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The Dilemma of Diagnosing Coronary Calcification: Angiography Versus Intravascular Ultrasound

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Objectives. **We sought to determine whether careful examination of angiograms in conjunction with other clinical information could reliably detect, quantitate and localize target lesion calcification before a coronary intervention.**

Background. **The presence, extent and location of calcium in coronary artery lesions are important determinants of outcome after coronary intervention. Intravascular ultrasound is proposed as a superior technique for identifying patients with coronary artery calcification. However, the precise role of this costly and invasive method has not yet been established.**

Methods. **Target lesion calcification was assessed in 183 patients (155 men; mean [±SD] age 58 ± 10 years) by angiography and intravascular ultrasound before a planned percutaneous coronary intervention.**

Results. **Ultrasound detected calcium in 138 patients (<90° in 56, 91° to 180° in 52, 181° to 270° in 22 and >270° in 8), whereas angiography showed calcification in 63 (1+ in 32, 2+ in 27 and 3+ in 4). The two techniques agreed in 92 patients and disagreed in 91. Sensitivity and specificity of angiography were 40% and 82%, respectively. The arc of calcium by ultrasound was greater in patients with angiographically visible calcification (175° ± 85° vs. 108° ± 71°, p = 0.0001). The depth of calcification by ultrasound was superficial in 61 patients (44%), deep in 68 (49%) and mixed in 8 (7%). The sensitivity of angiography in identifying superficial calcium was 35%. Of 120 patients without angiographically visible calcium at the target lesion site, 83 showed calcium by ultrasound. The only predictor of ultrasound calcium in these 120 patients was angiographic calcification elsewhere in the coronary tree (p = 0.0001). The probability of any calcium and superficial >90° calcium were 60% and 12%, respectively, in the 90 patients without angiographic calcifications anywhere in the coronary tree.**

Conclusions. **Despite poor sensitivity, angiography may help identify patients requiring intravascular ultrasound. When it is angiographically visible, the arc of calcium is likely to be large and superficial. Angiographic calcification at a remote site is a predictor of angiographically undetected target lesion calcium. Patients without angiographic calcification in the coronary tree may not need routine ultrasound examination, as the likelihood of >90° superficial calcium is low.**

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Calcification of the coronary arteries is an important sequela of coronary artery disease, which is generally associated with long-standing atherosclerosis (1–3). The presence and extent of calcification constitute a significant determinant of the outcome of various percutaneous coronary interventions (4). Calcification detected by angiography is associated with an increased risk of dissection after balloon angioplasty, typically occurring adjacent to the calcified areas (5,6). Calcium deposits within coronary artery plaques impair cutting and retrieval of the plaque using a currently available directional atherectomy device (7,8). For arteries with extensive angiographic calcification, some authorities have recommended percutaneous revascularization using rotational ablation (8,9). Accordingly, the detection and quantification of calcification constitute an important goal of diagnostic catheterization in the era of intervention.

The traditional approach to identification of coronary artery calcification employs cinefluoroscopy to visualize moving opacities in close proximity to the vessel. However, this approach is limited by many factors, including the moderate resolution of radiography and the inherent difficulty of evaluating a three-dimensional structure from a two-dimensional projection. A new imaging modality—intravascular ultrasound—has proved to be very sensitive in detecting the presence, extent and location of calcification. However, the invasive nature and additional cost of this technique have precluded widespread application. Few data exist comparing the relative value of angiography and intravascular ultrasound in the assessment of coronary artery calcification. We sought to determine whether careful examination of angiograms in conjunction with demographic and clinical information might

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differentiate patients with and without significant coronary calcification at the target site. This approach would allow a more tailored and potentially cost-effective utilization of intravascular ultrasound to confirm the extent and severity of calcification before coronary interventions.

Methods

Patient group. The study group included 183 patients who underwent angiography and intravascular ultrasound imaging before percutaneous coronary revascularization. The demographic and clinical characteristics of this population were recorded prospectively in an interventional database. Characteristics classified for subsequent analysis included age, gender, unstable angina, prior myocardial infarction, hypertension, diabetes mellitus, hypercholesterolemia and family history of coronary artery disease.

