Circulation. 1995;91:2174-2183

(*Circulation.* 1995;91:2174-2183.)

Articles

Comparative Validation of Quantitative Coronary Angiography Systems

Results and Implications From a Multicenter Study Using a Standardized Approach

Presented in part at the 66th Scientific Sessions of the American Heart Association, Atlanta, Ga, November 8-11, 1993.

David Keane, MB, MRCPI; Jürgen Haase, MD, PhD; Cornelis J. Slager, PhD; Eline Montauban van Swijndregt, MSc; Kenneth G. Lehmann, MD; Yukio Ozaki, MD, PhD; Carlo di Mario, MD, PhD; Richard Kirkeeide, PhD; Patrick W. Serruys, MD, PhD

From the Cardiac Catheterization, Intracoronary Imaging, and Experimental Cardiology Laboratories, Thoraxcenter, Erasmus University, Rotterdam, the Netherlands, and the Division of Cardiology (R.K.), Health Science Center, University of Texas, Houston.

Correspondence to Prof P.W. Serruys, MD, PhD, FESC, Department of Interventional Cardiology, Thoraxcenter, Erasmus University, PO Box 1738, 3000 DR Rotterdam, Netherlands.

Abstract

Background Computerized quantitative coronary angiography (QCA) has fundamentally altered our approach to the assessment of coronary interventional techniques and strategies aimed at the prevention of recurrence and progression of stenosis. It is essential, therefore, that the performance of QCA systems, upon which much of our scientific understanding has become integrally dependent, is evaluated in an objective and uniform manner.

Methods and Results We validated 10 QCA systems at core laboratories in North America and Europe. Cine films were made of phantom stenoses of known diameter (0.5 to 1.9 mm) under four experimental conditions: in vivo (coronary arteries of pigs) calibrated at the isocenter or by use of the catheter as a scaling device and in vitro with 50% contrast and 100% contrast. The cine films were analyzed by each automated QCA system without observer interaction. Accuracy and precision were taken as the mean and SD of the signed differences between the phantom stenoses, and the measured minimal luminal diameters and the correlation coefficient (r), the SEE, the y intercept, and the slope were derived by their linear regression. Performance of the 10 QCA systems ranged widely: accuracy, +0.07 to +0.31 mm; precision, ±0.14 to ±0.24 mm; correlation (r), .96 to .89; SEE, ±0.11 to ±0.16 mm; intercept, +0.08 to +0.31 mm; and slope, 0.86 to 0.64.

Conclusions There is a marked variability in performance between systems when assessed over the range of 0.5 to 1.9 mm. The range of accuracy, intercept, and slope values of this report indicates that absolute measurements of luminal diameter from different multicenter angiographic trials may not be directly comparable and additionally suggests that such absolute measurements may not be directly applicable to clinical practice using an on-line QCA system with a different edge detection algorithm. Power calculations and study design of angiographic trials should be adjusted for the precision of the QCA system used to avoid the risk of failing to detect small differences in patient populations. This study may guide the fine-tuning of algorithms incorporated within each system and facilitate the maintenance of high standards of QCA for scientific studies.

Key Words: angiography • coronary disease • stenosis

Introduction

Clinical trials incorporating quantitative coronary angiography (QCA) have made a significant impact on the practice of interventional cardiology. They have reported the results of vessel size, lesion severity, and short- and long-term angiographic outcome of patients undergoing interventional procedures. On the basis of the BENESTENT, STRESS, CAVEAT, and CCAT trials, angiographic guidelines have been proposed for the application of interventional devices.[1] [2] [3] [4] Furthermore, on the basis of restenosis prevention studies such as MARCATOR, PARK, and the US Angiopeptin trial and of progression-regression studies, pharmacological agents have been deemed to be ineffective because by the QCA approach a difference in minimal luminal diameter at follow-up has not been detected.[5] [6]

The results of these trials, however, have been generated by different off-line QCA systems. It is not known whether their results are all of equal reliability and to what extent each system overestimates or underestimates the true coronary dimensions. To determine the reliability of the angiographic results of interventional, restenosis, and progression-regression trials, a validation of 10 QCA systems at major core angiographic laboratories in North America and Europe (including the core laboratories that performed the QCA for all of the above-mentioned trials) was undertaken.

QCA systems with poor precision may fail to detect small but significant differences in study populations, whereas QCA systems with poor accuracy may provide misleading results of absolute measurements of minimal luminal diameter. The results of studies based on unreliable QCA systems may not be directly comparable to those of more reliable systems. To render the results of angiographic studies meaningful and universally applicable, it is important that QCA systems be validated in a systematic and standardized fashion. Results of single-center validation studies will vary according to the individual characteristics of the models of the phantom stenoses used and their radiographic acquisition.[7] [8] [9] [10] Without a standardized approach to validation, it becomes difficult to assess to what degree individual angiographic studies are reliable, the significance of their failure to detect relative changes in minimal luminal diameter, and how much weight should be attributed to absolute values of minimal luminal diameter derived from individual QCA systems. Furthermore, it is only by detailed validation studies that errors in QCA measurements can be identified and thereby provide guidance for the refinement of QCA systems.

To assess the QCA systems under radiographic conditions reflecting clinical practice in addition to those of optimal radiographic acquisition, phantom stenoses of known diameter were used as a reference both in vivo (after insertion in the coronary arteries of pigs) and in vitro (Plexiglas blocks). The QCA systems were assessed by their measurement of the absolute value (in millimeters) of the minimal luminal diameter within the artificial stenoses, which has previously been shown to be more reliable than relative measures (percent diameter stenosis) of coronary artery dimensions based on the definition of a reference contour.[11] [12] [13]

Methods

Phantom Stenoses

The phantom stenoses used in vivo as well as in vitro consisted of radiolucent acrylate and polyamide cylinders with precision-drilled circular lumens 0.5, 0.7, 1.0, 1.4, and 1.9 mm in diameter. Optical calibration of the stenosis channels using 40-fold magnification gave a tolerance of 0.003 mm. Parallel to the stenosis lumen, a second lumen 1.3 mm in diameter was drilled in the cylinders to enable their attachment to the tip of 4F Fogarty catheters (Vermed). The lumens of the Fogarty catheters contained a removable metallic stylet, which aided the intracoronary insertion of the phantoms as well as their positioning in the radiographic isocenter. Details of our experimental approach to QCA validation have been described.[14] [15] [16]

In Vivo Studies

The procedures followed were in accordance with institutional guidelines for animal studies. The phantom stenoses were inserted into the coronary arteries of anesthetized Yorkshire pigs (45 to 50 kg). Twelve-French introducer sheaths were surgically placed in both carotid arteries to allow the sequential insertion of the phantom stenoses on 4F Fogarty catheters and the insertion of the angiographic guiding catheter. To minimize the effect of respiration on angiographic acquisition, mechanical ventilation was temporarily discontinued immediately before each contrast injection. With two methods of calibration, two series of measurements were obtained for the in vivo series, providing an assessment of the variability of nonisocentric calibration.

In Vitro Studies

The phantom stenoses were serially inserted into a Plexiglas acrylate model to approximate the attenuation and beam hardening (peak kilovolt [kVp] level, 75 kV) produced by the human thorax.[17] [18] The Plexiglas channel, including the artificial stenosis, was then filled with contrast medium (iopamidol 370, Bracco; 370 mg iodine/mL) at concentrations of 50% and then 100%. Each phantom stenosis filled with contrast medium was recorded on cine film. By use of two concentrations of contrast medium, two series of measurements were obtained for the in vitro series, allowing an assessment of the variability introduced by contrast concentration.

