# Ultrafast Computed Tomography as a Diagnostic Modality in the Detection of Coronary Artery Disease

## A Multicenter Study

Matthew J. Budoff, MD; Demetrios Georgiou, MD; Alan Brody, MD; Arthur S. Agatston, MD; John Kennedy, MD; Christopher Wolfkiel, PhD; William Stanford, MD; Paul Shields, MD; Roger J. Lewis, MD, PhD; Warren R. Janowitz, MD; Stuart Rich, MD; Bruce H. Brundage, MD

***Background*** Ultrafast computed tomography (CT), by acquiring images of the proximal coronary arteries, detects coronary calcifications and has been demonstrated to be highly sensitive for the detection of coronary artery disease in many small studies. The aim of this study was to determine the relationship between ultrafast CT scanning and coronary angiography in a large number of symptomatic patients.

***Methods and Results*** The study population consisted of 71C patients from six participating centers. A multivariate logistic regression model was used to evaluate the individual contributions of age, number of calcified vessels, and the calcium score for the probability of angiographically significant disease. 01 the 710 patients enrolled, 427 patients had significant angiographic disease, and coronary calcification was detected in 404. yielding a sensitivity of 95%. Of the 23 patients withoul calcifications, 19 (83%) had single-vessel disease at angiogranhv. Of the 283 patients without angiographically significant disease, 124 had negative ultrafast CT coronary studies, for a specificity of 44%. An increasing number of vessels with calcification present on ultrafast CT was found to increase specificity for the presence of obstructive coronary artery disease in at least one vessel (P<.0001). As the log of the calcium score increases, the probability of multivessel obstructive disease increases (P<-0001).

***Conclusions*** Ultrafast CT scanning is a noninvasive, nonexercise-dependent test with an excellent sensitivity for the detection of coronary artery disease. The presence of calcifications in multiple vessels and in younger populations correlates with higher specificities for obstructive disease, making ultrafast CT coronary scanning a very useful diagnostic test. ***(Circulation.*** **1996;93:898-904.)**

***Key Words*** • coronary disease • tomography • diagnosis imaging* plaque

Coronary heart disease remains the number one cause of mortality in both men and women in the United States.' The need to detect coronary atherosclerosis early in its course has been well recognized by clinicians and epidemiologists for decades.[2] Many studies have documented the ability to alter the progression of coronary atherosclerosis by modifying certain identifiable risk factors. At present, there exists no effective noninvasive tool for the early detection of coronary artery disease in the general population. For example, stress ECG requires that the patient be able to exercise, have a near normal baseline ECG, and the presence of a trained physician to supervise the study. In a review of the literature, Detrano and Froelicher[3] found stress ECG to have a sensitivity of detecting coronary artery disease that varied from 14% to 88%.

Pathological studies have demonstrated a strong correlation between the presence of calcium and coronary artery disease.[2,4-7] The presence of coronary calcium is invariably an indicator of intimal atherosclerosis.[8] Ultrafast computed tomography (CT), by acquiring images of the proximal coronary arteries, detects coronary calcifications and is highly sensitive for the detection of coronary artery disease[9-15]; yet these conclusions are based on studies using relatively small sample sizes, which preclude precise measurement of the sensitivity, specificity, and predictive values of ultrafast CT for the detection of obstructive coronary artery disease. For this reason we have conducted a large multicenter study of ultrafast CT and angiography.

Received July 20, 1995; revision received September 13, 1995; accepted October 4, 1995.

From the Department of Medicine, Division of Cardiology, Harbor-UCLA Medical Center, Torrance, Calif (M.J.B., D.G., J.K., B.H.B.); the Department of Radiology, SUNY-Buffalo, Buffalo, NY (A.B.); Mount Sinai Hospital, Miami, Fla (A.S.A., W.R.J.); the Department of Medicine, Division of Cardiology, University of Illinois, Chicago (C.W., S.R.); the Department of Radiology, University of Iowa, Iowa City (W.S.); the Health, Research, and Education Center, Washington State University at Spokane (P.S.); and the Department of Emergency Medicine, Harbor-UCLA Medical Center, Torrance, Calif (R.J.L.).

Dr Brundage serves on the Scientific Advisory Board of Imatron and has a research grant from Siemens Systems, Iselin, NJ.

This study was presented in part at the 66th Annual Meeting of the American Heart Association, Atlanta, Ga, November 8-11, 1993, and at the 43rd Annual Meeting of the American College of Cardiology, Atlanta, Ga, March 13-17, 1994.

Reprint requests to Bruce H. Brundage, MD, Saint John's Cardiovascular Research Center, 1124 W Carson St, RB-2, Torrance, CA 90502.



