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iREVIEWS

STATE-OF-THE-ART PAPER

Quantification of Coronary Arterial Stenoses by Multidetector CT Angiography in Comparison With Conventional Angiography

Methods, Caveats, and Implications

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Multidetector computed tomography (MDCT) is a rapidly evolving technology for performing noninvasive coronary angiography. Despite good sensitivity and specificity for detecting significant coronary artery disease in patients, disagreement on individual coronary arterial stenosis severity is common between MDCT and the current gold standard, conventional angiography. The reasons for such disagreement are numerous, but are at least partly inherent to MDCT's modest spatial and temporal resolution at present. Less well acknowledged, however, is the fact that MDCT and conventional angiography are fundamentally different technologies, rendering good agreement on the degree of lumen narrowing rather unrealistic, given both of their respective limitations. Discrepant stenosis assessment by MDCT and conventional angiography receives remarkable attention, whereas its significance for patient outcome is less certain. On the other hand, the ability to noninvasively assess coronary arterial plaque characteristics and composition in addition to lumen obstruction shows strong promise for improved risk assessment and may at last enable us to move beyond mere coronary stenosis assessment for the management of patients with coronary artery disease. (J Am Coll Cardiol Img 2011;4:191–202) © 2011 by the American College of Cardiology Foundation

Coronary angiography using multidetector computed tomography (MDCT) is used increasingly for the evaluation of coronary artery disease (CAD). Numerous clinical studies have documented high diagnostic accuracy of current-generation MDCT. For detection of obstructive CAD, areas under the receiver-operator characteristic curve average 0.98 for single-center studies and range between 0.93 and 0.96 for multicenter studies (1–6). Currently, MDCT is predominantly being used for ruling out obstructive CAD in symptomatic patients with low to intermediate pre-test probability of disease. This indication, for which there is broad endorsement from major societies (7,8), is supported by consistently high negative predictive values for detecting obstructive CAD.

In the most common scenario for the application of MDCT, the study is negative for obstructive CAD, and the management is fairly straightforward. The situation is more cumbersome if the MDCT study is suggestive of significant CAD. Although the negative pre-

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dictive values have been remarkably consistent among studies, the positive predictive values have not, ranging from 64% to 91% on a patient-level analysis among the 3 major multicenter studies (4–6). Variations in disease prevalence partly explain the differences. However, when applied to the low- to intermediate-risk population for which MDCT is advocated, a false positive rate of up to 35% per patient (9) is common even in experienced centers and may be even higher at sites with less expertise. Careful assessment of stenosis severity is a prerequisite to minimize misinterpretation in coronary computed tomography (CT) angiography. This report reviews the methods for coronary stenosis quantification by MDCT as well as conventional angiography and discusses the reasons and implications for discrepant findings among these modalities for coronary arterial lesion assessment.

ABBREVIATIONS AND ACRONYMS

CAD = coronary artery disease

CT = computed tomography

IVUS = intravascular ultrasound

MDCT = multidetector computed tomography

MLA = minimum lumen area

MLD = minimum lumen diameter

QCA = quantitative coronary angiography

SPECT = single-photon emission computed tomography

Coronary Arterial Stenosis Assessment by MDCT

General considerations. There are multiple ways of assessing coronary artery lumen for stenosis. Most commonly, an estimate of luminal diameter stenosis is used, less frequently, area stenosis, minimum lumen diameter (MLD), or minimum lumen area (MLA) is considered. When correlating with hemodynamic evaluation, i.e., coronary flow or myocardial perfusion assessment, estimating lumen area appears preferable to diameter evaluation (10–12). This is intuitive when considering irregular arterial lumen shapes for which diameter assessment is difficult (13). Since irregular lumen shapes are not uncommon at lesion sites, diameter assessment may misrepresent true lumen narrowing in many instances (14,15). Absolute assessment, i.e., MLA, also eliminates an important error source, the selection of an appropriate reference segment, and thus, appears attractive in several ways. However, almost all clinical studies for the evaluation of coronary arterial stenoses used diameter assessment since the gold standard, i.e., invasive coronary angiography, typically employs diameter measurements for its evaluation. For the same reason, coronary assessment is based on diameter evaluation in clinical practice. Diameter assessment by MDCT, therefore, will be the preferred lumen evaluation for the near future, whereas lumen area assessment may be used more frequently once its feasibility and superiority have been conclusively shown in clinical practice.