Calibration

All the in vitro cine frames were calibrated off-line by scaling from a steel object of 3-mm diameter recorded at the radiographic isocenter as previously described.[14] [15] [16] Both the 3-mm scaling object and subsequently the in vitro phantom stenoses were filmed precisely at the isocenter of the x-ray system.[19] The calibration procedures available in each off-line QCA system were applied to the images obtained by automated edge detection to produce the corresponding calibration factors (millimeters per pixel).

All in vivo frames were calibrated by scaling from the isocentric 3-mm steel object; subsequently, the analysis was repeated and frames were calibrated by scaling from the angiographic catheter, which was achieved by the nonisocentric radiographic acquisition of the unfilled tip of the contrast catheter (positioned at the coronary ostium as in routine clinical practice). A recent study using a centimeter grid showed that QCA measurements correspond to the outer diameter of the catheter and that the use of contrast-empty catheters (-2.9%) yields more accurate results than contrast-filled catheters (-7.1%).[20] [21] The diameter of the nontapering part of each 8F polyurethane catheter was measured (diameters of the individual catheters ranging from 2.49 to 2.54 mm) with a precision micrometer (No. 293-501, Mitutoyo; accuracy, 0.001 mm), resulting in the respective calibration factors (millimeters per pixel). In the in vivo series, after the intracoronary insertion of each phantom stenosis and before angiographic recording, the radiopaque tip of the guide wire of the Fogarty catheter that was located in the side channel of each phantom was used as a marker in two planes to ensure that the phantom stenosis lay at the radiographic isocenter. The guide wire was then removed before coronary angiography.

Image Acquisition and Processing

A monoplane Philips Poly Diagnost C2 machine equipped with an MRC x-ray tube and powered by an Optimus CP generator (Philips Medical Systems International BV) was used for all radiographic imaging. The 5-in (12.5-cm) field mode of the image intensifier (focal spot, 0.8 mm) was selected, and the radiographic system settings were kept constant (kVp, mA, ms) in each projection. All phantoms were imaged in two projections sequentially and acquired on 35-mm cine film (CFE type 2711, Kodak) at a frame rate of 25 images per second with an Arritechno 90 cine camera (Arnold & Richter) with an 85-mm lens. The cine films were processed by a Refinal developer (Agfa-Gavaert) for 4 minutes at 28°C. The film gradient was measured in all cases to ensure that the optical densities of interest were on the linear portion of the sensitometric curve. From each angiogram that fulfilled the requirements of quantitative analysis (no superimposition of surrounding structures, no major vessel branching at the site of the phantom), a homogeneously filled end-diastolic coronary image was selected. Ten in vitro and 19 in vivo frames were suitable for quantitative analysis of the artificial stenoses.

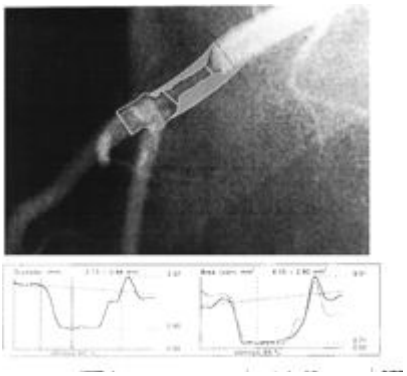
Quantitative Angiographic Analysis

The cine films of the phantom stenoses were analyzed off-line by 10 QCA systems in nine participating centers. Each center had a unique combination of QCA software and hardware. The default settings of optical magnification, light-emitting diode settings, etc, at each core laboratory were used without alteration. It is assumed in this study that each core laboratory (through continuous internal quality control assessments) has established

for itself the optimal settings and operations for its individual QCA system. The resultant pixel size after digitization depended on the video camera pixel matrix (Table 1) of each system and ranged from 0.07 to 0.20 mm/pixel. The list of participating centers and details of their QCA systems are given in alphabetical order in Table 1 (it should be noted that the subsequent results for the 10 systems are given in a different order anonymously). None of the QCA systems tested had been previously calibrated at prior validation testing with the type of phantom used. One of the investigators (E.M.v.S.) visited all the centers, bringing the same set of films for analysis to each center consecutively. The same set of preselected cine frames was analyzed at each center to avoid the introduction of any variability between QCA systems associated with frame selection by each operator.[22] A technician working at each center who was unaware of the true diameters of the phantom stenoses performed the automated QCA analysis of all cine frames in the presence of the investigator. To maintain scientific objectivity and to ensure that the direct comparisons between the 10 QCA systems were valid, operator intervention or editing of the automated edge detection was not permitted. An example of a contrast-filled phantom stenosis in vivo and its subsequent contours outlined by one of the QCA systems is given in Fig 1.

View this table:
[in this window]
[in a new window]

Table 1. Details of QCA Systems



View larger version (112K):
[in this window]
[in a new window]

Figure 1. The borders of a coronary segment containing a phantom stenosis are outlined by the automated edge-detection algorithm of one of the validated quantitative coronary angiography systems. Diameter function is plotted at bottom of figure.

Statistical Analysis

The individual geometric measurements of minimal luminal diameter were compared

with the true phantom diameters by simple subtraction and by linear regression analysis. The mean of the signed differences between measured values and the known diameter of the phantom stenoses was considered an index of accuracy and the SD of the differences an index of precision.

- Top
- Abstract
- Introduction
- Methods
- Results
- Discussion
- References

Results

The individual indexes of accuracy and precision are given for all four validation series (in vivo with two calibration techniques and in vitro with two contrast concentrations) along with the average of their unsigned (absolute) values for all 10 QCA systems validated in Table 2. The averages for accuracy and precision, for correlation coefficient and SEE, and for intercept and slope for all 10 QCA systems are given in Table 3.

View this table: [in this window] [in a new window]

Table 2. Accuracy and Precision

View this table: [in this window] [in a new window]

Table 3. Summary of Validation Results

Indexes of Agreement

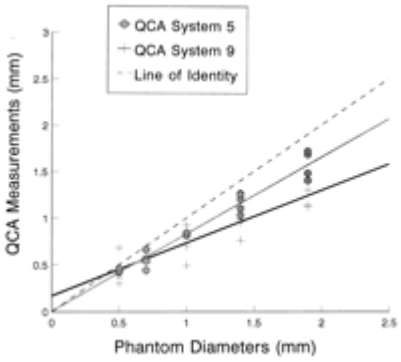
Accuracy of the 10 QCA systems ranged from 0.07 to 0.31 mm, and the correlation coefficient ranged from .96 to .89. The intercept of the regression line was positive for all 10 QCA systems and ranged from +0.08 to +0.31 mm, whereas the slope of the regression

line for all 10 QCA systems was <1.0 and ranged from 0.86 to 0.64. Application of these regression lines indicates percentage accuracies for the 10 QCA systems ranging from +26% to -1% (mean, +7.2%) for measurements of lumen diameters of 0.5 mm, percentage accuracies from -7% to -24% (mean, -14.9%) for lumen diameters of 1.5 mm, and percentage accuracies from -11% to -29% (mean, -20.5%) for lumen diameters of 3.0 mm.

Indexes of Noise and Consistency

Precision of the 10 QCA systems ranged from ±0.14 to ±0.24 mm, and the SEE ranged from ±0.11 to ±0.16 mm.

An indication of the variability of performance among the 10 QCA systems can be visualized by comparing the results of the in vivo test calibrated by the catheter for two of the systems depicted in Fig 2.