## Methods

### Participating Centers

This study was conducted at Harbor-UCLA Medical Center, Torrance, Calif, SUNY-Buffalo, Buffalo, NY; Mount Sinai Hospital, Miami, Fla; University of Illinois, Chicago; University

TABLE 1. **Patient Characteristics by Site**

| Site | No. | Age, y | Men (%) | Women (%) | Normal Coronaries | Nonobstructive Disease (<50%) | 1-Vessel Disease | Multivessel Disease |
|---|---|---|---|---|---|---|---|---|
| SUNY-Buffalo | 105 | 48-9 | 66(63%) | 39(37%) | 44(42%) | 21 (20%) | 19(18%) | 21 (20%) |
| Harbor-UCLA | 89 | 55-9 | | 42(47%) | 35(39%) | 8(9%) | 19(21%) | 27(30%) |
| University of Illinois | 137 | 58-12 | 69(50%) | 68(50%) | 51 (37%) | 19(14%) | 21 (15%) | 46(34%) |
| University of Iowa | 95 | | 55(58%) | 40(42%) | 28(29%) | 12(13%) | 26(27%) | 29(31%) |
| Mount Sinai | 234 | 58-11 | 1 79(76%) | 55(24%) | 36(15%) | 22(9%) | 72(31%) | 104(44%) |
| Spokane | 50 | 59-10 | 40(80%) | 10(20%) | 4(8%) | 3(6%) | 17(34%) | 26(52%) |
| Totals | 710 | **56-12** | **456(64%)** | 254(36%) | 198(28%) | 85(12%) | 174(25%) | 253(36%) |

of Iowa, Iowa City; and Washington State University, Spokane. This study was approved by the institutional review board at each participating center. Investigators at each center recorded patient information using a case-report form that included biographical data including age, sex, dates, and results of ultrafast CT and angiographic studies. The case-report form was forwarded to the coordinating center at Harbor-UCLA Medical Center.

### Patient Population

The patient population consisted of patients undergoing coronary angiography for clinical indications, the majority of which was suspicion of coronary artery disease with a minority undergoing angiography for evaluation of other cardiac diseases. Patients also underwent ultrafast CT scanning to evaluate for coronary calcifications. Patients whose ultrafast CT scans were performed more than 3 months after the angiogram were excluded from the study.

### Angiographic Protocol

The coronary angiograms were analyzed by an experienced reader at each institution. Each coronary vessel (left main, left anterior descending, circumflex, and right coronary artery) was assessed, and the visual estimation of the percent luminal reduction for each lesion was reported. Multiple projections were acquired to discern the maximal coronary artery luminal narrowing. Investigators recorded the maximum stenosis in each vessel in one of five categories: none, luminal irregularities (<50% stenosis), 50% to 75%, 75% to 99%, or 1110% occlusion. Angiographic abnormalities were considered significant if >50% luminal diameter stenosis was found in any vessel.

### Ultrafast Coronary Scan Protocol

The ultrafast CT studies were performed with an Imatron C-100 ultrafast CT scanner in the high resolution volume mode, using a 100-ms exposure time. ECG triggering was used so that each image was obtained at the same point in diastole, corresponding to 80% of the RR interval. Proximal coronary artery visualization was obtained without contrast medium injection, and at least 20 consecutive images were obtained at 3-mm intervals beginning 1 cm below the caring and progressing caudally to include the proximal coronary arteries. Total radiation exposure using this technique was <1 rad per patient (<.01 Gy).

Each center used a CT threshold of 130 Hounsfield units (Hu) for identification of a calcific lesion. Centers used varying minimum area for identifying calcific lesions. Harbor-UCLA, University of Miami, and Spokane each used 0.68 mm*l* as the lower limit to differentiate calcific disease from CT artifact. University of Iowa, SUNY-Buffalo, and University of Illinois required a minimum area of 1.02 mm'. The lesion score was calculated by multiplying the lesion area by a density factor derived from the maximal Hounsfield unit within this area, as described by Agatston et al.[13] The density factor was assigned in the following manner: 1 for lesions whose maximal density were 130 through 199 Hu, 2 for lesions 200 through 299 Hu, 3 for lesions 300 through 399 Hu, and 4 for lesions >400 Hu. A total calcium score was determined by summing individual lesion scores from each of four anatomic sites (left main, left anterior descending, circumflex, and right coronary arteries).

### Statistical Analysis

All values are reported as mean-SD. Data were analyzed using $\chi^2$ and Fisher's exact test for comparing categorical variables. The Wilcoxon rank sum test was used for comparing continuous variables. All tests of significance were two-tailed, and significance was defined at <_.05. A multivariate logistic regression model was used to evaluate the individual contributions of age, number of calcified vessels, and the calcium score for the probability of angiographically significant disease.' „ The calcium score was transformed by taking the natural log of (1 + calcium score) for inclusion in the model. All statistical analyses were performed using the SAS software system.17, 18

## Results

Seven hundred ten patients, 456 men and 254 women, were enrolled from the six participating centers. The mean age was 56--12, ranging from 24 to 86 years. Patient characteristics, by center, are detailed in Table 1. Several characteristics of the patient population showed statistically significant variation between sites. This heterogeneity included age (P<.0001), sex (P<.001), and the proportion of patients with multivessel disease by angiography (P<.001).