Stenosis evaluation. VISUAL STENOSIS ESTIMATE. Because of its convenience and speed, visual stenosis estimation is the most commonly performed coronary lumen assessment in clinical practice, both for coronary CT angiography as well as for invasive coronary angiography. The observer interrogates the lesion in multiple views and identifies the MLD. The observer then compares the MLD to an arterial diameter at an appropriate reference site, i.e., a nondiseased arterial segment in closest proximity to the lesion, preferably with no branch vessels in between (Fig. 1). Maximum diameter stenosis severity can be graded using either a qualitative or semiquantitative stenosis grading system, for example, mild, moderate, severe, or 1% to 24%, 25% to 49%, and so on (16–18). Tables 1 and 2 provide the stenosis grading recommended by the Society of Cardiovascular Computed Tomography.

QUANTITATIVE STENOSIS ESTIMATE. Most cardiac CT workstations allow quantification of coronary arterial stenoses. Measurements of lumen dimensions can be performed manually or semiautomatically. For manual assessment, the reader uses an internally calibrated ruler or caliper, and determines luminal diameters guided by visual assessment. The diameters can be drawn using cross-sectional or longitudinal lumen display (Figs. 2 and 3), both appear similarly accurate when compared with quantitative coronary angiography (QCA) (18). Drawing the diameters on a cross-sectional display has the advantage of assessing all lumen borders in 1 view, whereas longitudinal views only allow the evaluation from 1 particular viewing angle, requiring the assessment of multiple views to ascertain the most adequate display. One important caveat for quantitative stenosis assessment by MDCT is that window and level settings may influence the displayed luminal diameter and area (17).

SEMIAUTOMATED ARTERIAL CONTOUR DETECTION. In addition to manual measurements, most workstations also offer semiautomatic lumen contour detection for coronary CT angiography (Fig. 4). While these contour detection algorithms have not been adequately validated, initial data are encouraging, as similar accuracies for automated and manual assessments are being reported (19,20). Of note, semiautomatically generated lumen assessment by MDCT resulted in better positive predictive values for diagnosing CAD than visual assessment in comparison to

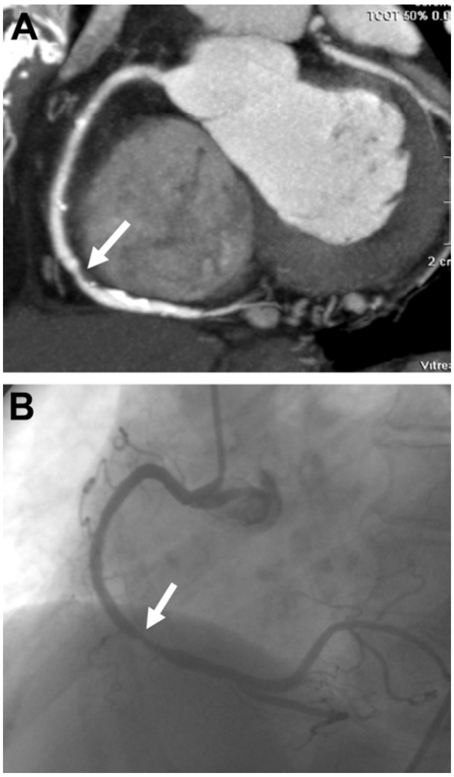

Figure 1. Visual Stenosis Assessment

The image displays a thick-slab, maximum-intensity projection showing a stenosis **(arrow)** in the distal right coronary artery and the corresponding conventional angiographic view **(A)**. By visual assessment, the lesion was estimated as 50% diameter stenosis on both computed tomography (CT) and conventional angiography **(B)** when compared with normal reference diameter proximal and distal to the stenosis.

QCA (21,22). However, current-generation contour detection algorithms still require manual editing, and more data are needed to assess their performance in more challenging populations before they can be adopted more broadly. With ongoing refinements, contour detection algorithms likely will lead to more reproducible and possibly more accurate luminal assessment as compared with visual evaluation.