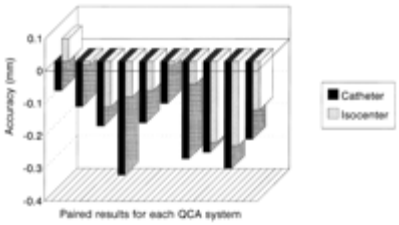


View larger version (20K):
[in this window]
[in a new window]

Figure 2. Graph showing in vivo data for two of the quantitative coronary angiography (QCA) systems validated. An indication of the variability of performance of the QCA systems validated is demonstrated by linear regression of the results for QCA systems 5 and 9. The raw data for the in vivo QCA analysis calibrated by the catheter as a scaling device has been plotted on the *y* axis with the true phantom stenosis diameters on the *x* axis. Each data point represents a single analysis of a cine frame from each angiographic sequence. The accuracy was -0.19 mm for system 5 and -0.33 mm for system 9; the precision was ±0.13 mm for system 5 and ±0.26 mm for system 9; the correlation was .98 for system 5 and .91 for system 9; and the SEE was ±0.09 mm for system 5 and ±0.14 mm for system 9.

Influence of the Validation Model

As expected, it can be seen in Table 2 that the performance of each individual system varied from one validation test to another. In the in vivo series, accuracy was better when calibrated at the isocenter than on catheter calibration in all 10 systems validated (see Fig 3). The method of calibration did not influence the precision or SEE of QCA. In the in vitro series, both accuracy and the SEE were found to improve when the concentration of the injected contrast was 100% compared with 50% during validation of 8 of the 10 systems.



View larger version (46K):
[in this window]
[in a new window]

Figure 3. Bar graph showing effect of calibration on accuracy of the in vivo series. The accuracy of quantitative coronary angiography (QCA) is seen to improve during calibration at the isocenter compared with the use of the angiographic catheter as a scaling device. Solid bars indicate catheter; shaded bars, isocenter.

- Top
- Abstract
- Introduction
- Methods
- Results
- Discussion
- References

Discussion

This study demonstrates the wide range of performance provided by 10 QCA systems currently in use in North America and Europe. The clinical implications of such widely different results are considerable and can be divided into the clinical implications of inaccuracy and the clinical implications of imprecision of QCA measurements.

Clinical Implications of QCA Inaccuracy

All systems were found to have a positive intercept (>0) and a slope of <1, indicating that many clinical studies to date using QCA may have overestimated the baseline minimal luminal diameter of their study populations and underestimated the acute gain in minimal luminal diameter after coronary intervention. For example, with QCA system 9, the linear regression analysis of which is displayed in Fig 2, a vessel of 2-mm diameter will be reported as 1.31 mm, and a procedural improvement in minimal luminal diameter from 0.5 to 1.9 mm will be reported as a luminal gain of only 0.77 mm. This may result in the establishment of angiographic guidelines that, when directly adopted in clinical practice using on-line QCA,[7] [14] [23] [24] may lead to device-vessel mismatching and inappropriately aggressive luminal gains and when adopted in subsequent clinical trials may lead to inappropriate inclusion criteria. By underestimation in the range of typical reference vessel diameters (in addition to overestimation in the range of typical minimal luminal diameters), clinical studies reporting their QCA results exclusively in terms of percent diameter stenosis will be less instructive than studies disclosing the absolute values of the

minimal luminal diameter. These findings contrast with visual assessments of luminal diameter, which tend to overestimate acute luminal gain (it should be noted, however, that the variability between visual measurements has previously been shown to be many times higher than between QCA measurements[25] [26] [27] [28]).

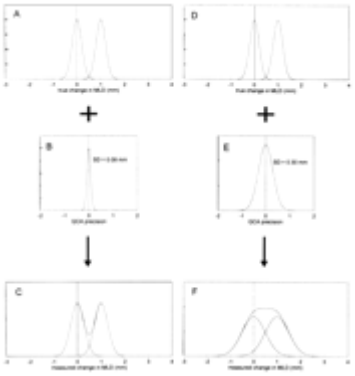
Measurements by some QCA systems were so different from the true phantom diameters and so different from other QCA systems that the direct pooling of absolute angiographic data from different core laboratories may be rendered invalid. Although little could be done to correct for the random error in QCA results before the sharing of data between core angiographic laboratories, application of a corrective function could be applied to compensate (recalibrate) for the known systematic errors of each QCA system. Specifically, the regression formula [y=a+b(x)] derived from standardized validation studies of each QCA system could be applied to the results of angiographic trials, thereby normalizing to an intercept of 0 and a slope of 1 for each core laboratory [corrected result=(measurement result-intercept)/slope]. Such a step might facilitate the meta-analysis of complementary intervention studies such as STRESS and BENESTENT or such as CAVEAT and CCAT.

Clinical Implications of QCA Imprecision

It could be proposed that poor accuracy or consistent overestimation or underestimation of absolute luminal diameters does not inherently abrogate the value of QCA in the detection of changes in serial angiographic studies, and perhaps the inherent noise (random error) of the system is more important for clinical trials. The high absolute values for precision (up to ±0.30 mm) and SEE (up to ±0.22 mm) provided by some systems indicate that calculation of study power and sample size for clinical studies should differ from one angiographic core laboratory to another. For example, for a two-limb angiographic restenosis study, a population size of 1022 patients would be required if QCA system 5 (precision, ±0.13 mm) were used, whereas a population size of 1356 patients would be required if QCA system 10 (precision, ±0.30 mm) were used to detect a difference in loss of minimal luminal diameter at follow-up of ≥0.10 mm (providing a value of α=.05 and a power of 90% and allowing for a patient dropout rate of 15%).[6] [29] [30] However, it should be acknowledged that the value of precision reflects not only the random error of measurements but also the systematic errors of a measurement system.[31] It may therefore be more appropriate to use the known SEE of a QCA system for the power calculations of clinical trials rather than the value of precision of the QCA system. In the absence of such adjustments in study design, differences between study groups may go undetected or fail to reach statistical significance if a QCA with a large random error is used.

The effect of the precision of a QCA system on the ability to clearly detect a difference among study populations can be seen graphically in Fig 4, in which a hypothetical study population has been analyzed by two different QCA systems, one with a poor precision and one with a good precision (the mathematical analysis used Lotus 1-2-3, Release 2.0 for Windows, Lotus 1993): The patient populations in graphs A and D are identical and represent a hypothetical study population in a restenosis trial 6 months after coronary intervention; one group of patients (treated with placebo) has "restenosis" (mean change

in minimal luminal diameter at follow-up of 1.0 mm), and the other group does not have "restenosis" (mean change in minimal luminal diameter at follow-up of 0.0 mm) after successful treatment with a drug. Graphs B and E display the precision (0.08 and 0.30 mm) of two hypothetical QCA systems used to analyze the above study populations. Graphs C and F show the resultant measurements of the same study population by the two different QCA systems. In graph C, the significant difference between the two treatment groups (placebo and active drug) has been clearly detected by the highly precise QCA system. In graph F, the difference between the treatment groups has been lost (or the difference does not reach statistical significance) when analyzed by the imprecise QCA system. Similarly, a bimodal distribution of luminal renarrowing within a population may appear as unimodal when assessed by an imprecise QCA system.[32]



View larger version (19K):
[in this window]
[in a new window]

Figure 4. Graphs showing the effect of the precision of quantitative coronary angiography (QCA) systems on the ability to clearly detect a difference among study populations when a hypothetical study population (graphs A and D) has been analyzed by two different QCA systems: one with good precision (graph B) and one with poor precision (graph E). The difference between the treated and placebo patients has been detected (graph C) by the precise QCA system, whereas analysis by the imprecise QCA system (graph F) fails to detect the difference or fails to reach statistical significance (the mathematical analysis used Lotus 123, Release 2.0 for Windows, Lotus 1993). MLD indicates minimal luminal diameter.

