Slice thickness and CAC Scoring

- ◆ ECG-gated CACS using 1 mm slices (instead of 2.5 mm) overestimate calcium scores by:
 - ◆ +5% in stationary phantoms¹
 - ◆ +30% in patients¹
- ◆ CAC detection at lung screening CT:

¹ Invest Radiol 2005;40:695-699

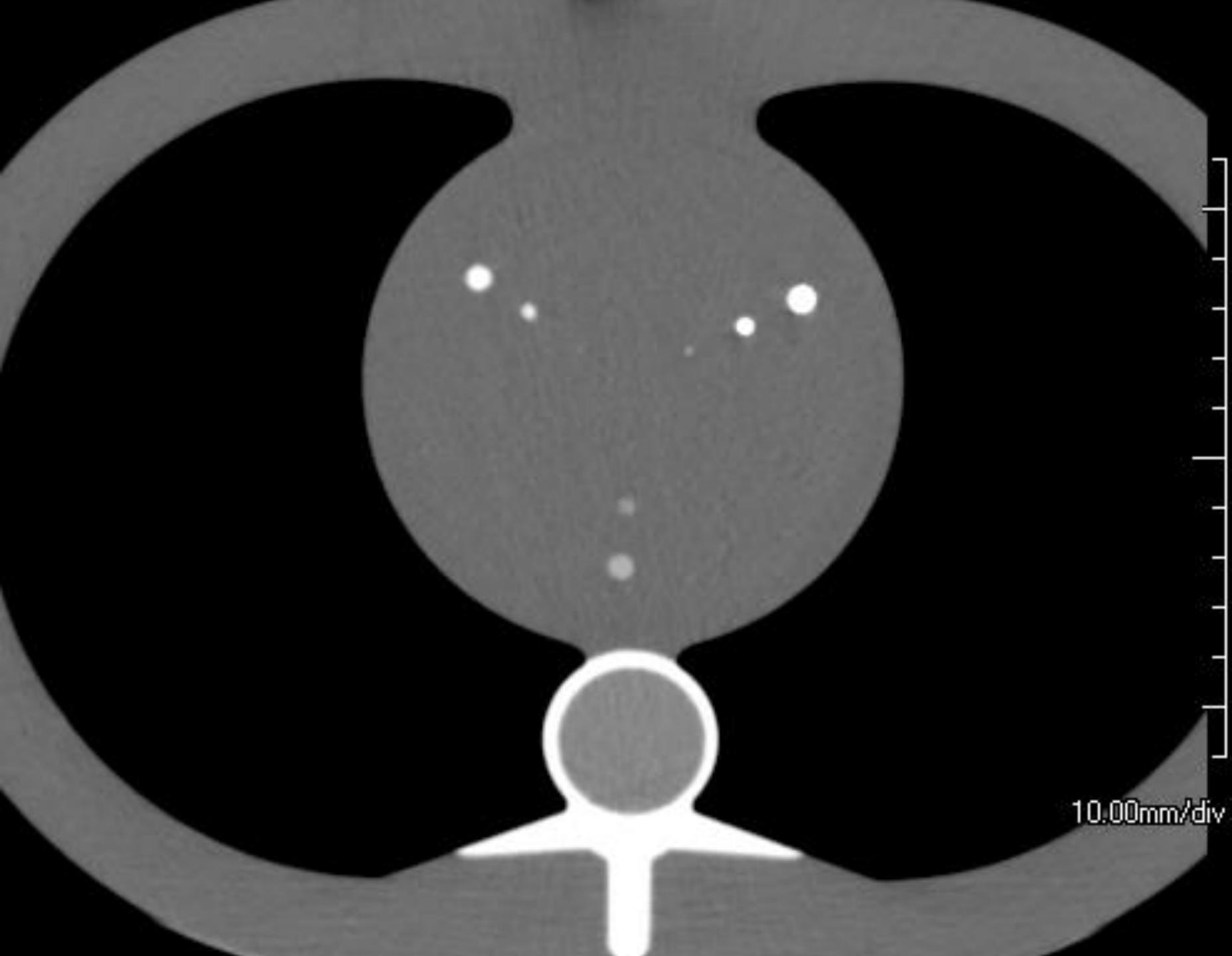
Protocol (Attenuation and Slice Thickness)	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)	Accuracy (%)
130 H 1 mm	98	53	60	98	72
2.5 mm	91	89	91	93	90

² AJR 2008;190:917-922.

Coronary calcium phantom



Device courtesy of Philips Healthcare and Harvey Hecht, M.D.