LUMEN AREA STENOSIS ASSESSMENT. Measurement of MLA is infrequently used for coronary arterial stenosis evaluation at present. However, assessment of lumen area has distinct advantages over diameter measurements, i.e., less dependency on viewing angle, closer correlation with indices of hemodynamic significance, and less reliance on reference sites. In a comparison study of MLA quantification using manually traced data on cross-sectional reconstructions, 64-slice CT was found to have good correlation to intravascular ultrasound

Table 1. Recommended Qualitative Stenosis Grading

Descriptive Lumen Obstruction	Qualitative Stenosis Grading
Normal	Absence of plaque/no luminal stenosis
Minimal	Plaque with negligible impact on lumen
Mild	Plaque with no flow-limiting stenosis
Moderate	Plaque with possible flow-limiting disease
Severe	Plaque with probable flow-limiting disease
Occluded	

Qualitative coronary arterial stenosis grading as recommended by the Society of Cardiovascular Computed Tomography. Adapted, with permission, from Raff et al. (17).

(IVUS) (r = 0.88) but with rather large variations of 42% to 44% for individual stenoses (23). Another study found a fairly good correlation (r = 0.75) of MDCT with IVUS for lumen assessment in a small study of 11 patients (24). Further research is necessary to establish a role for routine MLA measurements in clinical practice, particularly in the setting of fair image quality and advanced coronary arterial calcification.

COMMON SCENARIOS LEADING TO FALSE NEGATIVE/POSITIVE FINDINGS. False negative results, i.e., missing significant coronary arterial stenoses, tend to occur in smaller coronary arterial segments and at arterial bifurcations (25). Figure 5 shows an example of an initially missed lesion in an ostial obtuse marginal branch. Confirming findings in multiple orientations and viewing angles is usually necessary to avoid these mistakes. In this particular case, the lesion was only apparent by MDCT when multiple views were obtained (Fig. 5D). False positive reads are often related to technical problems and motion artifacts, leading to suboptimal image quality. The necessity to confirm any MDCT findings in several views and on image reconstructions from multiple cardiac phases cannot be overemphasized. The presence of calcified plaques is one of the leading

Table 2. Recommended Quantitative Stenosis Grading

Descriptive Lumen Obstruction	Quantitative Stenosis Grading
Normal	Absence of plaque/no luminal stenosis
Minimal	Plaque with <25% stenosis
Mild	25%–49% stenosis
Moderate	50%–69% stenosis
Severe	70%–99% stenosis
Occluded	

Quantitative coronary arterial stenosis grading as recommended by the Society of Cardiovascular Computed Tomography. Adapted, with permission, from Raff et al. (17).

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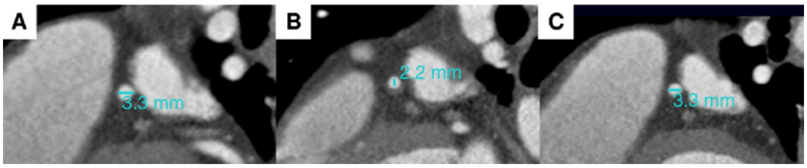

Figure 2. **Quantitative Stenosis Assessment**

Three cross-sectional computed tomography (CT) images of the proximal left anterior descending coronary artery (LAD) are shown demonstrating cross-sectional measurements of percentage diameter stenosis, calculated by comparing minimal luminal diameter at the site of maximal stenosis with normal reference diameters proximal and/or distal. **(A)** shows the LAD lumen proximal to stenosis. **(B)** shows the LAD lumen at the site of minimum lumen diameter. **(C)** shows the LAD lumen distal to the stenosis. Percentage diameter stenosis = (3.3 mm − 2.2 mm)/3.3 mm = 33%. It must be noted that window-level settings may influence the displayed luminal diameter measurements.

causes of misjudging lumen narrowing because the calcifications can obscure the contrast-filled lumen, resulting most frequently in overestimation of stenosis degree (Fig. 6) (26). Adjusting the window level, using appropriate reconstruction kernels, and post-processing settings (e.g., thin-slice display) may help in visualizing the lumen in calcified segments (25,27).