In Vivo Versus In Vitro Data

The tables of results provided in this report contain an average of the four validation tests for each QCA system. It is debatable, however, whether the results of in vivo tests (in which veiling glare and scatter are heterogeneous because of overlying structures) and in vitro tests (in which veiling glare and scatter are homogeneous) calibrated by different methods should be grouped together and thus attributed equal importance in view of their unique characteristics and implications.[17,18] Correlation between the different validation series was poor; however, this was to be expected, given the different combinations of hardware and software components of the 10 QCA systems (eg, different weightings of the first and second derivative would be expected to respond differently to the sharper change in brightness profile associated with 100% contrast or using a steel object for calibration). Although the contrast of the steel object was sharp, it was on the linear portion of the sensitometric curve, and, indeed, rather than resulting in a greater underestimation of stenosis measurements, QCA measurements calibrated by the steel object were associated (to a major or minor degree) with less underestimation of true

diameters compared with catheter calibration, as shown in Table 2♠ and Fig 3♠. This finding of improved accuracy most likely results from the isocentric location of the steel calibration device rather than the catheter, which lay in the coronary ostium proximal to the coronary segment containing the stenosis as in clinical practice (with subsequent out-of-plane magnification). The results of the in vivo validation test calibrated by the catheter most closely reflect the practice of off-line analysis as performed in multicenter angiographic trials by a core laboratory, and in most of the 10 systems these results were poorer than those of the other three validation tests.

Influence of Hardware and Software Components of Each QCA System

The influence of the camera and cine-video converter on the final result of QCA analysis is highlighted by this study, which showed that although three centers had the same software package, remarkably different results were obtained because of their unique combinations of hardware components. Although our study was not designed to determine which components of the QCA chain were responsible for introducing the most noise, it is clear from our results that a core laboratory conducting follow-up studies should revalidate its QCA system whenever a hardware or software component is exchanged or upgraded.[33] [34] This is of particular relevance to progression-regression trials, in which a QCA system 4 years old is likely to have been upgraded at the core laboratory by more modern versions of the software.

Positive Directions and the Future of QCA

The results of this study have already been used by the producers of some of the QCA systems to refine the algorithms incorporated within each system. Many of the systematic errors detected can be corrected by recalibration of the QCA software or tuning of the weighting of the first to the second derivative in the edge-detection algorithm,[35] [36] whereas it would be expected to be more difficult to clear a system of noise, which usually reflects hardware impediments. Experimental algorithms currently under development include an adaptive dynamic weighting of the first and second derivatives to overcome the problem of overestimating measurements of small vessels and underestimating measurements of large diameters[37] [37A] and a gradient field transform incorporating a "shortest-path" algorithm rather than a traditional smoothing "minimal-cost" algorithm to cope with the abrupt changes in luminal contour encountered after coronary angioplasty.[38]

Given the considerable time, effort, and cost of conducting restenosis and progression-regression trials, it seems reasonable to aim for a precision of clinical QCA measurements of ≤0.20 mm for the analysis of current multicenter angiographic studies. It is hoped that such an arbitrary threshold could be reduced over coming years when high-resolution digital x-ray cameras and high-resolution digital export formats (with lossless compression) are widely available at all investigating centers. An additional proposal that could be considered for clinical studies to reduce the variability of QCA measurements would be for the investigators to reduce the setting of the focal spot size of the x-ray source to its smallest value (currently 0.4 mm in most x-ray systems) for the recording of the individual angiograms of patients participating in angiographic trials. Other steps for

the reduction of variability of QCA measurements and the standardization of angiographic acquisition have been described in detail.[37] [39] [40] [41] [42] [43]

Despite the variabilities in QCA measurements highlighted by this study, we should remain appreciative of the increased understanding of coronary artery disease afforded to us by the widespread application of QCA to scientific research and clinical practice. QCA has alleviated the subjectivity and high variability of visual assessments,[26] [28] [44] [45] [46] the errors and invalidity of the percent diameter stenosis for the assessment of progression/regression (pseudoprogression),[12] [25] [43] and the limitations of the dichotomous approach for the evaluation of restenosis.[13] [31] [47] [48] [49] [50] [51] [52] [53] [54] [55] [56] The provision by QCA of objective and absolute measurements of coronary luminal diameter has significantly enhanced our approach to the assessment of noninvasive and invasive coronary interventions. It is hoped that the findings of our study will serve as a stimulus for the further improvement of QCA so that it may remain the gold standard and complementary technique to the new intracoronary imaging modalities for the acute and serial assessment of coronary artery dimensions.

Study Limitations

Although this study assessed the variability of measurements provided by automated QCA of a standardized set of cine films, it does not quantify the additional variability that might be introduced by variation in patient position and x-ray gantry settings during serial angiographic studies[40] [57] (although this is now minimized by the design of most current trial protocols), the recording and developing of cine films at different institutions, frame selection (although this is now standardized by selection of end-diastolic frames[22] [41]), and the occasional manual correction of detected contours (although this should be kept to an absolute minimum in angiographic core laboratories). The cumulative imprecision, including these factors, has been quantified in two clinical studies using one of the QCA systems validated and has been found in both studies to be ±0.20 mm (SD of measurements of serial angiograms).[25] [58]

It can be seen in Fig 1 that although the contours of our phantom stenoses possessed an abrupt (90°) onset and termination, they were smooth over their 8-mm length. In clinical practice, many lesions are irregular, with rapidly changing arterial boundaries after coronary intervention. Given the use of a smoothing minimal-cost algorithm along scan lines perpendicular to the axis of the vessel, currently available QCA systems might be expected to fare less favorably if challenged with dissections and complex lesions compared with the angiographic stenoses presented in our study. Initial results with an experimental gradient-field transform algorithm provide hope that future QCA systems might be able to cope with more complex lesions.[38] This could perhaps be best tested in future validation studies by postmortem casts of diseased human coronary arteries with ulcerated plaques, dissections, and complex morphology.

The diameters of the phantom stenoses in this study (0.5 to 1.9 mm) were in the range of obstruction diameters of human coronary stenoses rather than typical reference vessel size. It is noteworthy that the average minimal luminal diameters before, immediately after, and at 6-month follow-up are 1.03, 1.78, and 1.48 mm for balloon angioplasty,[29]

0.98, 2.03, and 1.47 mm for directional coronary atherectomy,[3] and 1.07, 2.5, and 1.83 mm for stent implantation.[1] The positive intercept values of the regression line for all the systems in this study indicate that most QCA systems tend to overestimate in the lower range of luminal diameters (<1 mm). The slope (b), however, was <1 for all systems, indicating that for larger reference vessels, the QCA systems tested would underestimate the true lumen diameter. A standardized set of phantoms of large diameter should be produced for future multicenter studies to comprehensively examine the performance of QCA systems over the complete range of vessel size. The intracoronary insertion of phantom stenoses of large diameter may, however, prove to be difficult in the porcine model in view of the limited size of the coronary artery lumen.

Conclusions

This study has revealed wide differences in the performance of currently available QCA systems, highlighting the difficulties in attempting to make direct comparisons between absolute measurements of one angiographic study and those derived from a different QCA system or with on-line analysis in clinical practice. Power calculations and study design of angiographic trials should be adjusted for the precision of the QCA system used to avoid the risk of failing to detect small differences in patient populations.