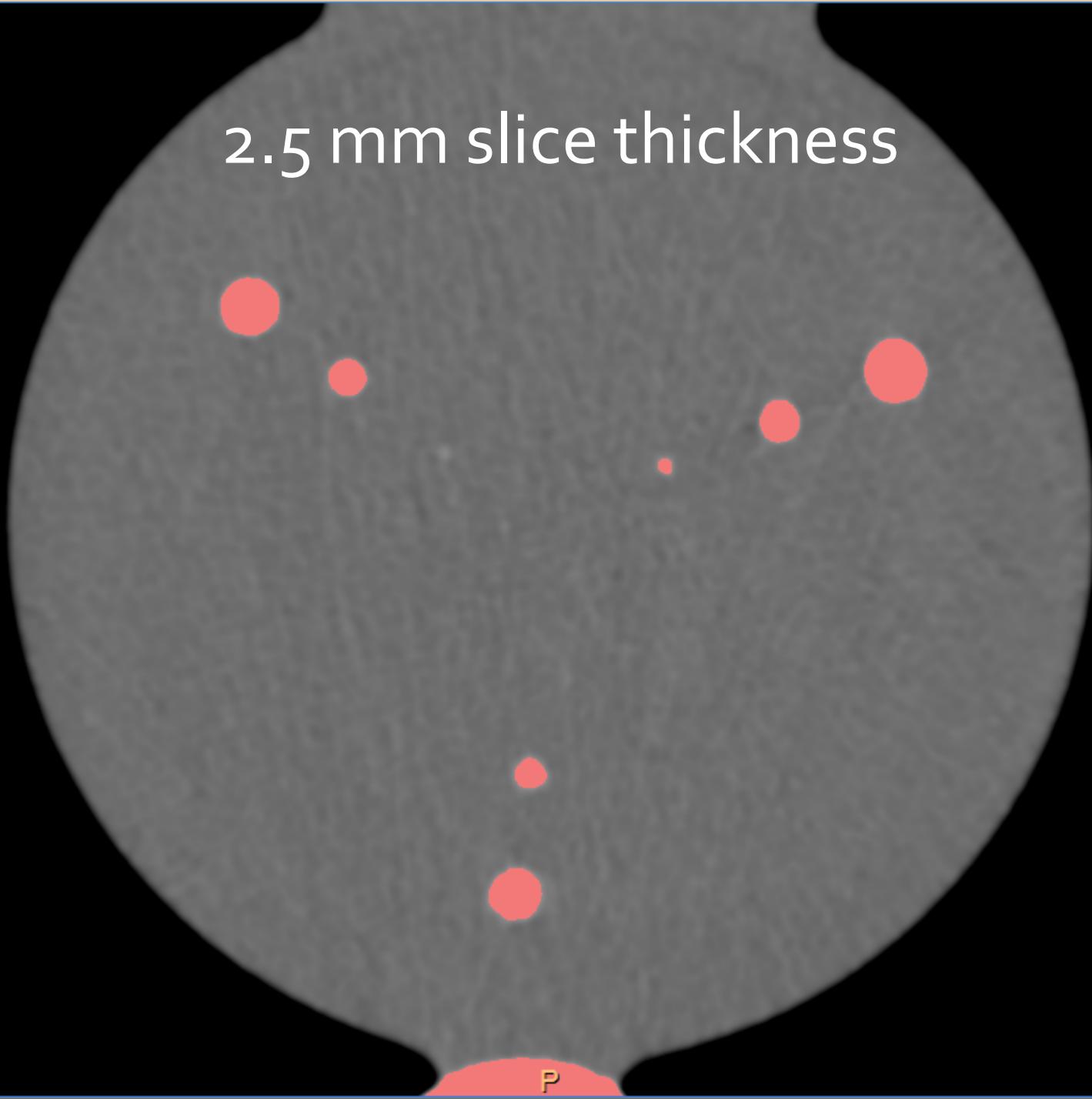


10.00mm/div

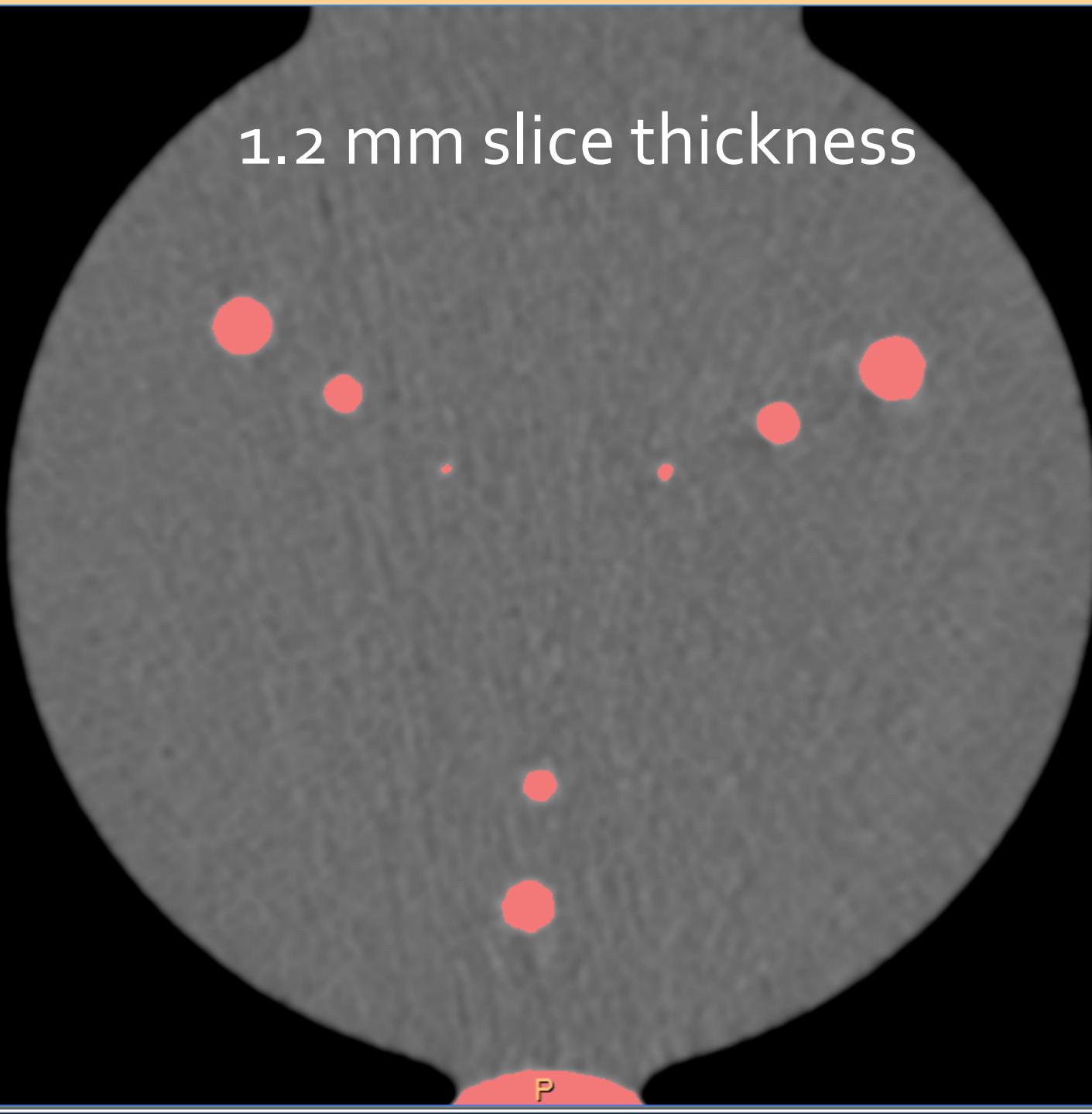


10.00mm/div

2.5 mm slice thickness

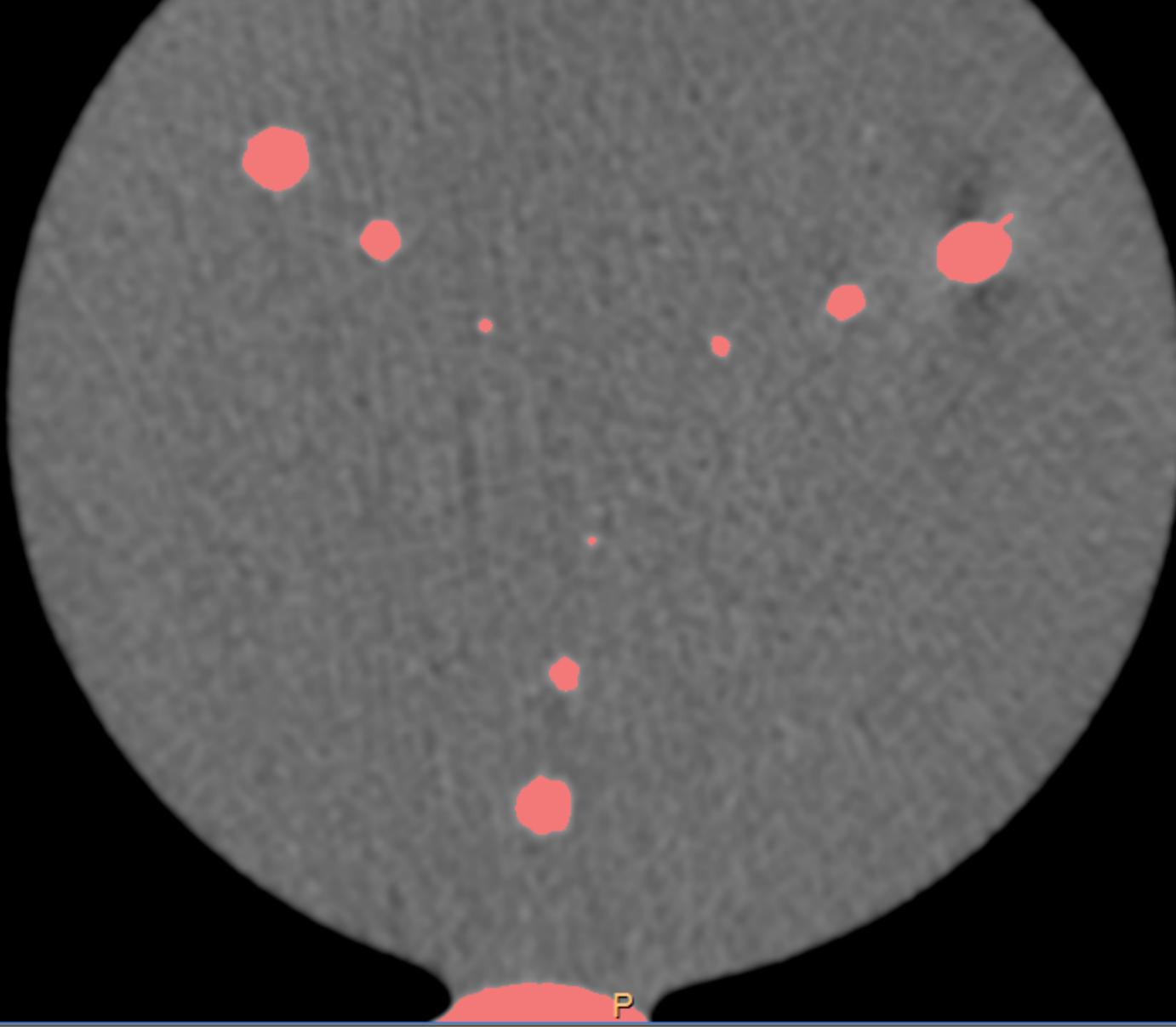


1.2 mm slice thickness



P

0.6 mm slice thickness



P

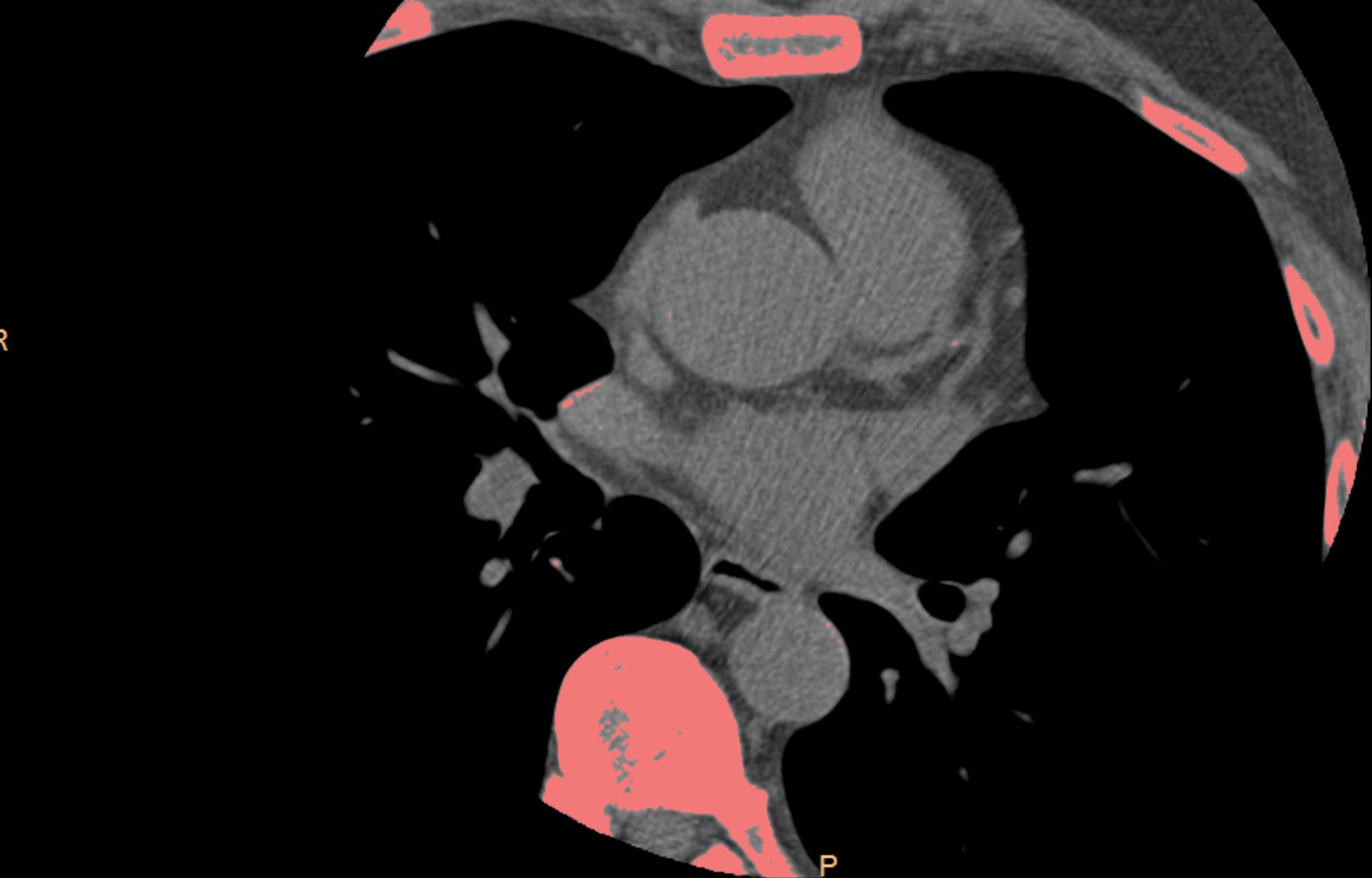
Slice thickness and CAC Scoring

- ◆ 2.5 mm thick CAC protocols may underestimate calcium scores relative to ground truth
- ◆ Chance of missing a 1mm calcified lesion of a given density

Slice thickness	800 mg/cm ³	400 mg/cm ³	200 mg/cm ³
2.5 mm	0%	100%	100%
1.2 mm	0%	86%	100%
0.6 mm	0%	14%	95%

Slice thickness and CAC Scoring

- ◆ The traditional 2.5 and 3.0 mm thick CAC scoring protocols will miss smaller lesions and underestimate disease burden
- ◆ This limitation would affect primarily younger subjects with near zero or lower calcium scores and is encountered in clinical practice