Visual versus quantitative stenosis assessment. Almost all clinical studies addressing the diagnostic accuracy of MDCT compared with catheter-based angiography utilized visual estimates by MDCT and quantitative assessment by invasive angiography. In general, visual inspection overestimates coronary arterial stenosis severity compared with QCA by 10 to 20 points, for example, a 70% stenosis by visual conventional angiographic estimate, often measures only 50% to 60% by QCA (28). Accordingly, a coronary stenosis quantified as 50% to 60% by QCA typically corresponds to a hemodynamically significant lesion by fractional flow reserve, an invasive measure of coronary blood flow (29,30). This discrepancy between visual and quantitative assessment of coronary arterial stenoses by conventional angiography may at least partly explains the tendency in clinical validation studies for MDCT to overestimate stenoses compared with QCA. The CorE-64 (CORonary Evaluation Using 64 Detectors) trial is the only major clinical study that employed both visual and quantitative MDCT analysis in all subjects (4). In contrast to most other reports, MDCT analysis generally did not overestimate stenoses compared with QCA, leading to greater specificity and positive predictive values. Although CorE-64 showed that both visual and quantitative MDCT assessment can be performed with similar accuracy, it is likely that the quantitative assessment induced a bias for the visual inspection to lower the stenosis grade, resulting in less overestimation. Furthermore, a conscious effort was made by QCA-experienced MDCT readers in CorE-64 to match the anticipated stenosis grade by QCA, which also lowered the degree of MDCT overestimation. For the same reasons, however, sensitivity and negative predictive values were lower.

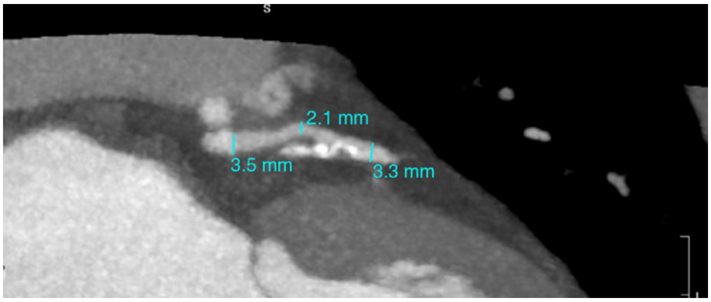

Figure 3. **Influence of Reference Site Selection**

A thick-slab (3- to 5-mm) maximum intensity projection computed tomography (CT) image is shown of the left anterior descending coronary artery along the long axis of the vessel to create an angiographic-like view. Compare the luminal diameter at the stenosis with a normal reference site, either proximal or distal to the stenosis. Note that in this example, because the measured normal distal reference diameter is slightly smaller than the proximal reference diameter, the calculated percentage diameter stenosis result will vary depending on which reference site is selected. The percentage diameter stenosis using the proximal reference site = (3.5 mm − 2.1 mm)/3.5 mm = 40%. The percentage diameter stenosis using the distal reference site = (3.3 mm − 2.1 mm)/3.3 mm = 36%.

The choice of visual versus quantitative assessment of coronary stenoses depends on its application and on the reference standard's mode of lumen assessment. In clinical practice, visual MDCT assessment typically suffices as it is compared to visual stenosis assessment by conventional angiography in the cardiac catheterization laboratory. In research on the other hand, it appears more suitable to compare quantitative MDCT assessment to quantitative conventional angiographic evaluation, i.e., QCA. With the ease of stenosis quantification by MDCT, we likely will see a trend to establish quantitative MDCT evaluation as the routine assessment also for clinical applications, particularly if variability of reading results can be reduced (22).