QCA validation studies should be performed in a uniform and standardized manner to provide meaningful data that can be used to compare the performance of QCA systems, to guide the recalibration of QCA algorithms, and to facilitate the maintenance of high standards of QCA for clinical practice and scientific studies. The entire chain of a QCA system should be revalidated each time the version of QCA software is upgraded or a hardware component is exchanged.

In the reporting of angiographic studies, absolute values of luminal diameter and values of statistical significance for differences between study populations should be accompanied by the results of the appropriate validation parameters of the QCA system used so as to facilitate the interpretation of clinical studies.

View this table:
[in this window]
[in a new window]

Table 1A. (Continued)

Acknowledgments

David Keane, MB, MRCPI, is a recipient of a traveling grant from the Peel Trust for Medical Research, UK. The authors greatly appreciate the collaborative spirit of all participating investigators and core laboratories in the interest of achieving high standards of QCA. The authors would like to thank Rein Melkert, MD, for his statistical advice. The collaboration of the Experimental Laboratory, Thoraxcenter, is gratefully acknowledged.

The following centers and investigators participated in this study (both the centers and investigators are given in alphabetical order).

Beth Israel Hospital, Boston, Mass: Donald Baim. Brigham and Women's Hospital, Boston, Mass: C. Michael Gibson. Cleveland Clinic, Cleveland, Ohio: Stephen Ellis, Eric J. Topol. George Washington University, Washington, DC: John Reiner, Allan Ross. Hôpital Universitaire Saint Jacques, Besançon, France: Jean Pierre Bassand. Mount Sinai Hospital, Toronto, Ontario: Allan Adelman. St Michaels Hospital and Sunnybrook Health Science Center, Toronto, Ontario: Paul W. Armstrong, Anatoly Langer, Normand Robert, Bradley Strauss, Martin Yaffe. Thomas Jefferson Hospital, Philadelphia, Pa: David Fischman, Sheldon Goldberg. Thoraxcenter, Rotterdam, the Netherlands: Carlo di Mario, Jürgen Haase, David Keane, Eline Montauban van Swijndregt, Patrick W. Serruys, Cornelis Slager. Washington Cardiology Center, Washington, DC: Martin B. Leon, Jeffrey Popma.

Received October 10, 1994; revision received November 2, 1994; accepted November 13, 1994.

▲Top
▲Abstract
▲Introduction
▲Methods
▲Results
▲Discussion
▪ References

References

1. Serruys PW, de Jaegere P, Kiemeneij F, Macaya C, Rutsch W, Heyndrickx G, Emanuelsson H, Marco J, Legrand V, Materne P, Belardi J, Sigwart U, Colombo A, Goy JJ, Vandenheuvel P, Delcan J, Morel MA, on behalf of the Benestent Study Group. A comparison of balloon-expandable-stent implantation with balloon angioplasty in patients with coronary artery disease. *N Engl J Med.*

1994;331:489-495. [Abstract/Free Full Text]

2. Fischman DL, Leon MB, Baim DS, Schatz RA, Savage MP, Penn IM, Detre K, Veltri L, Ricci D, Nobuyoshi M, Cleman MW, Heuser R, Almond D, Teirstein PS, Fish RD, Colomo A, Brinker J, Moses J, Shaknovich A, Hirshfeld J, Bailey S, Ellis S, Rake R, Goldberg S. A randomized comparison of coronary-stent placement and balloon angioplasty in the treatment of coronary artery disease. *N Engl J Med.* 1994;331:496-501. [Abstract/Free Full Text]

3. Topol EJ, Leya F, Pinkerton CA, Whitlow PL, Hofling B, Simonton CA, Masden RR, Serruys PW, Leon MB, Williams DO, King SB III, Mark DB, Isner JM, Holmes DR, Ellis SG, Lee KL, Keeler GP, Berdan LG, Hinohara T, Califf RM, for the CAVEAT Study Group. A comparison of directional atherectomy with coronary angioplasty in patients with coronary artery disease. *N Engl J Med.* 1993;329:221-227.[Abstract/Free Full Text]

4. Adelman AG, Cohen EA, Kimball BP, Bonan R, Ricci DR, Webb DR, Laramee L, Barbeau G, Traboulsi M, Corbett BN, Schwartz L, Logan AG. A comparison of directional atherectomy with balloon angioplasty for lesions of the left anterior descending coronary artery. *N Engl J Med.* 1993;329:228-233. [Abstract/Free Full Text]

5. Faxon DP, on behalf of the MARCATOR investigators. Angiotensin converting enzyme inhibition and restenosis: the final results of the MARCATOR trial. *Circulation*. 1992;86(suppl I):I-53. Abstract.

6. Serruys PW, Klein W, Tijssen JPG, Rutsch W, Heyndrickx GR, Emanuelsson H, Ball SG, Decoster O, Schroeder E, Leibermann H, Eichhorn E, Willerson JT, Anderson HV, Khaja F, Alexander RW, Baim D, Melkert R, Oene JC, Van Gool R. Evaluation of ketanserin in the prevention of restenosis after percutaneous transluminal coronary angioplasty: a multicenter randomized double-blind placebo-controlled trial. *Circulation.* 1993;88:1588-1601. [Abstract/Free Full Text]

7. Mancini GBJ, Simon SB, McGillem MJ, LeFree MT, Friedman HZ, Vogel RA. Automated quantitative coronary arteriography: morphologic and physiologic validation in vivo of a rapid digital angiographic method. *Circulation.* 1987;75:452-460. [Abstract/Free Full Text]

8. Johnson MR, Skorton DJ, Ericksen EE, Fleagle SR, Wilson RF, Marcus ML. Videodensitometric analysis of coronary stenoses: in-vivo geometric and physiologic validation in humans. *Invest Radiol.* 1988;23:891-898. [Medline] [Order article via Infotrieve]

9. Herrington DM, Walford GA, Pearson TA. Issues of validation in quantitative coronary angiography. In: Reiber JHC, Serruys PW, eds. *New Developments in Quantitative Coronary Arteriography*. Dordrecht, Netherlands: Kluwer Academic Publishers; 1988:125-141.

10. Reiber JHC. Why and how should QCA systems be validated? In: Serruys PW, Foley DP, deFeyter PJ, eds. *Quantitative Coronary Angiography in Clinical Practice*. Dordrecht, Netherlands: Kluwer Academic Publishers; 1994:1-6.

11. Serruys PW, Luijten HE, Beatt KJ, Geuskens R, de Feyter PJ, van den Brand M, Reiber JHC, ten Katen HJ, van Es GA, Hugenholtz PG. Incidence of restenosis after successful coronary angioplasty: a time-related phenomenon. *Circulation.* 1988;77:361-371. [Abstract/Free Full Text]

12. Beatt KJ, Luijten HE, de Feyter PJ, van den Brand M, Reiber JHC, Serruys PW. Change in diameter of coronary artery segments adjacent to stenosis after percutaneous transluminal coronary angioplasty: failure of percent diameter stenosis measurement to reflect morphologic changes induced by balloon dilatation. *J Am Coll Cardiol.* 1988;12:315-323. [Abstract]

13. Beatt KJ, Serruys PW, Hugenholtz PG. Restenosis after coronary angioplasty: new standards for clinical studies. *J Am Coll Cardiol.* 1990;15:491-498. [Abstract]

14. Haase J, di Mario C, Slager CJ, van der Giessen W, den Boer A, de Feyter PJ, Reiber JHC, Verdouw PD, Serruys PW. In-vivo validation of on-line and off-line geometric coronary measurement systems using insertion of stenosis phantoms in porcine coronary arteries. *Cathet Cardiovasc Diagn.* 1992;27:16-27. [Medline] [Order article via Infotrieve]

15. Di Mario C, Haase J, den Boer A, Reiber JHC, Serruys PW. Edge detection versus densitometry in the quantitative assessment of stenosis phantoms: an in vivo comparison in porcine coronary arteries. *Am Heart J.* 1992;124:1181-1189.