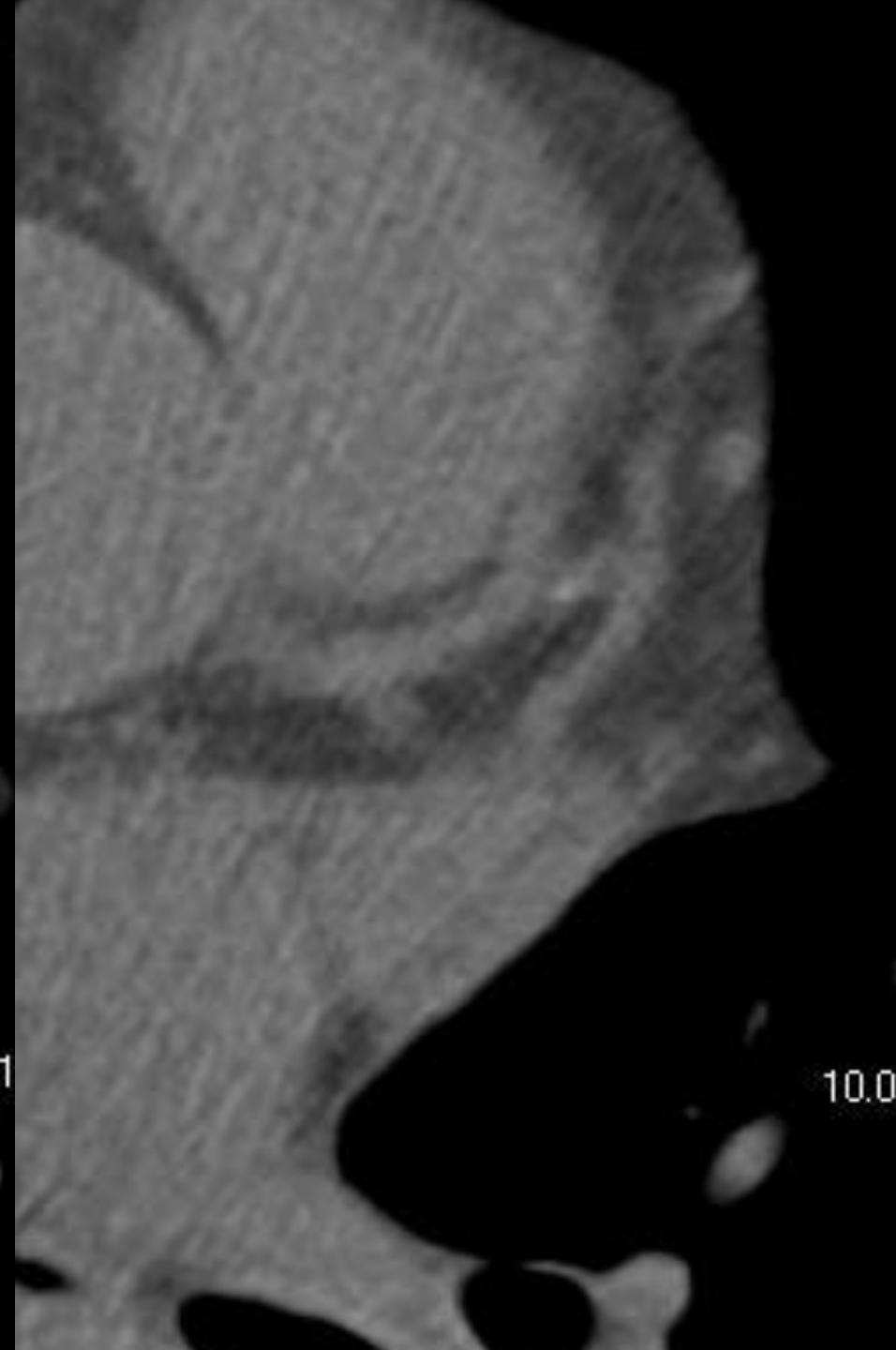
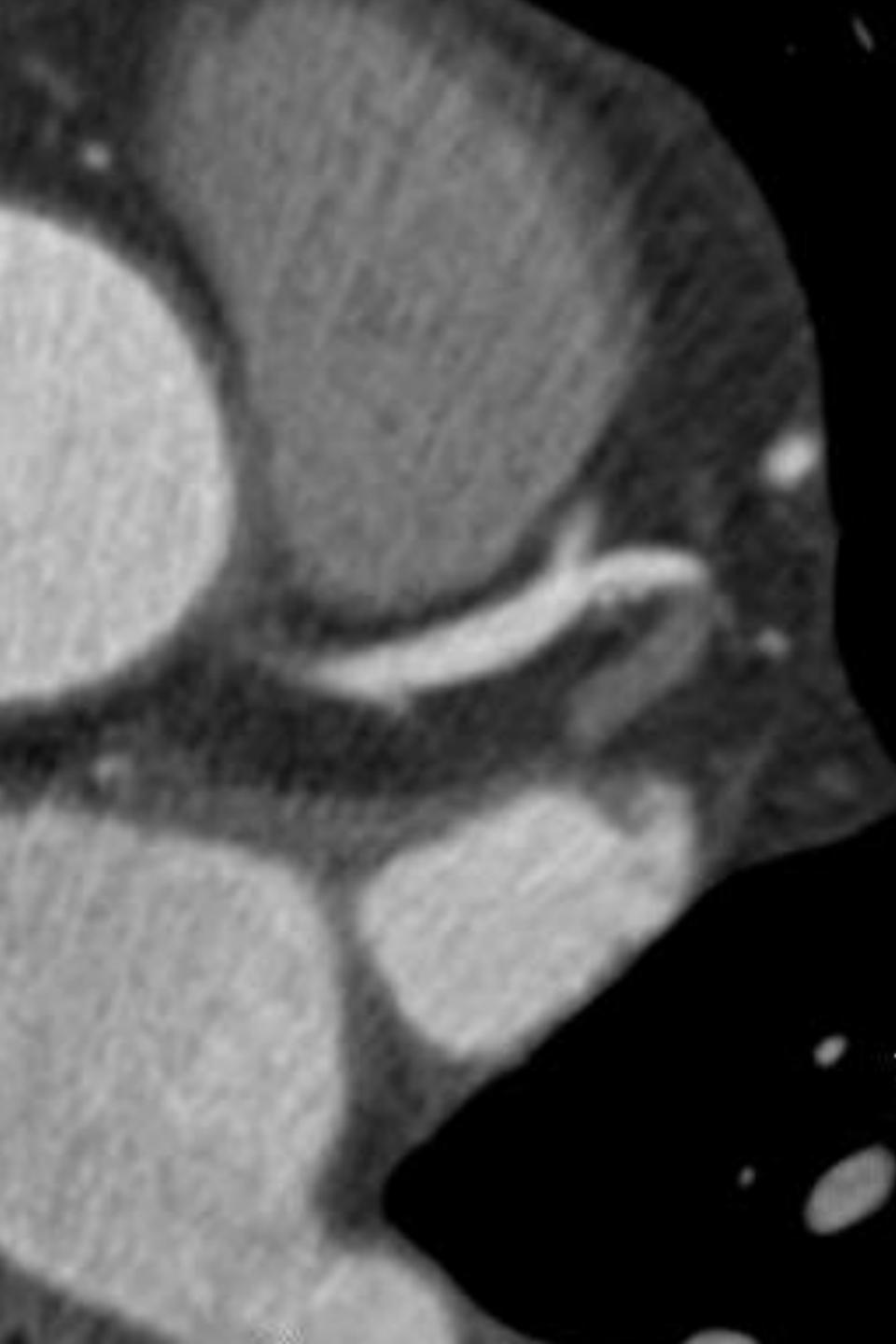
Scoring Results : Agatston Score Protocol

Total Coronaries

Score	0
#ROI's	0
areaSq (sq.mm.)	0



10.00mm/div



Risk of significant coronary stenosis with a zero CACS

- ◆ In asymptomatic subjects: 1%
 - ◆ 10 year cardiac event risk = 1%
- ◆ In asymptomatic diabetic patients: 5%
- ◆ In symptomatic patients: 5-19%

Yoo DH, et al. Int J Cardiovasc Imaging 2011;27 Suppl 1:27-35.

Kim YJ, et al. Eur Heart J Cardiovasc Imaging 2012 Mar 29. [Epub ahead of print]

Kamimura M, et al. Int Heart J 2012;53:23-8.