Coronary angiography. Angiograms of the 183 patients were reviewed for calcification by two investigators who were unaware of the ultrasound findings. From the angiograms, the presence and extent of calcification were assessed using four semiquantitative methods: 1) Calcification at the target lesion (the stenosis that was about to undergo coronary intervention) was graded according to a four-point system—0 = no calcification, 1+ = calcification barely visible on close examination, 2+ = readily visible but mild degree of calcification and 3+ = obvious, heavy calcification. 2) After injection of a radiographic contrast agent, the depth of angiographic calcification was assessed and defined as superficial if calcification appeared near the coronary lumen or deep when it appeared closer to the adventitia. 3) The extent of calcification was graded by determining whether it was evident in one or both of two orthogonal projections. 4) Last, the entire coronary artery tree was examined to identify calcification at sites other than the target lesion site.

Intravascular ultrasound imaging. Intravascular ultrasound imaging was performed using a 30-MHz, 3.5-F ultrasound catheter (Boston Scientific) interfaced to a dedicated scanner (Hewlett-Packard). The ultrasound catheter consisted of a 135-cm long monorail device with a transducer enclosed in an acoustically transparent housing located 20 mm from the tip. A drive shaft rotated the transducer at 1,800 rpm to generate a 360° imaging plane angulated 15° forward from a plane perpendicular to the long axis of the catheter. The axial resolution of the imaging system varies with distance, averaging 80 to 100 μm, whereas lateral resolution typically ranges from 150 to 200 μm. This device generates ultrasound images at 30 frames per second that were continuously recorded on 0.5-in. Super-VHS videotape for subsequent analysis. Before the planned coronary intervention, the ultrasound catheter was advanced over a 0.014-in. angioplasty guide wire and positioned distal to the target lesion. To generate images along the length of the vessel, the ultrasound catheter was gradually withdrawn from this distal location during continuous imaging.

Analysis of ultrasound images was performed by observers who were unaware of the angiographic and clinical findings.

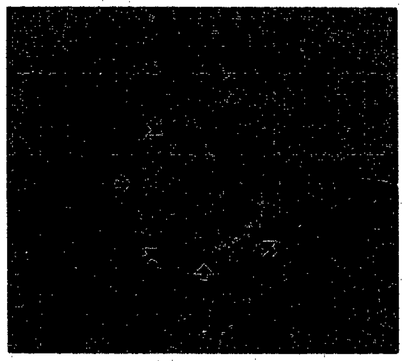
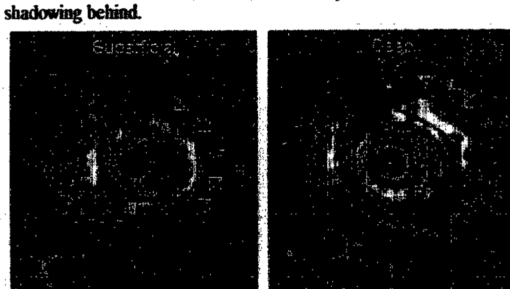


Figure 1. Ultrasound image containing extensive calcium identified by bright echos (arrows) and shadowing behind.

For each examined site, a short segment of videotape (10 to 20 s) was digitized at 30 frames/s into a 640 × 480-pixel matrix image with 8-bit depth (256 gray levels). The most severely narrowed segment of the target lesion was examined frame by frame to select the image with the largest calcified arc. Identification of coronary artery calcification by means of ultrasound employed standard criteria previously validated by in vitro imaging (10). This approach categorizes an atheroma as calcified when it contains a region of high echogenicity that exhibits acoustic shadowing due to obstruction of ultrasound penetration to the deeper vessel wall structures (Fig. 1).