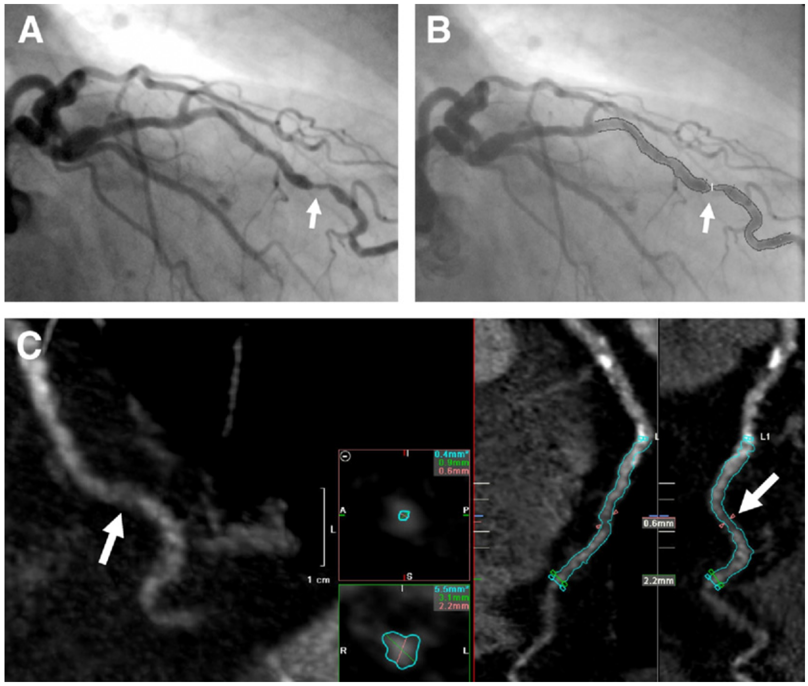

Figure 4. Stenosis Assessment Using a Lumen Contour Detection Algorithm

(A) shows a stenosis in the distal LAD **(arrow)** by conventional angiography. **(B)** shows the assessment of this stenosis by quantitative coronary angiography (QCA). **(C)** shows a multiplanar reformatted image (MPR) by multidetector computed tomography (MDCT) of the same stenosis as well as a curved MPR with lumen contour tracing and stenosis assessment. Note diffuse atherosclerosis within the artery, external arterial remodeling at the lesion site (which is not apparent by conventional angiography), and suboptimal image quality. Although the minimum lumen diameter was assessed similarly by these 2 technologies (0.61 mm by QCA vs. 0.60 mm by MDCT), percentage stenosis was 79% by QCA and 70% by MDCT because of different reference diameters (2.88 vs. 2.2 mm). Note that the lumen at the distal reference site is noncircular as seen in the 2 orthogonal MDCT curved MPR views and cross-sectional views, leading to overestimation of the reference diameter by QCA.

MDCT Versus Conventional Angiography for Stenosis Quantification

Disadvantages of MDCT. It must be emphasized that MDCT and conventional angiography are fundamentally different imaging modalities with specific strengths and weaknesses that greatly influence any comparison of respective coronary assessment. Both the spatial (0.2 mm vs. 0.35 to 0.6 mm) and temporal (5 to 10 ms vs. 80 to 175 ms) resolution typically encountered in clinical practice are currently superior for conventional angiography (31).

Furthermore, and of major importance, MDCT is much more vulnerable to suboptimal scan conditions at present. Higher heart rates (>65 beats/min) and larger patients (body mass index >40) frequently lead to decreased image quality, which reduces the diagnostic accuracy (32). Although a recent phantom study showed that under ideal conditions, CT has the potential to quantify coronary stenoses at least as accurately as fluoroscopic angiography—with an advantage for lesions with noncircular geometry (14)—this may not necessarily be transferred to the in vivo situation if lower image quality is found in patient investigations (33).

Furthermore, image display settings, such as adjustments of window level and depth, significantly influence interpretation. Probably the greatest limitation for MDCT currently is its difficulty in visualizing the arterial lumen in the presence of severe coronary calcification. Analysis of the CorE-64 study showed that coronary arterial segment calcification was associated with reduced diagnostic accuracy (34). Fortunately, severe coronary calcification is not frequently encountered in the target population for MDCT, i.e., low-intermediate pretest probability for obstructive CAD. Even in patients referred for invasive conventional angiography, thus, a higher-risk population, less than 10% of coronary atherosclerotic plaques are densely calcified (35). Last, radiation exposure has been cited as a major concern for the use of MDCT. However, ongoing advancements, particularly prospective scan triggering, have led to drastic reductions in radiation doses, increasingly to levels even lower than conventional angiography (36,37).

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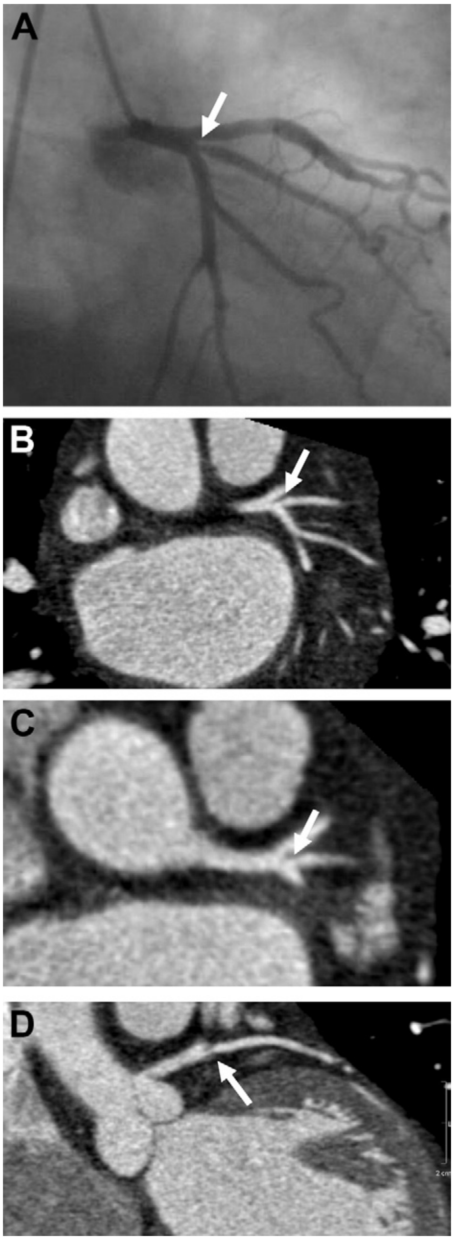