Of the 710 patients, 427 (60%) had significant angiographic disease, defined as at least a 50% luminal diameter stenosis in any vessel. Of the 427 patients with significant disease, coronary calcification was detected in 404, for an overall sensitivity of 95%. Of the 283 patients without angiographically significant disease, 124 had negative ultrafast CT coronary studies, for a specificity of 44%. The positive predictive value of coronary calcification for obstructive disease was 72%. The negative predictive value was 84%. There were 174 patients with single-vessel disease, 120 patients with two-vessel disease, 111 patients with three-vessel disease, and 22 patients with four-vessel disease (defined as three vessel **plus** left main disease). Ultrafast CT sensitivities (any calcium present) for detecting one-, two-, three-, and four-vessel angiographic disease were 89%, 99%, 97%, and 100%, respectively. Ultrafast CT detected calcification in 250 of 253 patients with multivessel angiographic disease (two or more vessels) for a sensitivity of 99%.

Only 23 of 427 patients with angiographically significant disease had no calcifications by ultrafast CT. Of these 23 patients, 19 (83%) had single-vessel disease at angiography. Of the remaining 4 patients, 1 patient had two-vessel disease and 3 had three-vessel disease. No patients with a negative ultrafast CT study had left main

**TABLE 2. Comparison of UFCT Calcium Detection to Obstructive Lesions on Angiography by Decade**

| | Age, y | | |
|---|---|---|---|
| | <40 (n=53) | 40-50 (n=178) | >50 (n=478) |
| Sensitivity | 13/19(68) | 84/100(84) | 305/306 (99) |
| Specificity | 25/34(74) | 41/78(53) | 58/172(34) |
| Positive predictive value | 13/22(59) | 84/121 (69) | 305/419 (73) |
| Negative predictive value | 25/31 (81) | 41/57(72) | 58/59(98) |

UFCT indicates ultrafast computed tomography.
Percentages are shown in parentheses. Trends are all highly significant (P<.0001).

**TABLE 3. Prediction of Obstructive Angiographic Disease by Number of Calcified Vessels on UFCT**

| No. of Calcified Vessels | Sensitivity | Specificity | Positive Predictive Value | Negative Predictive Value |
|---|---|---|---|---|
| 1-Vessel calcification | 92% | 54% | 84% | 71 |
| 2-Vessel calcification | 76% | 78% | 90% | 55% |
| 3-Vessel calcification | 56% | 88% | 93% | 43% |
| 4-Vessel calcification | 20% | 98% | 96% | 31% |

UFCT indicates ultrafast computed tomography. Four-vessel disease represents coronary calcification in the left anterior descending, right coronary, left main, and circumflex arteries.

disease by angiography. Nineteen of the false-negatives were men and 4 were women. These 23 patients were significantly younger than the patients with angiographically significant disease and coronary calcium detected by ultrafast CT scanning (42±8 versus 59--11; P<.0001).

Two hundred eighty-three patients without significant angiographic disease (no disease or <50% luminal stenosis) had significantly lower mean calcium scores than the patients with obstructive lesions on angiogram (103±261 versus 537±870; P<.0001). When ultrafast CT was used to detect any angiographically demonstrated coronary artery disease, including luminal irregularity, the overall sensitivity of ultrafast CT was 92% and the specificity was 54%.

When the population was subdivided into age categories by decade, we found an increasing sensitivity and decreasing specificity with advancing age for coronary calcium to predict angiographic disease (Table 2). The differences in sensitivity and specificity with increasing age are statistically significant (P<.0001).

When the dependence of the sensitivity and specificity of ultrafast CT on patient sex was examined, we found no significant differences with respect to sensitivity for obstructive disease (94.1% in men versus 96.2% in women). However, women had a significantly higher specificity (38.5% in men versus 48.6% in women, P<.001). Average ages for men and women were not significantly different (55±11 years for men versus 59±12 for women).

Centers used different minimum areas for identifying calcific lesions. The three centers that used >0.68 mm' achieved a combined sensitivity (373 patients) of 96% and specificity of 45%. The three centers that used >1.02 $mm^2$ as a minimum area studied a total of 337 patients had an average sensitivity of 92.6% and an average specificity of 43%. Thus, there were no significant differences in the sensitivities or specificities due to this difference of technique (P=.18).

The number of vessels with calcification present on ultrafast CT was found to correlate strongly with the presence of obstructive coronary artery disease in at least one vessel (P<.0001). Of the 110 patients with calcifications in all four vessels (left main, left anterior descending, circumflex and right coronary arteries), 99 (90%) had obstructive coronary disease on angiography. Specificity increased as the number of calcified vessels increased (Table 3).