Treatment Guidelines for CAC

- National Cholesterol Education Program guidelines for asymptomatic individuals with moderate risk for CHD events

Table II. Guidelines for treatment in asymptomatic patients classified as moderately high-risk patients by NCEP (Framingham 10-20% 10-year risk)

CAC score/percentile	Framingham risk group equivalent	LDL goal (mg/dL)	Drug therapy (mg/dL)
0	Lower risk	<160	≥190 160-189: drug optional
1-10 and ≤75th percentile	Moderate risk (10-y risk <10%)	<130	≥160
11-100 and ≤75th percentile	Moderately high risk; 2+ risk factors (10-y risk: 10-20%)	<130	≥130
101-400 or >75th percentile	High risk; CAD risk equivalent (10-y risk: >20%)	<100 Optional goal <70	100-129: consider drug ≥100 <100: consider drug
>400 or >90th percentile	Highest risk*	<100 Optional goal <70	Any LDL level

*Consider β blockers and angiotensin-converting enzyme inhibitors for CAC score >1000.

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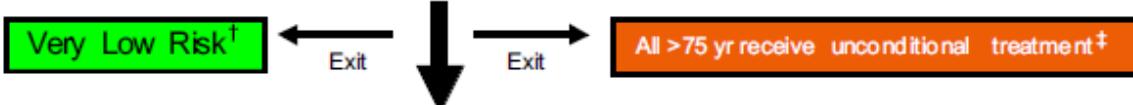
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The 1st SHAPE Guideline

Toward the National Screening for Heart Attack Prevention and Education (SHAPE) Program

Apparently Healthy Population Men >45 yr, Women >55 yr*

Step 1



Atherosclerosis Test

- CACS or
- CIMT & Carotid Plaque §

Step 2

Negative Test

- CACS = 0
- CIMT <50th percentile

No Risk Factors ||

Risk Factors

Positive Test

- CACS ≥1
- CIMT ≥50th percentile or Carotid Plaque

• CACS <100 & <75th percentile	• CACS 100 – 399 or >75th percentile	• CACS >100 & >90th percentile or CACS ≥400
• CIMT <1 mm & <75th percentile & No Carotid Plaque	• CIMT ≥1 mm or >75th percentile or <50% Stenotic Plaque	• CACS ≥400 or ≥50% Stenotic Plaque ¶

Step 3

Lower Risk

Moderate Risk

Moderately High Risk

High Risk

Very High Risk

LDL Target

<160 mg/dL

<130 mg/dL

<130 mg/dL
<100 mg/dL Optional

<100 mg/dL
<70 mg/dL Optional

<70 mg/dL

Retest Interval

5–10 years

5–10 years

Individualized

Individualized

Individualized

Follow Existing Guidelines

Angiography

Myocardial Ischemia Test

Yes

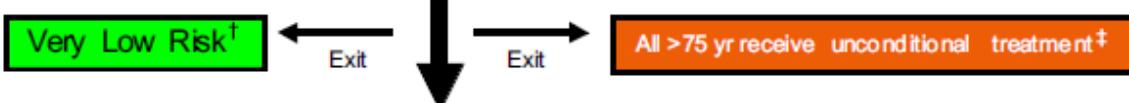
No

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• CIMT <1 mm & <75th percentile & No Carotid Plaque	• CIMT ≥1 mm or >75th percentile or <50% Stenotic Plaque	• CACS ≥400 or ≥50% Stenotic Plaque¶

Lower Risk

Moderate Risk

High Risk

Very High Risk

Step 3

LDL Target

<160 mg/dL

<130 mg/dL

<130 mg/dL
<100 mg/dL Optional

<100 mg/dL
<70 mg/dL Optional

<70 mg/dL

Retest Interval

5–10 years

5–10 years

Individualized

Individualized

Individualized

Follow Existing Guidelines

Angiography

Myocardial Ischemia Test

Yes

No

Why 2.5 mm slices?

- ◆ 1984: Electron beam CT
 - ♦ Temporal resolution = 100ms
 - ♦ Spatial resolution = 2-3mm
- ◆ 1995: ECG-gated MDCT
 - ♦ Temporal resolution = 160ms
 - ♦ Spatial resolution = 1.25mm
- ◆ 2005: Dual Source CT
 - ♦ Temporal resolution = 75-83ms
 - ♦ Spatial resolution = 0.3mm

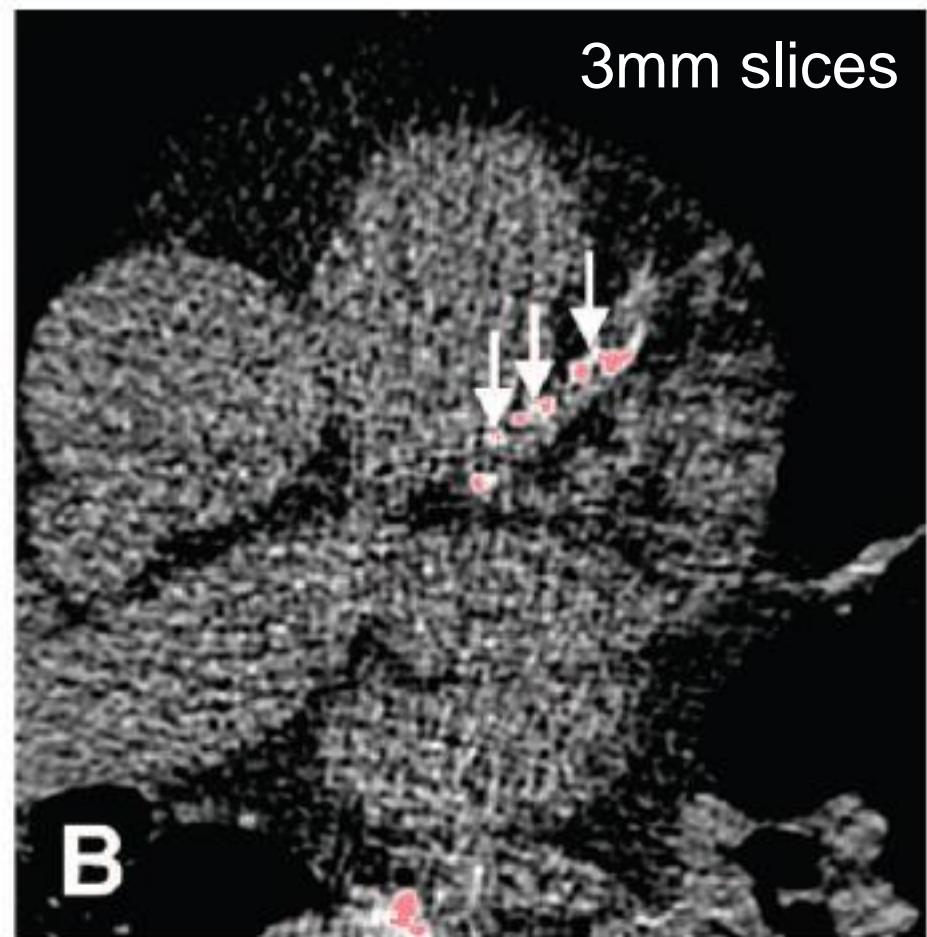
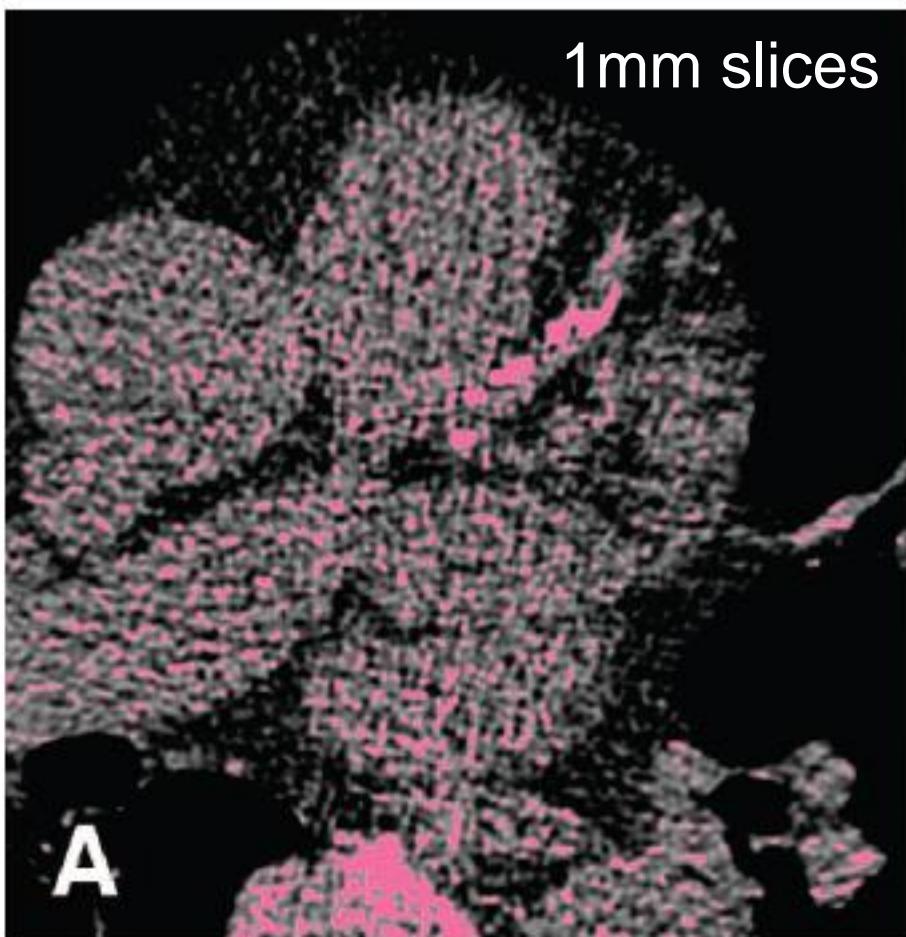