Figure 5. False Negative MDCT Reading of an Ostial Coronary Arterial Stenosis

(A) Shown is a discrete stenosis of the ostial first obtuse marginal branch of the left circumflex coronary artery by conventional angiography. Quantitative coronary angiography assessment suggests a 67% lumen narrowing. **(B to D)** Shown are multidetector computed tomography (MDCT) images of the same arterial segment. On standard image selection, the severity of the lumen narrowing is not apparent **(B and C)**. Only a few views reveal the true stenosis **(D)**, which shows noncalcified plaque causing significant lumen narrowing **(arrow)**.

Disadvantages of conventional angiography. Conventional angiography is inherently limited by its 2-dimensional vessel display, allowing only limited number of projections, which, importantly, are determined at image acquisition (13). Although MDCT allows the selection of any given viewing angle for the assessment of an arterial segment *after* image acquisition, the QCA reader is restricted to the few planes that were obtained in the catheterization laboratory. Although, ideally, 2 orthogonal projections are available for any coronary arterial stenosis evaluation, vessel overlap frequently allows only 1 adequate view for quantification (38). Furthermore, foreshortening is frequently present, leading to misrepresentation of coronary anatomy, which may not be appreciated in its milder forms (39,40). The limitations of a 2-dimensional arterial segment display have been well described (13). When compared with histopathology (41) or IVUS (42,43), conventional angiography revealed significant limitations in displaying coronary anatomy accurately. These limitations are particularly relevant with noncircular lesion geometries, which account for 20% to 30% of stenoses (14).

Since conventional angiography is considered the gold standard for coronary arterial stenosis assessment, its limitations introduce uncertainty regarding the soundness of MDCT validation studies. It is conceivable, that at least in a subset of lesions, MDCT analysis is actually more accurate than QCA, which, however, is dismissed in an analysis with QCA as the gold standard. In a study using IVUS as the gold standard, MDCT indeed had greater accuracy than QCA for estimating lumen obstruction (23).

Beyond stenosis assessment. A major advantage of MDCT over conventional angiography is its ability to assess the entire arterial wall, including visualization of atherosclerotic plaque. Direct inspection of plaque allows detecting CAD at early stages, assessment of total atherosclerotic plaque burden, and plaque characterization. Although such ability may turn out to be more valuable than coronary stenosis assessment (44–46), it may currently decrease MDCT's diagnostic accuracy in comparison with conventional angiography since it may contribute to overestimating disease, particularly when the readier is less experienced (25,47).

Observer Bias for Assessing Coronary Arterial Stenoses

Conventional angiography. Interobserver variability for the assessment of obstructive CAD by conventional angiography is substantial, particularly with visual estimates. Even when performed by experienced cardiologists (48), differences of ±20% are common among readers, especially for intermediate grade (40% to 70%) stenoses (49). In 1 study, visual estimates of moderately severe stenoses were on average 30% greater than actual percentage diameter stenosis (50). The severity of lesions >50% tended to be overestimated by visual reading, whereas lesions <50% tended to be underestimated (50). Importantly, this variability may lead to significant differences for deciding whether or not to proceed with coronary revascularization (51). Even quantitative assessment with conventional angiography, i.e., QCA, may yield substantial variability in results, depending on the software algorithm used and the extent of user input (52–54).