A receiver-operating characteristic (ROC) curve was created to determine the predictive power of the ultrafast CT score for obstructive coronary artery disease as a function of the minimum score required to define a positive study. The number of calcified vessels was similarly plotted on a ROC curve (Fig 1). The false-positive rate represents 1 specificity and is plotted horizontally. The area under each curve represents the ability to detect patients with obstructive angiographic disease. The area under the curves for both coronary calcium score and number of calcified vessels was 0.82. Exercise treadmill testing has been shown to have a similar accuracy for detecting angiographically significant disease.[19]

There is a strong association between the probability of multivessel angiographic disease and the log of the ultrafast calcium score plus one. As the log of calcium score increases, the probability of multivessel obstructive disease increases (P<.0001). The number of calcified vessels detected by ultrafast CT also is highly statistically significant for predicting multivessel disease (P<.0001). To determine the probability of multivessel obstructive disease based on both the log of one plus the calcium score and number of calcified vessels, a multivariate logistic regression model was created.[16] Fig 2 shows the probability of significant coronary artery disease as a function of the natural log (1 + score) for each number of calcified vessels (one, two, three, and four, respectively) with 95% confidence intervals. Separate curves have been plotted for men and women (Fig 3). This model demonstrates an increased risk for multivessel disease associated with the male sex, averaging 15% higher than women. Once the calcium score, sex, and the number of vessels involved by CT are included in the

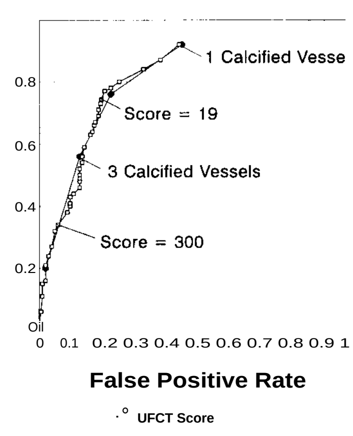


Fig 1. Receiver-operating characteristic curves for ultrafast computed tomography (UFCT) calcium score of calcified vessels. The false-positive rate represents 1 specificity. Area under the curve, representing the ability to detect patients with obstructive disease, is 0.82.