[Medline] [Order article via Infotrieve]

16. Haase J, Keane D, di Mario C, Escanned J, Ozaki Y, Slager C, van Bremen R, van der Giessen W, Serruys PW. Percutaneous implantation of coronary stenosis phantoms in an anaesthetized swine model to validate current quantitative angiography analysis systems. In: Reiber J, Serruys PW, eds. *Progress in Quantitative Coronary Arteriography*. Dordrecht, Netherlands: Kluwer Academic Publishers; 1994:49-65.

17. Seibert JA, Nalcioglu O, Roeck W. Removal of veiling glare by mathematical deconvolution techniques. *Med Phys.* 1986;13:13-18. [Medline] [Order article via Infotrieve]

18. Shaw CG, Ergun D, Myerowitz PD, Lysel MSV, Mistretta CA, Zarnstorff WC, Crummy AB. A technique of scatter and glare correction for videodensitometric studies in digital subtraction videoangiography. *Radiology.* 1982;142:209-213. [Abstract/Free Full Text]

19. Wollschlager H, Lee P, Zeiher A, Solzbach U, Bonzel T, Just H. Improvement of quantitative angiography by exact calculation of radiological magnification factors. *Comput Cardiol*. 1985;483-486.

20. di Mario C, Hermans WRM, Rensing BJ, Serruys PW. Calibration using angiographic catheters as scaling devices: importance of filming the catheters not filled with contrast medium. *Am J Cardiol.* 1992;69:1377-1378. Letter. [Medline] [Order article via Infotrieve]

21. Hermann J, Keane D, den Boer A, Serruys PW. Radiological quality of coronary guiding catheters: a quantitative analysis. *Cathet Cardiovasc Diagn.* 1994;33:55-60. [Medline] [Order article via Infotrieve]

22. Reiber JH, van Eldik J, Helleman P, Kooijman CJ, Tijssen JG, Serruys PW. How critical is frame selection in quantitative coronary angiographic studies? *Eur Heart J.* 1989;10(suppl F):54-59.

23. LeFree MT, Simon SB, Mancini GBJ, Bates ER, Vogel RA. A comparison of 35 mm cinefilm and digital radiographic image recording: implications for quantitative coronary arteriography: film vs. digital coronary quantification.

Invest Radiol. 1988;23:176-183. [Medline] [Order article via Infotrieve]

24. Skelton TN, Kisslo KB, Bashmore TM. Comparison of coronary stenosis quantitation results from on-line digital and digitized cinefilm images. *Am J Cardiol.* 1988;62:381-386. [Medline] [Order article via Infotrieve]

25. Waters D, Lesperance J, Craven TE, Hudon G, Gillam L. Advantages and limitations of serial coronary arteriography for the assessment of progression and regression of coronary atherosclerosis: implications for clinical trials. *Circulation*. 1993;87(suppl II):II-38-II-47.

26. Zir LM, Miller SW, Dinsmore RE, Gilbert JP, Harthorne JW. Interobserver variability in coronary arteriography. *Circulation.* 1976;53:627-632. [Abstract/Free Full Text]

27. Reiber JHC, Serruys PW, Kooijman CJ, Wijns W, Slager CJ, Gerbrands JJ, Schuurbiers JHC, den Boer A, Hugenholtz PG. Assessment of short-, medium-, and long-term variations in arterial dimensions from computer-assisted quantitation of coronary cineangiograms. *Circulation.* 1985;71:280-288. [Abstract/Free Full Text]

28. De Rouen TA, Murray JA, Owen W. Variability in the analysis of coronary arteriograms. *Circulation.* 1977;55:324-328. [Abstract/Free Full Text]

29. Serruys PW, Rutch W, Heyndrickx GR, Danchin N, Mast EG, Wijns W, Rensing BJ, Vos J, Stibbe J, for the Coronary Artery Restenosis Prevention on Repeated Thromboxane-Antagonism Study Group (CARPORT). Prevention of restenosis after percutaneous transluminal coronary angioplasty with thromboxane A_2-receptor blockade: a randomized, double-blind, placebo-controlled trial. *Circulation.* 1991;84:1568-1580. [Abstract/Free Full Text]

30. MERCATOR Study Group. Does the new angiotensin converting enzyme inhibitor cilazapril prevent restenosis after percutaneous transluminal coronary angioplasty? Results of the MERCATOR Study: a multicenter randomized double-blind placebo-controlled trial. *Circulation.* 1992;86:100-110. [Abstract/Free Full Text]

31. Haase J, Keane D, di Mario C, Escanned J, Slager C, Serruys PW. How reliable are geometric coronary measurements? In vitro and in vivo validation of digital and cinefilm-based quantitative coronary analysis systems. In: Serruys PW, Foley DP, de Feyter PJ, eds. *Quantitative Coronary Angiography in Clinical Practice*. Dordrecht, Netherlands: Kluwer Academic Publishers; 1994:27-49.

32. Serruys PW, Foley DP, Kirkeeide R, King SB III. Restenosis revisited: insights provided by quantitative coronary angiography. *Am Heart J.* 1993;126:1243-1267. [Medline] [Order article via Infotrieve]

33. Haase J, Escanned J, Montauban van Swijndregt E, Ozaki Y, Gronenschild E, Slager JC, Serruys PW. Experimental validation of geometric and densitometric coronary measurements on the new generation cardiovascular angiography analysis system (CAAS II). *Cathet Cardiovasc Diagn.* 1993;30:104-114. [Medline] [Order article via Infotrieve]

34. Haase J, van der Linden M, di Mario C, van der Giessen WJ, Foley DP, Serruys PW. Can the same algorithm be applied to on-line and off-line analysis systems? Validation of a new cinefilm-based geometric coronary measurement software. *Am Heart J.* 1993;126:312-321. [Medline] [Order article via Infotrieve]

35. Beier J, Oswald H, Fleck E. Edge detection for coronary angiograms: error correction and impact of derivatives. *Comput Cardiol*. 1992;513-516.

36. Wunderlich W, Linderer T, Backs B, Fischer F, Schroder R. Quantitative coronary arteriography: does optimum edge detection detect minimum diameter changes optimally? Abstract Book of the 5th International Symposium on Coronary Arteriography, Rotterdam. 1993:182. Abstract.

37. Keane D, Serruys PW. Quantitative coronary angiography: an integral component of interventional cardiology. In: Topol EJ, Serruys PW, eds. *Current Review of Interventional Cardiology*. 2nd ed. Philadelphia, Pa: Current Medicine. In press.

37. Keane D, Gronenschild E, Slager CJ, Ozaki Y, Haase J, Serruys PW. In-vivo validation of an experimental adaptive quantitative coronary angiography algorithm to circumvent overestimation of small luminal diameters. *Cathet Cardiovasc Diagn*. In press.

38. van der Zwet PMJ, Reiber JHC. A new approach for the quantification of complex lesion morphology: the gradient field transform: basic principles and validation results. *J Am Coll Cardiol.* 1994;24:216-224. [Abstract]

39. Umans V, Hermans W, Herrman JP, Pameyer J, Serruys PW. Experiences of a quantitative coronary angiography core laboratory in restenosis prevention trials. In: Serruys PW, Foley DP, de Feyter PJ, eds. *Quantitative Coronary Angiography in Clinical Practice*. Dordrecht, Netherlands: Kluwer Academic Publishers; 1994:121-135.