The depth of calcification was also classified by ultrasound. Calcification was classified as superficial if the calcium involved the lumen surface or deep if noncalcified atherosclerotic plaque was interposed between the echogenic calcified region and the lumen (Fig. 2). The angular extent of calcification was expressed as the degrees of arc of vessel wall exhibiting acoustic shadowing. This measurement was performed by positioning a protractor at the center of the artery and determining the arc of acoustic shadowing. If a target segment contained more than one arc of calcification, the total circumference of calcification was recorded. For analysis, patients

Figure 2. Two types of calcification. **Left,** Superficial calcification identified by bright echoes located at the lumen interface (arrows) with shadowing behind. **Right,** Deep calcification identified by bright echoes (arrows) located in the atheroma away from the lumen with shadowing behind.



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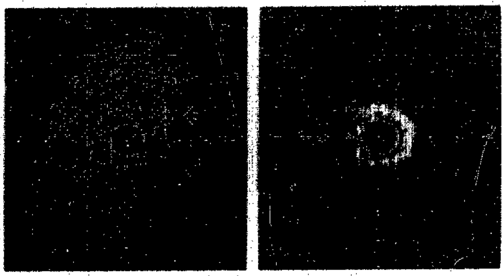


Figure 3. Two examples of ultrasound-detected calcium at the site of coronary stenosis. **Left,** Deep <90° of calcium arc in a severely obstructive atheroma that is otherwise free of calcification. **Right,** Severely stenosed coronary artery with superficial calcium subtending the entire circumference (360°). The rest of the arterial wall cannot be seen because of shadowing.

were classified according to the number of quadrants with calcification: no calcium, 1° to 90°, 91° to 180°, 181° to 270° and >270° of arc (Fig. 3).

Statistical analysis. The association between categorical factors was tested using a chi-square test. For normally distributed continuous factors, a *t* test was used to compare mean values between the two groups. For data not normally distributed, a Wilcoxon rank-sum test was employed. Stepwise multiple logistic regression was used to test for independently significant factors with a dichotomous outcome. An entry criteria of 0.05 was used with a level of ≤0.10 being necessary to remain in the model. The odds ratio with a 95% confidence interval is reported. Results are expressed as mean value ± SD unless indicated otherwise.

Results

The demographics and clinical characteristics of the patient group were similar to a typical patient group undergoing coronary interventions (Table 1). Of the 183 target lesions, 95 (52%) were located in the left anterior descending, 67 (37%) in the right coronary artery, 12 (7%) in left circumflex and 9 (5%) in the saphenous vein grafts.

Calcification by angiography. Examination of the angiograms revealed calcification at the target lesion site in 63 patients (34%). In 120 patients (66%), no calcification of the target lesion by angiography was reported by either observer in any view. Angiographically detected calcification was more prevalent in older patients, in patients with hypercholesterolemia and in those without diabetes mellitus (Table 1). There were no differences between the patients with and without calcified lesions with regard to gender, presence of unstable angina, history of remote myocardial infarction, hypertension, smoking history and family history of coronary artery disease.

Using angiography, the observers were unable to assess the location (depth) of calcification at 35 (56%) of the 63 sites. For 28 segments in which the location was reported, calcification was deep at 13 sites and superficial at 15 sites. Two orthogonal views adequate for evaluation were available in 44 patients. Calcification was visible in both orthogonal views in 29 patients and in only one view in 15 patients. Calcification was 1+ in 32, 2+ in 27 and 3+ in 4 patients. Two observers reviewed 20 angiograms separately to grade the severity of coronary artery calcification. Kappa statistics showed a close agreement (Cohen's kappa = 0.66).

Ultrasound extent of calcification. Ultrasound examination showed some calcification at target lesions in 138 (75%) of 183 patients, more than twice the number detected by angiography. There were no differences between the demographics and clinical characteristics of those with and without ultrasound-detected calcium, except for absence of diabetes (Table 1). The total arc of calcification was 1° to 90° in 56 patients (41%), 91° to 180° in 52 (38%), 181° to 270° in 22 (16%) and >270° in 8 (6%). The depth of calcification was superficial in 61 patients (44%), deep in 68 (49%) and mixed in 8 (7%).