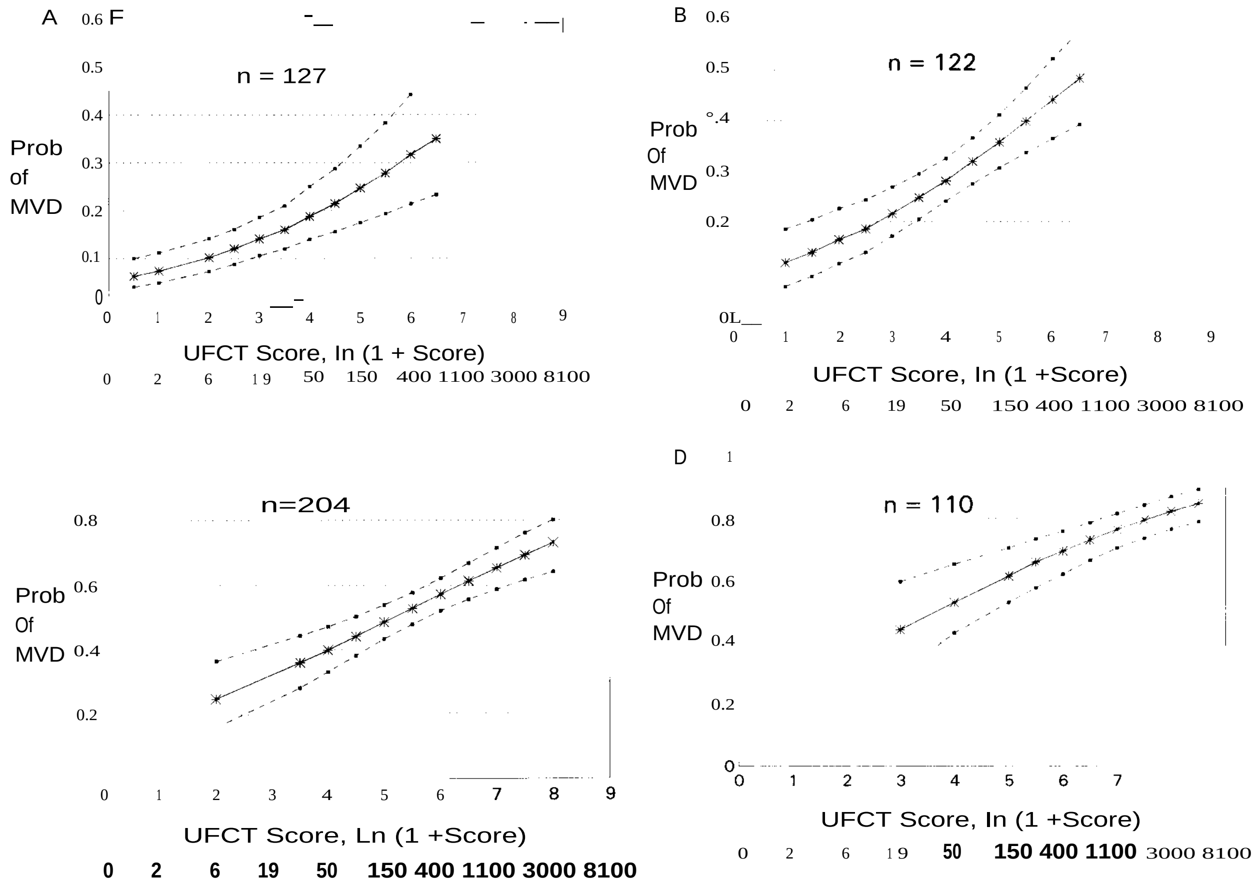


**Fig 2.** **Natural log of the ultrafast computed tomography (UFCT) score plotted against the probability of angiographic multivessel disease (MVD) for each number of calcified vessels. Dashed lines represent 95% confidence intervals. A, One calcified vessel; B, two calcified vessels; C, three calcified vessels; and D, four calcified vessels. Numbers at the bottom of each panel are approximations of the raw calcium score.**

model, the addition of age as an independent variable does not quite achieve statistical significance (P=.062).

## Discussion

Coronary artery disease is the major cause of mortality in the United States today.[1] Autopsy studies have demonstrated a strong correlation between coronary calcification and atherosclerotic disease.[2,4-7] Ultrafast CT scanning is noninvasive, can be rapidly performed, and does not require the presence of a physician during the test. An ultrafast CT scanner costs approximately $1.5 to 2 million. In contrast to other studies for detection of coronary artery disease, a typical study can be performed in under 10 minutes, and costs range from $350 to $400 per test, which is similar to an exercise treadmill test. Radiation doses received during an ultrafast CT study are much lower than angiography, and central axial doses are similar to thallium- and technetium-based nuclear scans.[20-22] Ultrafast CT scanning is a non-exercise-dependent study with an excellent sensitivity for the detection of coronary artery disease, comparable to any noninvasive cardiac test.

Fluoroscopy has long been studied as a potential modality for the diagnosis of coronary artery disease. Many studies have demonstrated a correlation between fluoroscopically detected calcium and angiographic stenosis. However, fluoroscopy is not widely used as a diagnostic test due in part to its insufficient sensitivity.[19,23,24] Detrano et al[19] reviewed eight studies comparing fluoroscopy and angiography, and sensitivities for fluoroscopy ranged from 40% to 79%. Ultrafast CT, with its inherently better densitometric resolution, is able to detect smaller amounts of calcium, thus improving sensitivity. In addition, aortic wall, valvular, and coronary calcification can be clearly differentiated using ultrafast CT due to high spatial resolution and fast acquisition time. Agatston et al[13] reported 50 patients who underwent angiography, fluoroscopy, and ultrafast CT and found ultrafast CT to be significantly more sensitive than fluoroscopy for the detection of angiographically significant coronary artery disease (90% versus 52%, P<.001).

Many small studies have demonstrated a relationship of ultrafast CT detection of calcium to coronary angiographic findings. Tannenbaum et al[12] first correlated ultrafast CT findings to angiography, reporting a sensitivity and specificity of 88% and 100%, respectively, in 54 patients. More recent studies comparing ultrafast CT and angiography have demonstrated sensitivities from 88% to 100%.[4,9,10,14] Our population, 710 patients from six centers, is the first multicenter study designed to determine a sensitivity and specificity in a large number of patients undergoing both angiography and ultrafast CT. Our findings, revealing a sensitivity of 95%, are consistent with these previous smaller studies of symptomatic populations.

This study population, spanning multiple age, ethnic, and socioeconomic subsets, is markedly heterogeneous.