MDCT. Observer variability for MDCT is less well established but appears to be similarly problematic. Analysis of the CorE-64 study showed that significant differences were found, particularly for specificity, independent of visual or quantitative assessment (55). Other recent evidence also points to significant differences between core laboratory and site readings (56). These findings raise the concern that published accuracy data for MDCT may not be representative of clinical practice. Reader experience and angiographic training appear to be of fundamental importance for reading stenoses by MDCT with acceptable accuracy. However, similar to conventional angiography, disagreement about the presence or absence of obstructive CAD by MDCT is common even among experienced, expert readers. Accordingly, it seems prudent that both clinical investigators and practitioners should acknowledge the extent of observer bias and move away from binary end points and adopt broader categories for stenosis assessment. Ongoing improvement of arterial contour detection algorithms may eventually provide stenosis assessment with low variability (22).

Reference site selection. Selecting the appropriate reference site for lesion assessment substantially influences the resulting stenosis value. Unfortunately, there is considerable variability in choosing the reference site(s), thus introducing another variable when comparing reads between observers and, particularly, between imaging modalities. In general, there are 3 commonly used methods for selecting a reference lumen site for stenosis assessment: single as well as dual reference selection at disease-free sites within the same coronary arterial segment, and third, a reconstructed lumen dimension at the lesion site serving as reference. A single reference site is most commonly chosen for visual stenosis assessment, whereas dual reference sites are typically selected when a quantitative approach is pursued. In either case, there is considerable subjectivity involved in such selection, opening the room for variability and bias (Figs. 3 and 4). This is particularly problematic when 2 fundamentally different imaging modalities are employed, as is the case with MDCT and conventional angiography. IVUS imaging revealed the insensitivity of conventional angiography for detecting CAD in segments with external arterial remodeling (57,58). Since MDCT, like IVUS, is capable of visualizing not just the lumen but the entire arterial wall, even mild disease in vessel segments with arterial remodeling is apparent (23). Accordingly, observers may select different sites within the arterial segment for reference because they may or may not see atherosclerotic disease (59).

Figure 6. **Influence of Cardiac Motion and Coronary Calcium on Diagnostic Accuracy**

A multidetector computed tomography (MDCT) image of a right coronary artery (RCA) is shown demonstrating a motion artifact in the mid-portion of the vessel **(dashed arrow)**, which makes it difficult to assess the degree of lumen stenosis. Furthermore, there is a calcified plaque in the mid-RCA **(arrow)** that obscures the arterial lumen leading to overestimation of stenosis severity. By conventional angiography, no stenosis is seen at the site of the motion artifact **(dashed arrow)** and only a mild stenosis is seen at the site of the calcified plaque **(arrow)**.

The third method of reconstructing the lumen at lesion site is almost exclusively used by QCA algorithms and only very recently introduced to MDCT (22). Since QCA is almost invariably used as the gold standard for coronary arterial stenosis assessment, the inability of MDCT to match reference determination by QCA creates a disadvantage for MDCT validation studies and is an additional source of error. A comparison of MLD or MLA would eliminate such bias, but unfortunately, such assessment is rarely performed.

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Reporting Formats

Based on the foregoing, reporting coronary arterial stenoses by MDCT should allow sufficient room to account for error margins by MDCT *and* the gold standard for comparison, i.e., conventional angiography. Thus, rather than comparing actual percentage stenoses, broad ranges should be provided (17).

The reporting physician should also be clear on what is meant when describing a "significant" or "obstructive" lesion. In the published reports, a 50% threshold is typically considered significant because QCA is employed. In clinical practice, the final assessment in regard to the degree of stenosis severity is most commonly made in the cardiac catheterization laboratory using visual assessment, for which a 70% threshold is commonly used for determining significance. The recommended reporting format for coronary arterial stenoses by MDCT is provided in Tables 1 and 2.