Agreement: angiography versus ultrasound. When intravascular ultrasound and angiography were compared, there was categoric agreement in classifying target lesions as calcified or noncalcified in only 92 patients. Of these, concordance

Table 1. Demographic and Clinical Characteristics of 183 Patients

		Angiography		Ultrasound	
	Total (n = 183)	No Calcification (n = 120)	Calcification (n = 63)	No Calcium (n = 45)	Calcium (n = 138)
Age (yr)	57.8 ± 10	56.8 ± 10	59.8 ± 10*	57 ± 10	58 ± 10*
Male	155 (85%)	104 (87%)	51 (81%)	36 (80%)	119 (86%)
Unstable AP	98 (54%)	64 (53%)	34 (54%)	25 (56%)	73 (53%)
Prior MI	66 (36%)	46 (38%)	20 (32%)	17 (38%)	49 (36%)
Hypertension	91 (50%)	63 (53%)	28 (44%)	26 (58%)	65 (47%)
Diabetes	28 (15%)	24 (20%)	4 (6%)†	12 (27%)	16 (12%)†
Smoking	110 (60%)	70 (58%)	40 (63%)	24 (53%)	86 (62%)
Hypercholesterolemia	66 (36%)	36 (30%)	30 (48%)†	16 (36%)	50 (36%)
Family history	50 (28%)	33 (28%)	17 (27%)	11 (25%)	39 (29%)

*p = 0.05. †p = 0.02. Data presented are mean value (±SD) or number (%) of patients. AP = angina pectoris; MI = myocardial infarction.

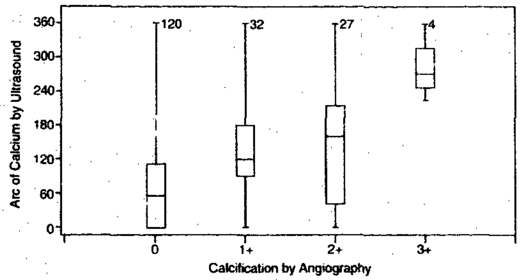


Figure 4. Extent of calcium by intravascular ultrasound and angiography. Calcium by ultrasound is expressed as degree of the arc involved. Angiographically visible calcifications are expressed as 1+ to 3+. **Horizontal lines** = median; **boxes** = 25th percentile; **vertical lines** = range of ultrasound-detected calcium.

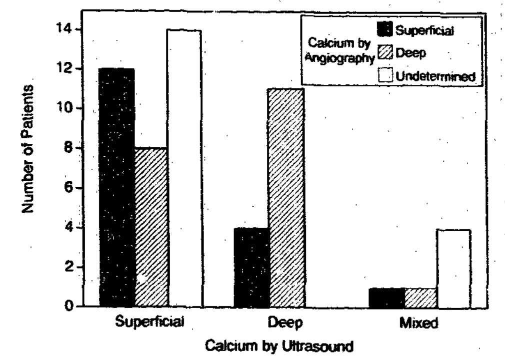


Figure 5. Location (depth) of calcium by ultrasound and angiography.

between ultrasound and angiography in classifying the target site as noncalcified was found in 37 patients. In the other 55 patients with concordant findings, calcification was detected by both imaging modalities. Classification of arteries by angiography and ultrasound was discordant in 91 patients. In 8 of these patients, calcification was detected by angiography, but not by ultrasound. In the other 83 patients, calcification was detected by ultrasound, but not by angiography. In comparison with ultrasound, the sensitivity of angiography in the detection of calcium varied with the arc of involvement. The sensitivity of angiography was 45% in detecting calcification of any degree, increased to 52% for calcium subtending >90° of arc and increased further to 63% if calcium involved >180 degrees of arc. The specificity of angiography in identifying ultrasound-detected calcification was 82%.

A multiple logistic analysis revealed angiographically visible calcification at any site in the coronary artery tree (either the target lesion or remote sites) as an independent predictor of the presence of any ultrasound-detected calcium ($p = 0.001$, odds ratio [OR] 6.2, 95% confidence interval [CI] 1.02 to 14.0). Similarly, angiographically visible calcium at any site in the coronary artery tree was also predictive of >90° ($p = 0.001$, OR 7.9, 95% CI 4.1 to 15.4) and >180° ($p = 0.001$, OR 7.1, 95% CI 3.1 to 13.3) arc of ultrasound calcium.