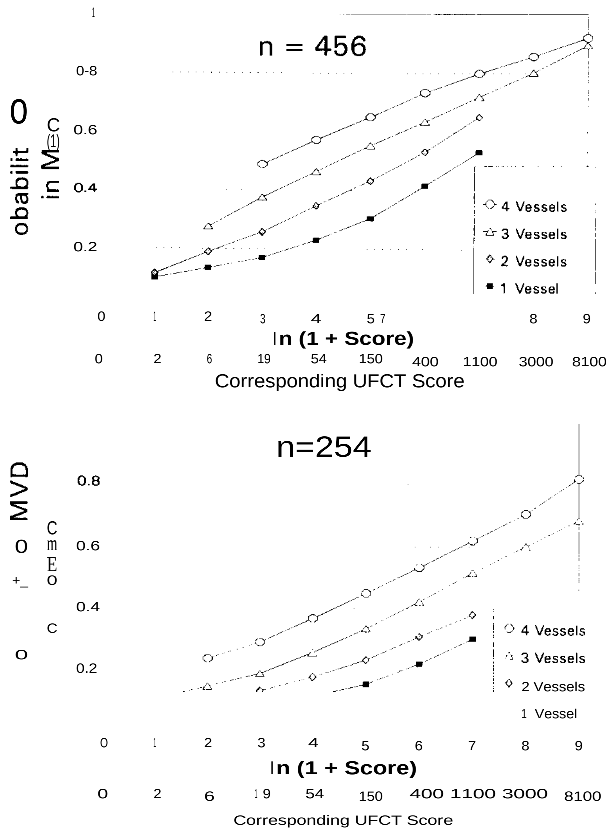


FIG 3. **Natural log of the ultrafast computed tomography (UFCT) score plotted against the probability of angiographically significant multivessel disease (MVD) in men and in women stratified by number of calcified vessels identified on UFCT scan. Plots were created from multivariate logistic regression model; male sex is associated with an increased risk of MVD at all points.**

It also contains significant geographic diversity. This heterogeneity makes the results applicable to many different populations.

Our data suggest that the use of ultrafast CT might differ among age groups. Because coronary atherosclerosis is so widespread in the older population, the absence of calcium might prove an important factor in excluding significant stenosis. The sensitivity of 99.7% in symptomatic patients more than 50 years of age is also promising. In younger patients, in whom advanced coronary atherosclerosis is much less prevalent, a positive study correlates well with the presence of obstructive coronary artery disease. The specificity of 74% in the population less than 40 years of age supports this view. However, another report of patients all aged <50 years revealed a sensitivity of 85% and a specificity of only 45%.'° The present study includes some of the same patients from this study by Fallavollita et al,''' and the reason for the disparity between the studies is not clear.

This study, in accordance with many previous studies on ultrafast CT, has demonstrated an excellent sensitivity but relatively poor specificity for defining the presence of obstructive coronary artery disease.'''' We therefore analyzed the data with respect to the number of vessels demonstrating coronary calcification on ultrafast CT to see if this was a better predictor of obstructive disease. The presence of calcium detected by ultrafast CT in multiple vessels becomes highly predictive of obstructive coronary artery disease in a symptomatic population. The greater the number of calcified vessels, the higher the specificity for obstructive coronary artery disease (Table 3). This improved specificity was at the cost of a reduced sensitivity.

ROC curves demonstrate that ultrafast CT can discriminate different levels of sensitivity and specificity for angiographically significant coronary artery disease. This can be accomplished as well using total calcium score or number of calcified vessels (Fig 1).

Multivessel disease confers high risk for coronary heart disease events.[25] This study demonstrated a 99% sensitivity for the detection of multivessel disease using the presence of any calcium. When combining ultrafast CT calcium score with the number of calcified vessels, we were able to create a statistical model for the prediction of multivessel disease. In patients with both a high calcium score and multiple calcified vessels, the prevalence of multivessel disease exceeds 80%, regardless of the patient age. Male sex conferred roughly a 15% increased likelihood of multivessel disease compared with women (Fig 2). While age is an important factor in regard to sensitivity and specificity (Table 2), it achieves only marginal statistical power (P=.062) when evaluated as an independent variable in this model for multivessel disease. This demonstrates that age is a weaker independent predictor of angiographic multivessel disease than sex, calcium score, and number of calcified vessels. This model provides a powerful tool for the noninvasive detection of the high-risk symptomatic patient.

## Limitations

In this study, angiograms were evaluated by visual inspection with the use of multiple views; quantitative coronary angiography was not used. The data collection included no systematic attempt to evaluate the two modalities blinded to the other. However, 85% of the angiograms were done prior to the ultrafast CT scans, and angiographic investigators were generally unaware of the results of the ultrafast CT, so biased interpretations of the angiogram should be minimal. Similarly, ultrafast CT readers, using the computer-assisted algorithm to assess the presence or absence and amount of coronary calcification, should be unbiased.

This study represents a collection of data from six centers, prospectively collected for other research protocols, and tight controls on the patient selection could not be imposed. We believe that these data represent a large enough population to overcome most collection biases; however, a large prospective study must now be done to corroborate our results.

This study was performed on patients referred to angiography for clinical indications. The vast majority of these patients were symptomatic and therefore had a higher pretest probability of atherosclerotic heart disease than the general population. The prevalence of angiographically significant disease was 6(1% in our population. This high prevalence could raise the sensitivity at the expense of specificity.

The limited specificity of ultrafast CT for obstructive coronary artery disease is somewhat expected. Calcifications in the coronary artery bed do not always correlate with obstructive disease on angiography. When evaluating for luminal irregularities, the specificity increases to 54%.

Mintz et al[26] recently found only 6.8% of angiographically normal segments to be normal by intravascular ultrasound. The specificity of ultrafast CT might increase dramatically with the use of intravascular ultrasound as the reference standard rather than angiography.