40. Reiber JHC, Serruys PW, Kooyman CJ, Slager CJ, Schuurbiers JHC, den Boer A. Approaches towards standardization in acquisition and quantitation of arterial dimensions from cineangiograms. In: Reiber JHC, Serruys PW, eds. *State of the Art in Quantitative Coronary Angiography*. Dordrecht, Netherlands: Martinus Nijhoff Publishers; 1986:145-155.

41. Jost S, Deckers J, Rafflenbeul W, Hecker H, Reiber JHC, Nikutta P, Wiese B, Hugenholtz P, Lichtlen P, and the INTACT-Group. International Nifedipine Trial On Antiatherosclerotic Therapy (INTACT): methodologic implications and results of a coronary angiographic follow-up study using computer assisted film analysis. *Int J Card Imaging.* 1991;6:117-133.

42. Jost S, Rafflenbeul W, Gerhardt U, Hecker H, Nellessen U, Reil GH, Lichtlen PR. Influence of ionic and non-ionic radiographic contrast media on the vasomotor tone of epicardial coronary arteries. *Eur Heart J.* 1989;10(suppl F):60-65.

43. De Feyter PJ, Serruys PW, Davies MJ, Richardson P, Lubsen J, Oliver MF. Quantitative coronary angiography to measure progression and regression of coronary atherosclerosis: value, limitations, and implications for clinical trials. *Circulation.* 1991;84:412-423. [Free Full Text]

44. Fleming RM, Kirkeeide R, Smalling RW, Gould KL. Patterns in visual interpretation of coronary arteriograms as detected by quantitative coronary arteriography. *J Am Coll Cardiol.* 1991;18:945-951. [Abstract]

45. Goldberg RK, Kleiman NS, Minor ST, Abukhalil J, Raizner AE. Comparison of quantitative coronary angiography to visual estimates of lesion severity pre and post PTCA. *Am Heart J.* 1990;119:178-184. [Medline] [Order article via

Infotrieve]

46. Detre KM, Wright E, Murphy ML, Takaro T. Observer agreement in evaluating coronary angiograms. *Circulation.* 1975;52:979-986. [Abstract/Free Full Text]

47. Rensing BJ, Hermans WR, Deckers JW, de Feyter PJ, Tijssen JGP, Serruys PW. Luminal narrowing after percutaneous transluminal coronary balloon angioplasty follows a near Gaussian distribution: a quantitative angiographic study in 1445 successfully dilated lesions. *J Am Coll Cardiol.* 1992;19:939-945. [Abstract]

48. Beatt KJ, Serruys PW, Luijten HE, Rensing BJ, Suryapranata H, de Feyter P, van den Brand M, Laarman GJ, Roelandt J. Restenosis after coronary angioplasty: the paradox of increased lumen diameter and restenosis. *J Am Coll Cardiol.* 1992;19:258-266. [Abstract]

49. Serruys PW, Foley DP, de Feyter PJ. Restenosis after coronary angioplasty: a proposal of new comparative approaches based on quantitative angiography. *Br Heart J.* 1992;68:417-424.

50. Kuntz RE, Baim DS. Defining coronary restenosis: newer clinical and angiographic paradigms. *Circulation.* 1993;88:1310-1323. [Free Full Text]

51. Kuntz RE, Safian RD, Levine MJ, Reis GJ, Diver DJ, Baim DS. Novel approach to the analysis of restenosis after the use of three new coronary devices. *J Am Coll Cardiol.* 1992;19:1493-1499. [Abstract]

52. Kuntz RE, Gibson CM, Nobuyoshi M, Baim DS. Generalized model of restenosis after conventional balloon angioplasty, stenting and directional atherectomy. *J Am Coll Cardiol.* 1993;21:15-25. [Abstract]

53. Popma JJ, De Cesare N, Pinkerton CA, Kerejakes DJ, Whitlow P, King SB, Topol EJ, Holmes DR, Leon MB, Ellis SG. Quantitative analysis of factors affecting late lumen loss and restenosis after directional atherectomy. *Am J Cardiol.* 1993;71:552-557. [Medline] [Order article via Infotrieve]

54. de Jaegere P, Strauss BH, de Feyter P, Suryapranata H, van den Brand M, Serruys PW. Stent versus balloon angioplasty: matching based on QCA, a surrogate for

randomized studies. *Am Heart J.* 1993;125:310-319. [Medline] [Order article via Infotrieve]

55. Foley DP, Bonnier H, Jackson G, Macaya C, Shepherd J, Vrolix M, Serruys PW. Prevention of restenosis after coronary balloon angioplasty: rationale and design of the fluvastatin angioplasty restenosis (FLARE) trial. *Am J Cardiol.* 1994;73:50D-61D.[Medline] [Order article via Infotrieve]

56. Herrman JP, Umans V, Peerbom P, Keane D, Bach D, Kobi P, Kerry R, Close P, Deckers J, Serruys PW, on behalf of the HELVETICA study group. Evaluation of recombinant hirudin in the prevention of restenosis after percutaneous transluminal coronary angioplasty: rationale and design of the HELVETICA trial, a multicenter randomized double blind heparin controlled study. *Eur Heart J*. In press.

57. Herrington DM, Siebes M, Sokol DK, Siu CO, Walford GD. Variability in measures of coronary lumen dimensions using quantitative coronary angiography. *J Am Coll Cardiol.* 1993;22:1068-1074. [Abstract]

58. Foley D, Deckers J, van den Bos AA, Heyndrickx G, Laarman GJ, Suryapranata H, Zijlstra F, Serruys PW. Usefulness of repeat coronary angiography 24 hours after successful balloon angioplasty to evaluate early luminal deterioration and facilitate quantitative analysis. *Am J Cardiol.* 1993;72:1341-1347.[Medline] [Order article via Infotrieve]

This article has been cited by other articles:

Circulation HOME

E. Camenzind, P. G. Steg, and W. Wijns

Response to Letter Regarding Article, "Stent Thrombosis Late After Implantation of First-Generation Drug-Eluting Stents: A Cause for Concern"

Circulation, October 16, 2007; 116(16): e390 - e390.

[Full Text] [PDF]

HEART ONLINE and EDUCATION IN HEART HOME

M A S Cordeiro, J M Miller, A Schmidt, A C Lardo, B D Rosen, D E Bush, J A Brinker, D A Bluemke, E P Shapiro, and J A C Lima

Non-invasive half millimetre 32 detector row computed tomography angiography accurately excludes significant stenoses in patients with advanced coronary artery disease and high calcium scores

Heart, May 1, 2006; 92(5): 589 - 597.

[Abstract] [Full Text] [PDF]

European Heart Journal HOME

F. Alfonso, R. Melgares, V. Mainar, R. Lezaun, N. Vazquez, J. Tascon, F. Pomar, A. Cequier, J. Angel, M.-J. Perez-Vizcayno, *et al.*

Therapeutic implications of in-stent Restenosis located at the stent edge.: Insights from the Restenosis Intra-stent Balloon angioplasty versus elective Stenting (RIBS) randomized trial

Eur. Heart J., October 2, 2004; 25(20): 1829 - 1835.

[Abstract] [Full Text] [PDF]

Journal of the American College of Cardiology HOME

J. I. E. Hoffman

Do we have agold standard yet?