Functional Relevance of Coronary Arterial Stenosis Detection by CT or QCA

The correlation between coronary arterial anatomy assessment by conventional angiography and coronary flow or ischemia evaluation has been modest to poor. Heller and others used both coronary flow reserve and single-photon emission computed tomography (SPECT) compared with QCA (60). Although they found a modest relationship between diameter stenosis by conventional angiography and coronary flow reserve, the variability, particularly in the intermediate range (40% to 70%) was substantial. Furthermore, neither a 50% nor a 70% threshold by QCA could predict stress-induced ischemia with reasonable accuracy. Similar results were reported for QCA and fractional flow reserve (30,61). On the other hand, IVUS assessment yielded greater than 90% diagnostic accuracy for detecting flow-limiting lesions as determined by coronary flow reserve or SPECT (62,63). These findings raise the question of whether a more accurate tool for stenosis assessment may more reliably predict myocardial ischemia. Since MDCT shares many of the favorable aspects of IVUS, i.e., cross-sectional lumen assessment, plaque visualization, and so on, MDCT may be a promising tool for noninvasive determination of flow-limiting coronary arterial stenoses. The preliminary results for stenosis assessment by MDCT and its correlation with hemodynamic significance, however, have been disappointing. Meijboom et al. (61) reported only minimal better performance of MDCT versus QCA for predicting flow-limiting stenoses by fractional flow reserve, with both performing poorly. Sato et al. (64) reported a diagnostic accuracy of 93% for MDCT to detect perfusion defects by SPECT when using minimum cross-sectional area, but only 83% for percentage stenosis, with both methods exhibiting significant scatter for data in the intermediate stenosis range. Gaemperli et al. (65) presented similar areas under the receiver-operator characteristic curves for detecting SPECT perfusion defects by QCA (0.87) and 64-slice CT (0.88). Recently, on the other hand, Rinehart et al. found an excellent correlation of MDCT stenosis assessment and FFR indices of hemodynamic significance (66).

It is possible that with refinements of methods, for example, automatic lumen area detection, and further advancements of MDCT technology, a more consistent anatomic correlate to hemodynamic significance will be found. On the other hand, those attempts may turn out to be futile because of the complexity of factors involved causing myocardial ischemia in addition to lumen narrowing, for example, lesion configuration, lesion length, collateral flow, endothelial function, and so on (67). Thus, a combination of anatomic and physiologic assessment may be necessary in most, if not all, cases for a comprehensive evaluation of CAD. Fortunately, recent advancements in MDCT stress perfusion imaging may allow comprehensive coronary assessment, i.e., anatomic and physiologic, using the same technology (68,69).

What Assessment of Coronary Artery Disease Matters Most?

Stress-induced ischemia is believed to be among the most powerful predictors of outcome in patients with stable CAD (70,71). Interestingly, the bulk of evidence supporting this notion is based on retrospective analyses. No large-scale, randomized clinical study conclusively showed superiority of ischemia assessment over coronary anatomy evaluation. A substudy of the COURAGE trial suggested worse outcome for patients with large ischemic burden; however, these results failed to achieve statistical significance when adjusted for randomized treatment (72). Importantly, it remains unclear, to what extent inducible ischemia itself poses a risk of adverse events, and to what extent inducible ischemia is merely a surrogate for more advanced CAD. The relationship between coronary atherosclerotic plaque burden and cardiac event risk is well established using coronary calcium scoring (73,74). Recently, the assessment of coronary calcification was shown to be incremental to an ischemia score by SPECT (75). Studies in increasing numbers suggest that assessing the presence and severity of CAD, as well as the atherosclerotic plaque characteristics, using MDCT coronary angiography provides at least similar, possibly even superior prognostic information compared with SPECT and invasive coronary angiography (74,76–82). Integrating information on total coronary atherosclerotic plaque burden and number and location of stenoses, plaque characterization is likely more important than mere stenosis assessment (79). Despite the lack of evidence that small differences in stenosis assessment alter patient outcome, the bulk of published reports comparing MDCT with conventional angiography concentrates on the accuracy of coronary arterial stenosis assessment. During the upcoming years, we will need to focus on the impact of MDCT imaging on patient management and outcome compared with traditional strategies. Given the consistency of very favorable prognostic data by MDCT compared with stress testing, we may see a major shift in the management of patients with suspected CAD.

Conclusions

MDCT allows accurate, noninvasive identification of patients with CAD compared with conventional angiography. However, disagreement on coronary arterial stenosis severity is common between MDCT and conventional angiography, as it is between conventional angiography and other coronary imaging modalities, such as IVUS. Reasons for this disagreement include variability in image quality, limited reader experience, variability in reference site selection, and poorer spatial resolution of MDCT. However, inconsistency of conventional angiography readings and limitations as a 2-dimensional technique are important reasons for discrepant results between MDCT and conventional angiography that are less acknowledged. Thus, perfect agreement on a stenosis-to-stenosis level of comparison is rather unrealistic, and importantly, of uncertain relevance for patient outcome. Assessment of *total* (calcified and noncalcified) coronary atherosclerotic plaque burden, number of lesions and location, as well as plaque characterization, show strong promise for superior prognostic impact than mere lesion quantification and thus, deserve more of our attention. In the upcoming years, we need to evolve from focusing on lumen stenosis to a comprehensive assessment of CAD and its impact on patient outcome.

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