There is some controversy among ultrafast CT users as to the minimum area that should be used to diagnose the presence of coronary calcium. The Agatston method" for ultrafast CT scanning used >1.00 $mm^2$, considering any smaller area of high CT number (>130 flu) an artifact. However, some researchers believe that even this minimum area is too small, thus including noise artifact on CT rather than detecting areas of coronary calcification. In this study, three centers used 0.68 $mm^2$ as the minimum area for the presence of calcium. The other three centers used a slightly larger region (1.02 $mm^2$) as the minimum area. The use of even larger areas for the detection of calcium should increase specificity by detecting only areas of true calcification but at the cost of sensitivity. When comparing the results from the different centers in this study, there were no significant differences in sensitivities and specificities. Ideally, all the scans would be read using the same protocol, including minimum area; nevertheless, there was no statistical difference between the two areas used in this study.

This article does not attempt to address clinical end points but rather angiographic stenosis. The study was not designed to determine whether coronary calcification detected by ultrafast CT can predict future coronary events. However, patients with fluoroscopically detected calcium have increased coronary event rates in longitudinal studies.[27] Ultrafast CT has improved densitometric sensitivity over fluoroscopy, so there is little reason to think the results from ultrafast CT should differ greatly.[27] Follow-up on the population reported in this study is now being performed to evaluate patients for clinical end points.

There is much interest in using ultrafast CT coronary artery scanning as a screening test, and certain companies are already marketing this tool to the general population. This study was not designed to assess ultrafast CT as a screening test. Only by studying asymptomatic patients will this modality be properly evaluated as a potentially cost-effective screening test. Detrano et al[27] recently have shown a correlation between fluoroscopic calcium and clinical end points in an asymptomatic population. Also, Brundage et alts recently have shown that a large amount of coronary calcification in asymptomatic adult men detected by ultrafast CT predicts a higher-than-expected rate for cardiac events. Utility and cost-effectiveness studies similar to that performed by Patterson et al[29] for coronary artery disease diagnostic tests must be applied to ultrafast CT to assess its exact role in the evaluation of coronary artery disease.

## Conclusions

The results from this heterogeneous population from six centers are very promising. The sensitivity and negative predictive values, especially for multivessel disease and left main disease, are excellent, making this a potential tool for ruling out significant coronary disease. Although the overall specificity is not high, the presence of calcifications in multiple vessels and in younger populations correlates with higher specificities for obstructive disease, making ultrafast CT coronary scanning very useful as a diagnostic test. Combining the number of calcified vessels with a quantified calcium score provides a powerful predictor of multivessel obstructive coronary artery disease. The presence of calcification denotes coronary atherosclerosis,[2,4-7] and this may have important prognostic implications. If prospective studies of asymptomatic patients demonstrate this high sensitivity, then ultrafast CT may well become a useful noninvasive test for the diagnosis of coronary artery disease.

## Acknowledgments

This study was supported by grants from Siemens Medical Systems, Iselin, NJ, and Saint John's Heart Institute, Santa Monica, Calif. Special thanks to Robert Detrano, MD, PhD, Matthew A. Romano, and Mark Bleiweiss, MD, for their contributions in preparation of the manuscript.