IF YOU DON'T JUMP INTO
THE VOLCANO, THE LIVES OF
PREVIOUS VOLCANO
JUMPERS WILL HAVE BEEN WASTED!

Slice thickness and CAC Scoring

- ◆ Detection of small CAC requires thinner slices
- ◆ However image noise increases with thinner slices given a constant radiation dose

Slice thickness and CAC Scoring



Lung versus CAC Screening

	Lung Screening CT	Coronary Calcium CT
Radiation dose	0.7 mSv (120kV, 15mAs)	0.7 mSv (120kV, 50mAs)
Scan length	Full chest	Cardiac only (40% of chest)

- ◆ The dose of CAC CT would have to be reduced by about 60% in order to match the very low dose of lung screening CT (0.7 mSv for entire chest).

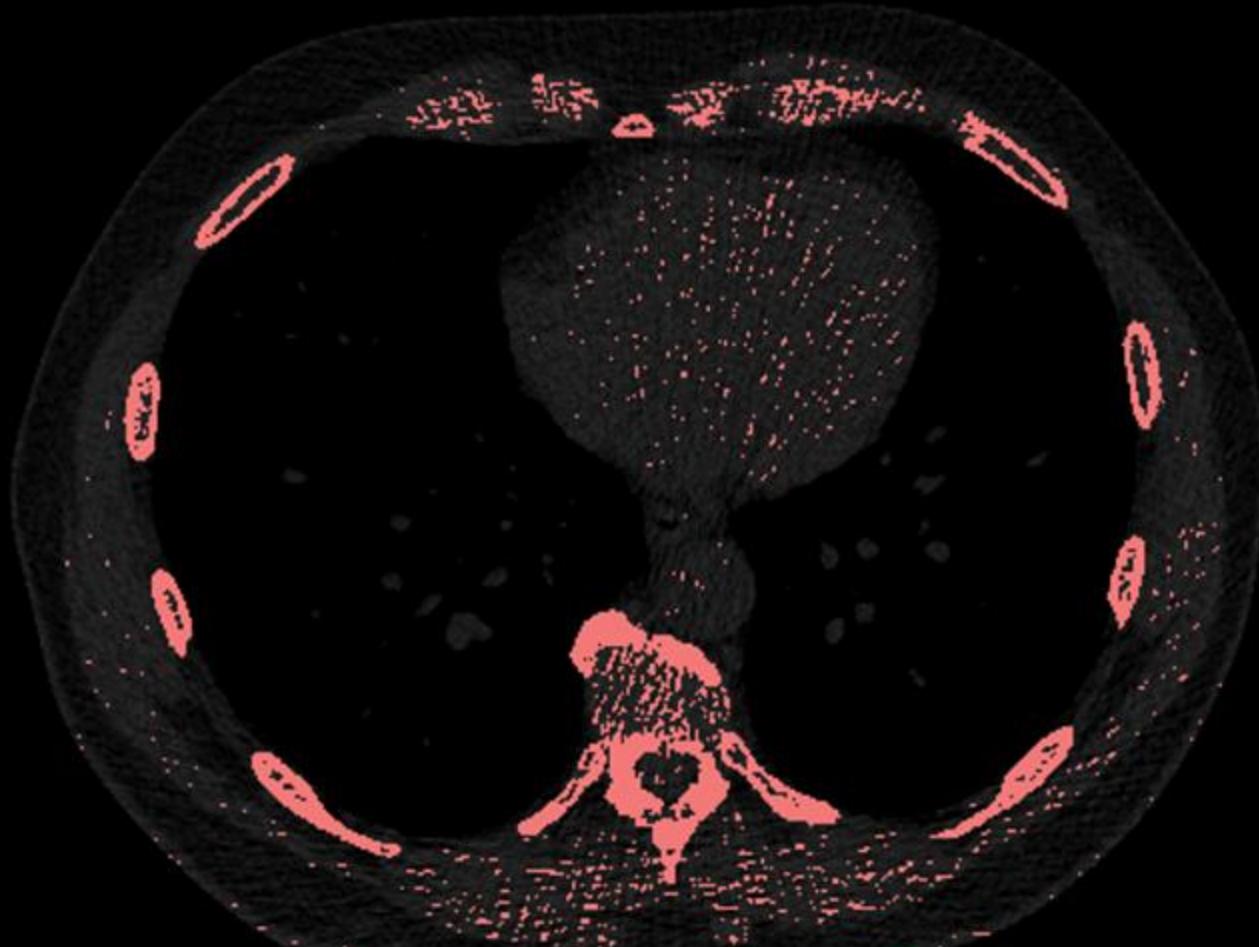


FBP Reconstruction – Bone Kernel

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Scoring Results : Agatston Score Protocol