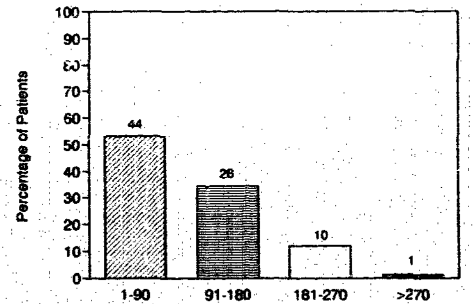
In the 55 patients with target lesion calcification shown by both modalities, the angiographic severity of calcification was 1+ in 30 patients, 2+ in 21 patients and 3+ in 4 patients. The mean arc of calcification by ultrasound was larger in patients with any angiographically visible calcification at target lesion site (175 ± 85° vs. 108 ± 71°, $p = 0.0001$). Similarly, the arc of ultrasonic calcification was greater in patients with 2+ or 3+ angiographic calcium than in those with 1+ calcium (194 ± 84° vs. 159 ± 84°, $p = 0.07$) (Fig. 4). Patients with calcification visible in both orthogonal angiographic views showed a larger arc of calcium by means of ultrasound than those with calcium apparent in only one view (190 ± 89° vs. 143 ± 70°, $p = 0.06$). Angiography was more frequently positive when calcification was superficial by ultrasound (52% vs. 21%, $p < 0.001$).

The depth of calcium by ultrasound and angiography in 55 patients in whom calcification was detected by both modalities is shown in Figure 5. Using ultrasound, calcium was shown to be deep in 15 patients, superficial in 34 and mixed in 6. Using angiography, the location of calcification was shown to be deep in 13 patients and superficial in 13, and could not be determined in 29 patients. Compared with intravascular ultrasound, the sensitivity and specificity of angiography in identifying superficial calcium were 35% and 92%, respectively. In identifying deep calcium, the sensitivity and specificity were 27% and 31%, respectively.

Absence of angiographic calcification. In 120 patients, observers reported no angiographically visible calcification at the target lesion site. Ultrasound confirmed the complete absence of calcification in only 37 (31%) of these 120 patients. In the other 83 (69%) patients, some degree of calcification was detected by ultrasound (108 ± 71°), but was highly variable in extent. In the 83 patients with ultrasonic but not angiographic calcification the calcium subtended <90° of arc in 44 (53%) patients (Fig. 6). Thus, in the cohort with negative angiography, ultrasound-detected calcification was relatively mild in only about half of the subjects.

Within the group of 120 subjects with no apparent calcifi-

Figure 6. Arc of calcium by quartiles in 83 patients with target lesion calcification by intravascular ultrasound but not angiography.



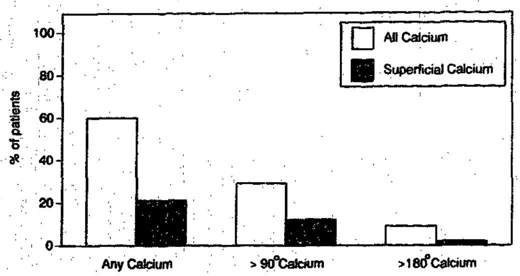


Figure 7. Ultrasound-detected calcium and superficial calcium in 120 patients with no angiographic calcification.

cation on angiography, there were no differences between the demographic or clinical factors of the 83 patients with versus the 37 without ultrasound calcium. Similarly, analyzed as a categorical variable, there were no differences between the clinical characteristics of the 73 subjects with no or <90° and the 47 with >90° of calcium arc.