J. Am. Coll. Cardiol., February 18, 2004; 43(4): 662 - 664.

[Full Text] [PDF]

Journal of the American College of Cardiology HOME

F. Alfonso, J. Zueco, A. Cequier, R. Mantilla, A. Bethencourt, J. R. Lopez-Minguez, J. Angel, J. M. Auge, M. Gomez-Recio, C. Moris, *et al.*

A randomized comparison ofrepeat stenting with balloon angioplasty in patients with in-stent restenosis

J. Am. Coll. Cardiol., September 3, 2003; 42(5): 796 - 805.

[Abstract] [Full Text] [PDF]

Journal of the American College of Cardiology HOME

C. G. Hanratty, Y. Koyama, H. H. Rasmussen, G. I. C. Nelson, P. S. Hansen, and M. R. Ward

Exaggeration of nonculprit stenosis severity during acute myocardial infarction: implications for immediate multivessel

revascularization
J. Am. Coll. Cardiol., September 4, 2002; 40(5): 911 - 916.
[Abstract] [Full Text] [PDF]

Circulation HOME
C. Di Mario, J. W. Moses, T. J. Anderson, R. Bonan, T. Muramatsu, A. C. Jain, J. Suarez de Lezo, S. Y. Cho, M. Kern, I. T. Meredith, *et al.*
Randomized Comparison of Elective Stent Implantation and Coronary Balloon Angioplasty Guided by Online Quantitative Angiography and Intracoronary Doppler
Circulation, December 12, 2000; 102(24): 2938 - 2944.
[Abstract] [Full Text] [PDF]

European Heart Journal HOME
J.J Piek, E Boersma, C di Mario, E Schroeder, C Vrints, P Probst, B de Bruyne, C Hanet, E Fleck, M Haude, *et al.*
Angiographical and Doppler flow-derived parameters for assessment of coronary lesion severity and its relation to the result of exercise electrocardiography
Eur. Heart J., March 2, 2000; 21(6): 466 - 474.
[Abstract] [PDF]

HEART ONLINE and EDUCATION IN HEART HOME
D M Whelan, W J van der Giessen, S C Krabbendam, E A van Vliet, P D Verdouw, P W Serruys, and H M M van Beusekom
Biocompatibility of phosphorylcholine coated stents in normal porcine coronary arteries
Heart, March 1, 2000; 83(3): 338 - 345.
[Abstract] [Full Text]

The American Journal of CLINICAL NUTRITION HOME
C. von Schacky
n-3 Fatty acids and the prevention of coronary atherosclerosis1
Am. J. Clinical Nutrition, January 1, 2000; 71(1): 224S - 227S.
[Abstract] [Full Text] [PDF]

THE ANNALS OF THORACIC SURGERY HOME
L. Gruberg, G. S. Mintz, L. F. Satler, K. M. Kent, A. D. Pichard, and M. B. Leon
Intravascular imaging and physiologic lesion assessment to define critical coronary stenoses
Ann. Thorac. Surg., October 1, 1999; 68(4): 1547 - 1551.
[Abstract] [Full Text] [PDF]

Journal of the American College of Cardiology HOME

P. J. Scanlon, D. P. Faxon, A.-M. Audet, B. Carabello, G. J. Dehmer, K. A. Eagle, R. D. Legako, D. F. Leon, J. A. Murray, S. E. Nissen, *et al.*

ACC/AHA guidelines for coronary angiography: A report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Committee on Coronary Angiography) developed in collaboration with the Society for Cardiac Angiography and Interventions

J. Am. Coll. Cardiol., May 1, 1999; 33(6): 1756 - 1824.

[Full Text] [PDF]

HEART ONLINE and EDUCATION IN HEART HOME

S C Eccleshall, P J Jordan, N P Buller, and J N Townend

In vitro validation of the luminal measurement of a novel catheter based moulding technique

Heart, February 1, 1999; 81(2): 206 - 211.

[Abstract] [Full Text]

European Heart Journal HOME

P.W. Serruys, D.P. Foley, G. Jackson, H. Bonnier, C. Macaya, M. Vrolix, A. Branzi, J. Shepherd, H. Suryapranata, P.J. de Feyter, *et al.*

A randomized placebo-controlled trial of fluvastatin for prevention of restenosis after successful coronary balloon angioplasty: Final results of the fluvastatin angiographic restenosis (FLARE) trial

Eur. Heart J., January 1, 1999; 20(1): 58 - 69.

[Abstract] [PDF]

Circulation HOME

E. V. Pomerantsev, Y. Kobayashi, P. J. Fitzgerald, E. Grube, W. J. Sanders, E. L. Alderman, S. N. Oesterle, P. G. Yock, and S. H. Stertzer

Coronary Stents : In Vitro Aspects of an Angiographic and Ultrasound Quantification With In Vivo Correlation

Circulation, October 13, 1998; 98(15): 1495 - 1503.

[Abstract] [Full Text] [PDF]

Circulation HOME

P. W. Serruys, C. di Mario, J. Piek, E. Schroeder, C. Vrints, P. Probst, B. de Bruyne, C. Hanet, E. Fleck, M. Haude, *et al.*

Prognostic Value of Intracoronary Flow Velocity and Diameter Stenosis in Assessing the Short- and Long-term Outcomes of Coronary Balloon Angioplasty : The DEBATE Study (Doppler Endpoints Balloon Angioplasty Trial Europe)

Circulation, November 18, 1997; 96(10): 3369 - 3377.

[Abstract] [Full Text]

Circulation HOME

J. A. Ormiston, F. M. Stewart, A. H. G. Roche, B. J. Webber, R. M. L. Whitlock, and M. W. I. Webster

Late Regression of the Dilated Site After Coronary Angioplasty : A 5-Year Quantitative Angiographic Study

Circulation, July 15, 1997; 96(2): 468 - 474.

[Abstract] [Full Text]

Circulation HOME

Y. Ozaki, A. G. Violaris, T. Kobayashi, D. Keane, E. Camenzind, C. Di Mario, P. de Feyter, J. R. T. C. Roelandt, and P. W. Serruys

Comparison of Coronary Luminal Quantification Obtained From Intracoronary Ultrasound and Both Geometric and Videodensitometric Quantitative Angiography Before and After Balloon Angioplasty and Directional Atherectomy

Circulation, July 15, 1997; 96(2): 491 - 499.

[Abstract] [Full Text]

Circulation HOME

Y. Ozaki, D. Keane, P. Ruygrok, W. J. van der Giessen, P. de Feyter, and P. W. Serruys

Six-Month Clinical and Angiographic Outcome of the New, Less Shortening Wallstent in Native Coronary Arteries

Circulation, June 15, 1996; 93(12): 2114 - 2120.

[Abstract] [Full Text]

Circulation HOME

K. G. Lehmann, R. Melkert, and P. W. Serruys

Contributions of Frequency Distribution Analysis to the Understanding of Coronary Restenosis : A Reappraisal of the Gaussian Curve

Circulation, March 15, 1996; 93(6): 1123 - 1132.

[Abstract] [Full Text]

Circulation HOME

Y. Ozaki, D. Keane, and P. W. Serruys

Progression and Regression of Coronary Stenosis in the Long-term Follow-up of Vasospastic Angina

Circulation, November 1, 1995; 92(9): 2446 - 2456.

[Abstract] [Full Text]

Circulation HOME

E. J. Topol and S. E. Nissen

Our Preoccupation With Coronary Luminology : The Dissociation Between Clinical and Angiographic Findings in Ischemic Heart Disease

Circulation, October 15, 1995; 92(8): 2333 - 2342.
[Abstract] [Full Text]