Total Coronaries

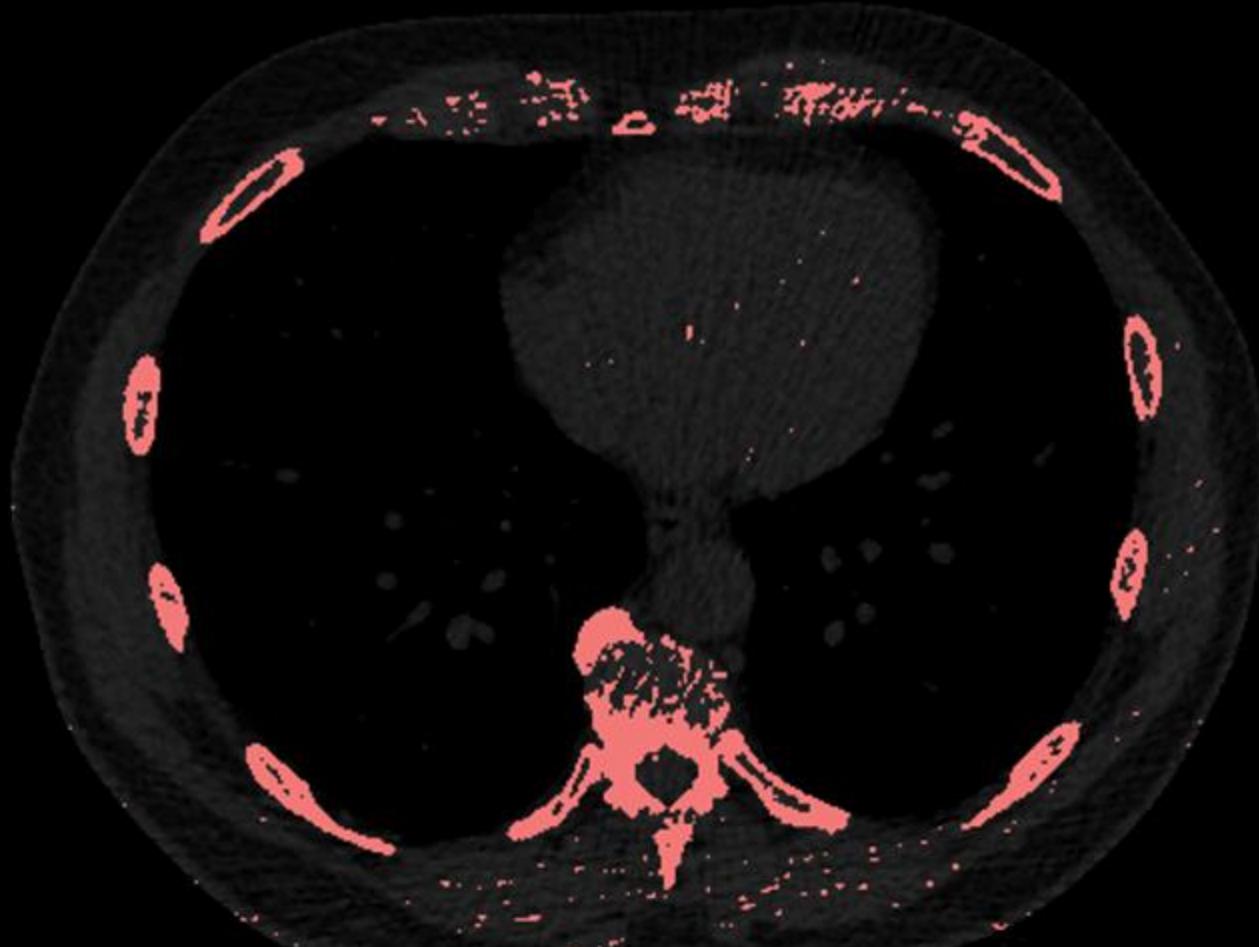


FBP Reconstruction – Soft Tissue Kernel

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Scoring Results : Agatston Score Protocol

Total Coronaries

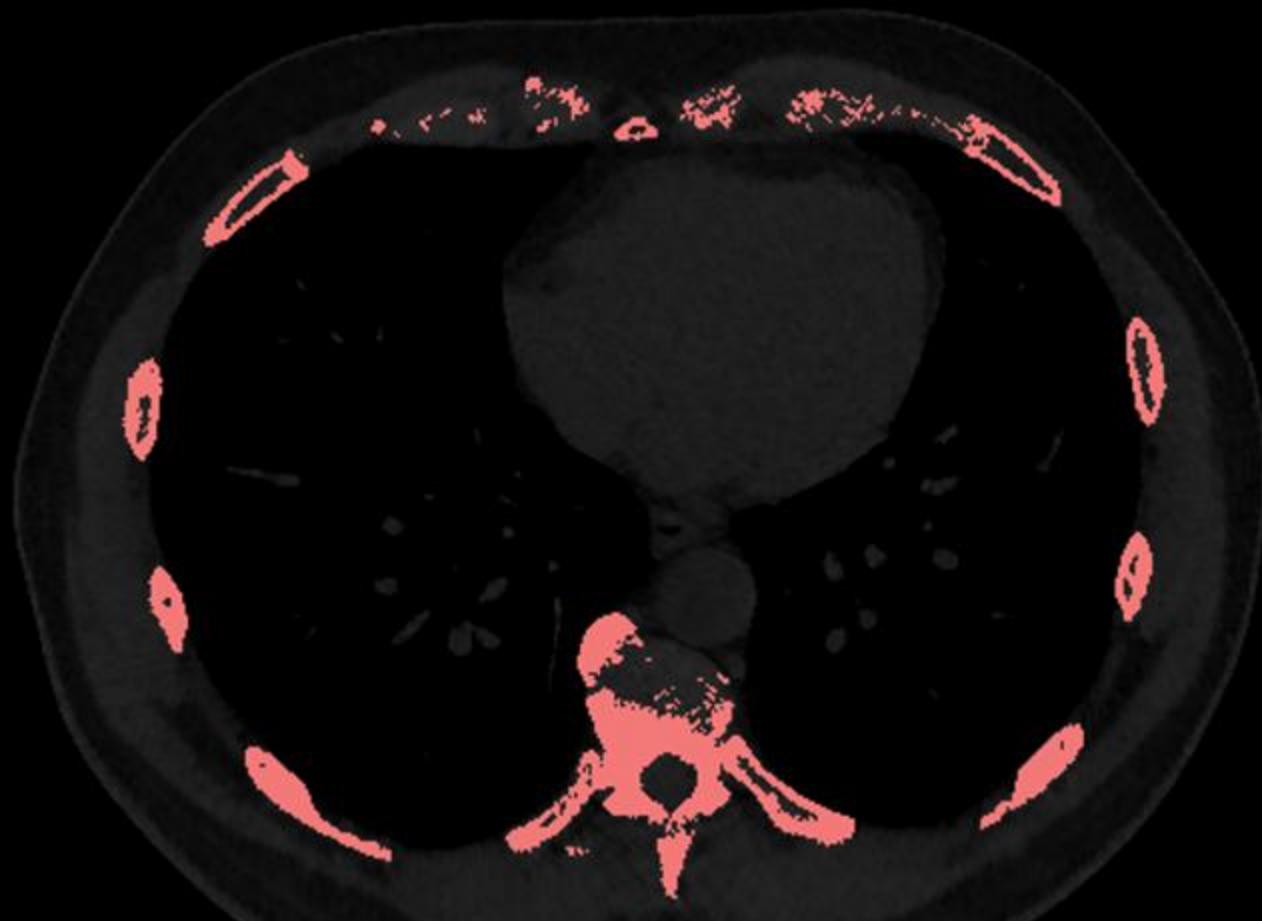


2009 - Iterative Reconstruction (100%)