## References


1. Mortality Patterns-United States, 1991. *MMWR.* 1993;42:891-900.
2. Eggen DA, Strong JP, McGill HC. Coronary calcification: relationship to clinically significant coronary lesions and race, sex, and topographic distribution. *Circulation.* 1965;32:948-955.
3. Detrano R, Froelicher V. A logical approach to screening for coronary artery disease. *Ann Intern Med.* 1987;106:846-852.
4. Simons DB, Schwartz RS, Edwards WD, Sheedy PF, Breen PF, Rumberger JA. Noninvasive definition of anatomic coronary artery disease by ultrafast computed tomographic scanning: a quantitative pathologic comparison study. *JAm Coll Cardiol.* 1992;20:1118-1126.
5. Margolis JR, Chen JT, Kong Y, Peter H, Behar VS, Kisslo JA. The diagnostic and prognostic significance of coronary artery calcification: a report of 800 cases. *Radiology.* 1980;137:609-616.
6. Simons DB, Schwartz RS, Sheedy PF, Breen JF, Edwards WD, Rumberger JA. Coronary artery calcification by ultrafast CT predicts stenosis size: a necropsy study. *Circulation.* 1990;82(suppl 111):111-62. Abstract.
7. Rumberger JA, Schwartz RS, Simons B, Sheedy PF, Edwards WD, Fitzpatrick LA. Relation of coronary calcium determined by electron beam computed tomography and lumen narrowing determined by autopsy. *Am J Cardiol.* 1994;74:1169-1173.
8. Janowitz WR, Agatston AS, Viamonte M. Comparison of serial quantitative evaluation of calcified coronary artery plaque by ultrafast computed tomography in persons with and without obstructive coronary artery disease. *Am J Cardiol.* 1991;68:1-6.
9. Breen JF, Sheedy PF, Schwartz RS, Stanson AW, Kaufmann RB, Moll PP, Rumberger JA. Coronary artery calcification detected with ultrafast CT as an indication of coronary artery disease. *Radiology.* 1992;185:435-439.
10. Fallavollita JA, Brody AS, Bunnell IL, Kumar K, Canty JM. Fast computed tomography detection of coronary calcification in the diagnosis of coronary artery disease. *Circulation.* 1994;89:285-290.
11. Agatston AS, Janowitz WR, Aizawa N, Gasso J, Hildner F, Viamonte M, Prineas R. Quantification of coronary calcium reflects angiographic extent of coronary artery disease. *Circulation.* 1991;84(suppl 11):11-159. Abstract.
12. Tannenbaum SR, Kondos GT, Veselik KE, Prendergast MR, Brundage BH, Chomka EV. Detection of calcific deposits in coronary arteries by ultrafast computed tomography and correlation with angiography. *Am J Cardiol.* 1989;63:870-872.
13. Agatston AS, Janowitz WR, Hildner FJ, Zusmer NR, Viamonte M, Detrano R. Quantification of coronary artery calcium using ultrafast computed tomography. *J Am Coll Cardiol.* 1990;15:827-832.
14. Bormann JL, Stanford W, Stcnberg RG, Winniford MD, Berbaum KS, Talman CL, Galvin JR. Ultrafast computed tomographic detection of coronary artery calcification as an indicator of stenosis. *Am J Card Imaging.* 1992;6:191-196.
15. Lcimgruber PP, Judge TP, Fuho EF, Viren FK, Shields JP. Correlation between coronary artery calcification assessed by ultrafast CT and angiographically documented coronary artery disease. *J Am Coll Cardiol.* 1993;21:54A. Abstract.

16. Hosmer DW, Lemeshow S. *Applied Logistic Regression.* New York, NY: John Wiley & Sons; 1989.
17. SAS Institute Inc. SASlSTAT *User's Guide, version 6.* 4th ed, vol 1. Cary, NC: SAS Institute Inc; 1989.
18. SAS Institute Inc. SASlSTAT *User's Guide, Version 6.* 4th ed, vol 2. Cary, NC: SAS Institute Inc; 1989.
19. Detrano R, Salcedo EE, Hobbs RE, Yiannikas J. Cardiac cinefluoroscopy as an inexpensive aid in the diagnosis of coronary artery disease. *Am J Cardiol.* 1986;57:1041-1046.
20. Wolfkiel CJ. Comparative safety of cardiac imaging techniques. In: Brundage BH, ed. *Comparative Cardiac Imaging.* Rockville, Md: Aspen Publishers; 1990:557-561.
21. Chang W, Franken EA. Performance evaluation of the Imatron cine-CT. *Radiology*. 1986;157:117. Abstract.
22. Syed 113, Flowers N, Granlith D, Samols E. Radiation exposure in nuclear cardiovascular studies. *Health Physics.* 1982;42:159-163.
23. Rifkin RD, Parisi AF, Folland E. Coronary calcification in the diagnosis of coronary artery disease. *Am J Cardiol.* 1979;44:141-147.
24. Gianrossi R, Detrano R, Colombo A, Froelicher V. Cardiac fluoroscopy for the diagnosis of coronary artery disease: a meta analytic review. *Am Heart J.* 1990;120:1179-1188.
25. Proudfit WJ, Bruschke AVG, MacMillan JP, Williams GW, Sones FM. Fifteen-year survival study of patients with obstructive coronary artery disease. *Circulation.* 1983;68:986-997.
26. Mintz GS, Painter JA, Pichard AD, Kent KM, Satler LF, Popma JJ, Chuang YC, Bucher TA, Sokolowicz LE, Leon MB. Atherosclcrosis in angiographically `normal' coronary artery reference segments: an intravascular ultrasound study with clinical correlations. *J Am Coll Cardiol.* 1995;25:1479-1485.
27. Detrano RC, Wong ND, Tang W, French WJ, Georgiou D, Young E, Brezden OS, Doherty TM. Prognostic significance of cardiac cinefluoroscopy for coronary calcific deposits in asymptomatic high risk subjects. *J Am Coll Cardiol.* 1994;24:354-358.
28. Brundage BH, Rich S, Rassman W, Wolfkiel C, Georgiou D, Friedman B, Nickerson S. Follow-up of asymptomatic individuals with high coronary calcium scores on UFCT scans. *J Am Coll Cardiol.* 1994;23:210A. Abstract.
29. Patterson RE, Eisner RL, Horowitz SF. Comparison of cost-effectiveness and utility of exercise ECG, single photon emission computed tomography, positron emission tomography, and coronary ang:ography for diagnosis of coronary artery disease. *Circulation.* 1995;91:54-65.