Of the 120 patients without angiographic target lesion calcification, 30 (25%) had calcification at a nontarget site. The presence of nontarget calcification was more frequent in patients with any degree than in those without ultrasound-detected calcium (35% vs. 2.7%, $p < 0.001$). In 90 patients who had no angiographically visible calcification anywhere in the coronary artery tree, calcium was seen by ultrasound in 54 patients (60%), >90° of calcium arc was detected in 26 patients (29%) and >180° in 8 (9%). In these patients, superficial arcs of calcium were seen less frequently. Any superficial calcium was evident in 19 (21%) of the 120 patients without angiographic target lesion calcification, >90° of superficial calcium in 11 patients (12%) and >180° in 2 (2%) (Fig. 7). Thus, the probability of >90° of superficial calcium in patients without angiographically visible calcification in the coronary artery tree was only 12%. Among all the demographic, clinical and angiographic factors, angiographic calcium at nontarget sites ($p = 0.001$) was the only predictor of ultrasound-detected calcium in these 120 patients without angiographic target lesion calcification.

Discussion

Detection of calcified plaque. In this study, we examined whether careful inspection of angiograms combined with clinical and demographic information could identify patients with significant calcification of coronary target lesions before intervention. The most salient finding is the poor sensitivity for angiography in detection of coronary artery calcification, regardless of its severity. Overall, angiography identifies less than half (45%) of the patients with any ultrasound-detected calcification at coronary lesions targeted for intervention. Angiography correctly recognized calcification in only 52% of patients with ultrasound-documented involvement subtending >90° of the vessel circumference. For patients with extensive calcification (>180° of arc), angiography correctly identified calcium in 63%. Although the sensitivity of angiography in detecting calcification is low, the specificity remains high. The false positive angiographic results in eight patients may be the result of calcium deposits located adjacent to the target lesion site or outside the coronary artery. This may also be the result of failure of ultrasound to detect calcium located deep in the vessel wall. Angiography does not represent an effective method for localizing the depth of calcium deposits. Only one third of patients with superficial and one quarter with deep calcium were identified correctly by angiography. None of the demographic or clinical characteristics were helpful in identifying or localizing lesion calcification. Thus, neither angiography nor patient demographics can reliably predict the extent of lesion calcification.

However, when positive, angiography remains useful as a means of detecting and quantifying calcification. The presence of any angiographic calcium at the site intended for intervention suggests that the target lesion contains a relatively large arc of calcium, on average involving more than two quadrants (>180°). If angiographic calcification was graded as moderate to severe (2+ or 3+) or detected in two orthogonal views, the arc of involvement was also likely to be larger. If present on angiography, calcification was likely to be superficial or mixed in location (79% of patients) rather than deep (24%). Accordingly, interventional operators should anticipate that such lesions may resist directional atherectomy and require higher balloon pressures for dilation during balloon angioplasty. Conversely, in patients with angiographically visible calcification, if the interventional cardiologist contemplates using a device that is adversely affected by target lesion calcification, intravascular ultrasound may be helpful to further characterize the extent and localization of calcification.

Patients without angiographically visible calcification at the target lesion site represent a therapeutic dilemma. Sixty-nine percent of these patients had some calcification by ultrasound, 33% had more than one quadrant calcified and 9% had more than two quadrants involved. These patients with extensive calcification are particularly at risk for a suboptimal result or a dissection. None of the demographic or clinical characteristics were helpful in identifying these patients. The presence of calcium at other sites in the coronary artery tree was the only factor that increased the probability of angiographically unrecognized target lesion calcification. If there was no calcium at any site on the angiogram, the likelihood of >90° of calcium is 29%. However, superficial calcification subtending more than one quadrant was present in only 12% of these patients.

Clinical implications. These findings have important implications for interventional practice. Emerging data demonstrate that the spatial distribution and depth of calcification are important factors in determining the response to revascularization devices (6). Coronary artery calcification constitutes an important risk factor for major arterial dissections after balloon angioplasty (5,6). Recently, we observed a fourfold increase in the risk of dissection for arteries with mixed calcium and soft plaque (95% CI 2.3 to 17.4) (6). Extensive calcification is a relative contraindication to directional atherectomy, particularly if more than one quadrant of the vessel is involved and the calcium is superficially located near the luminal surface (7,8,11). Conversely, extensive calcification does not preclude successful atherectomy if calcium is located deep within the vessel wall. Extensive superficial calcification may also impair luminal gain with coronary stenting owing to resistance to full expansion of the balloon and the stent (12,13). Many reports recommend alternative revascularization techniques, particularly rotational ablation (8,9) for heavily calcified vessels. However, the increased complexity, training and cost of the alternative interventional approaches underscore the need for improved methods for the detection of calcification for better patient selection.