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Scoring Results : Agatston Score Protocol

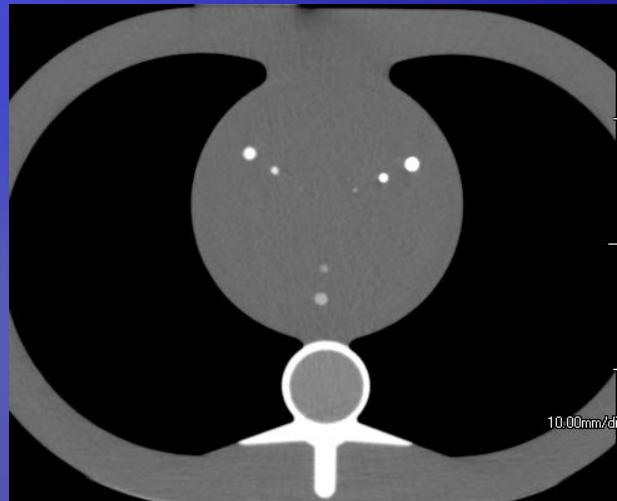
Total Coronaries



2012 - Model-based Iterative Reconstruction

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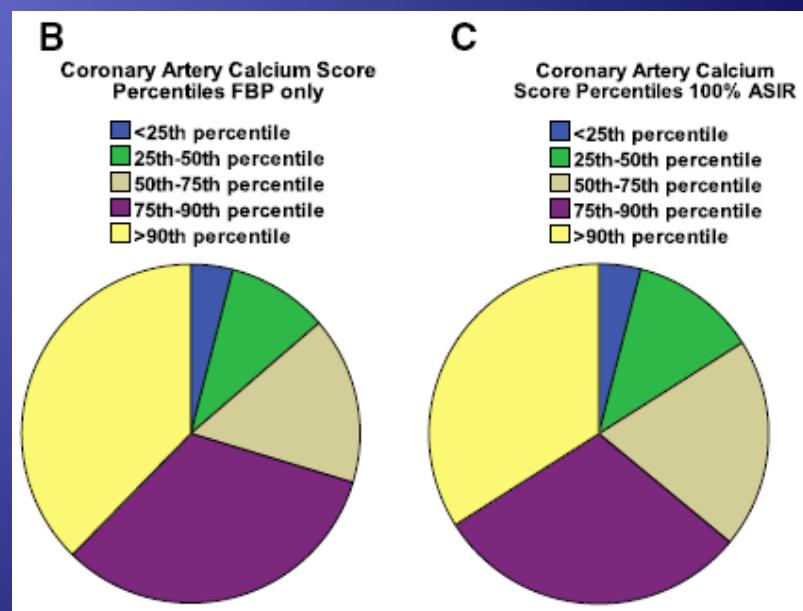
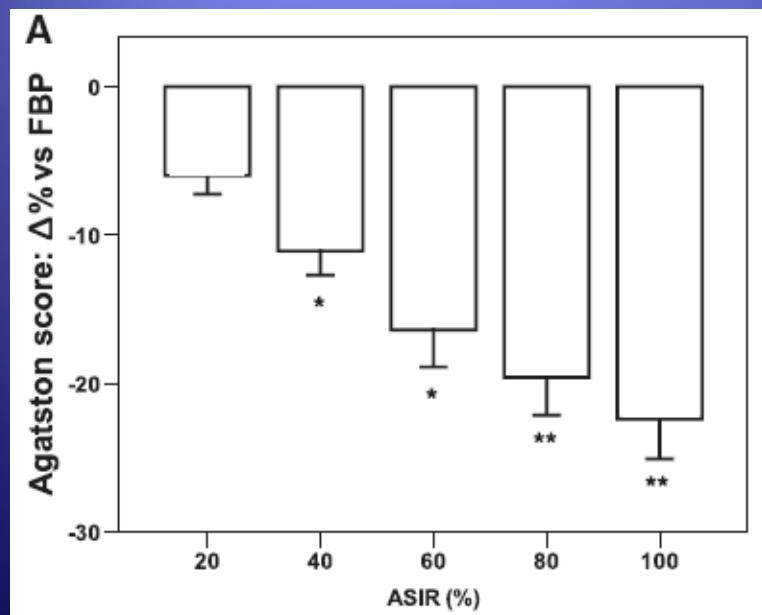
Effect of iterative reconstruction on CAC scores



- ◆ The maximum variability using iterative reconstruction is 2% in a stationary phantom
- ◆ This is much lower than our observed maximum interscan variability of 24% in a phantom

Effect of iterative reconstruction on CAC scores

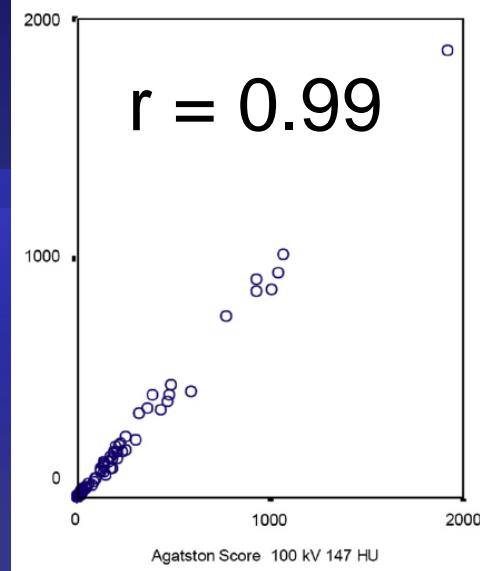
- Iterative reconstruction underestimates CAC scores by 6-22% compared to traditional filtered back projection



¹Gebhard C, et al. Int J Cardiol 2012; Sept 5. [epub]

The 0.2 mSv CACS CT

- ◆ 100 kV and 80 mAs, ECG-gated
- ◆ Employed a threshold of 147 HU (vs. 130 HU)
- ◆ High correlation w/ 120 kV 80 mAs scan ($r=0.99$)
- ◆ 3% of cases were unreadable due to noise
- ◆ Overestimation of CAC scores by about 11
- ◆ 7% had a misclassified risk categorization



Future directions

- ◆ How much interscan variability is acceptable?
- ◆ Should the gold standard always be 2.5 mm?
- ◆ Can the 130 HU threshold be optimized?
- ◆ How is CACS affected by:
 - ◆ Field of view
 - ◆ Helical versus axial CT
 - ◆ Increased noise (Slice thickness, Dose, Patient Size)
 - ◆ Newer noise reduction strategies
 - ◆ Other calcium scoring techniques (volume, mass)

Conclusion

- ◆ Combined lung and cardiac CT screening will require the latest technologies to optimize radiation dose and diagnostic accuracy
- ◆ Existing limitations in CAC measurements should be recognized and addressed
- ◆ CT protocols may need to be individually tailored to improve risk stratification

Thank You!