The prevalence of coronary artery calcification in patients with coronary artery disease varied greatly according to the method of detection (3,14–17). In an angiographic meta-analysis, 58% of patients with coronary artery disease had calcification as shown by fluoroscopy (17), whereas an incidence of 79% was reported in a necropsy study (3). We have detected some degree of calcification in 75% of patients. In various reports, demographic and clinical characteristics, such as older age (18,19), long-standing disease (3), hyperlipidemia (20), hypercalcemia, renal failure (21,22) and smoking (16), were associated with coronary artery calcification. However, in the present study, angiographically detected target lesion calcification was more likely in older and hypercholesterolemic patients. Surprisingly, nondiabetics more frequently had calcified lesions than diabetics.

Other investigators have examined the extent and severity of calcification using intravascular ultrasound. In a large study, Mintz et al. (23) examined 1,117 patients before or after a coronary intervention. They reported a 73% incidence of ultrasound-detected coronary calcification, with similar rates of deep and superficial location, as found in the current study. The overall sensitivity of angiography in detecting the presence of target lesion calcium was 48%, similar to our report. Although Mintz et al. used somewhat different imaging devices and grading techniques, their results are similar to our own. Both studies illustrate the insensitivity of angiography in the detection of coronary artery calcification. Together the studies demonstrate the need to perform intravascular ultrasound in future investigations of new interventional devices to better understand the impact of calcified atheroma on the outcome of revascularization.

Study limitations. Our study has several limitations. We did not address the impact of various degrees of ultrasound-detected calcium on the short- and long-term outcome of various interventions. The association between ultrasound-detected coronary artery calcification and the efficacy of various interventional methods rely principally on observational studies. Although echogenic plaque with acoustic shadowing usually represents calcification, we cannot absolutely preclude the possibility that some of these lesions may consist of very dense fibrotic plaques without calcium. At necropsy, calcium deposits are not homogeneous, exhibiting both nodular and plate-like patterns. Because acoustic shadowing precludes measurement of the thickness of calcified plaque, these different patterns cannot be appreciated by ultrasound. We analyzed single images from the most extensively calcified lesion. However, calcium deposits occupy the vessel wall not only axially but also longitudinally. Our study is limited to an analysis of calcification at the most severe part of the target lesion. Although quantitative assessment of the longitudinal extent of calcification may affect the probability of success of a percutaneous intervention, calibrated, mechanical "pullback" devices were not routinely used in our patients to allow this type of analysis. Digital fluoroscopy, which is becoming increasingly available, may enhance the sensitivity of angiography for detecting calcification.

Conclusions. Despite the poor sensitivity in the overall detection of coronary artery calcification, angiography does provide useful information to assist in identifying patients who need intravascular imaging for further evaluation. The presence of target lesion calcification on the angiogram suggests a large arc of superficial calcium. If calcification is 2+ or 3+ or observed in two views, the calcified arc by ultrasound is likely to be even larger. Thus, patients with angiographically apparent calcification probably do not require ultrasound imaging unless the precise location and extent of calcium need to be known. In patients without angiographically visible target lesion calcification, calcium at a remote site in the coronary artery tree increases the likelihood of target lesion calcification detection by ultrasound. These patients may benefit from further evaluation by ultrasound to determine the presence, extent and depth of calcium. Patients without angiographically visible calcification anywhere in the coronary artery tree have a relatively low likelihood of a target lesion with >90° of superficial calcification. Accordingly, as knowledge expands regarding the impact of calcification on the results of revascularization procedures, the combination of angiographic examination and selective ultrasound imaging may guide the interventional practitioner.

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