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Coronary angiographic scoring systems: an evaluation of their equivalence and validity

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Structured Abstract

Background—Multiple scoring systems have been devised to quantify angiographic coronary artery disease (CAD) burden, but it is unclear how these scores relate to each other and which scores are most accurate. The aim of this study was to compare coronary angiographic scoring systems 1) with each other and 2) with intravascular ultrasound (IVUS) derived plaque burden in a population undergoing angiographic evaluation for CAD.

Methods—Coronary angiographic data from 3600 patients was scored using 10 commonly used angiographic scoring systems and inter-score correlations were calculated. In a subset of 50 patients, plaque burden and plaque area in the left anterior descending coronary artery was quantified using IVUS and correlated with angiographic scores.

Results—All angiographic scores correlated with each other (range for Spearman coefficient (ρ): 0.79–0.98, $p < 0.0001$); the two most widely used scores, Gensini and CASS-70, had a $\rho = 0.90$, $p < 0.0001$. All scores correlated significantly with average plaque burden and plaque area by IVUS (range ρ : 0.56–0.78, $p < 0.0001$ and 0.43–0.62, $p < 0.01$, respectively). The CASS-50 score had the strongest correlation (ρ : 0.78 and 0.62, $p < 0.0001$) and the Duke Jeopardy score the weakest correlation (ρ : 0.56 and 0.43, $p < 0.01$) with plaque burden and area, respectively.

Conclusions—Angiographic scoring systems are strongly correlated with each other and with atherosclerotic plaque burden. Scoring systems therefore appear to be a valid estimate of CAD plaque burden.

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Keywords

Atherosclerosis; Angiography; Coronary Disease; Intravascular Ultrasound; Scoring Systems

Introduction

Coronary angiography is an important tool for the quantification of CAD burden in both clinical practice and scientific investigation.¹ Researchers have attempted to define angiographic CAD burden using quantitative scoring systems. Historically, this was performed by designation of a single-, double-, triple-vessel and left main disease classification, with luminal stenosis of either 50 or 70% used to define significance.² However, this simple scoring system was limited in its ability to stratify patients with different levels of disease risk³, and led to the development of more comprehensive scoring systems for defining atherosclerotic burden and prognosis.³⁻⁴

Current scoring systems are heterogeneous, lack standardization, and have not been directly compared with each other. Some scoring systems are easily reproducible, have been validated in multiple settings, and provide prognostic value while others require sophisticated computer software and are not widely applicable.⁵⁻⁶ Additionally, use of angiography to estimate CAD burden is challenged by under- or over-estimation of atherosclerotic narrowing and diffuseness, limitations in technique and resolution, and disparities between lesion severity determined by angiography and true atherosclerosis burden.⁷⁻⁹

Intravascular ultrasound (IVUS) is a powerful tool for the evaluation of atherosclerosis and is more accurate and reproducible than coronary angiography for the assessment of atherosclerotic burden, because unlike angiography it measures wall atheroma and not just luminal encroachment.¹⁰⁻¹⁴ Because widespread use of IVUS is limited by cost and availability and since the vast majority of CAD registries continue to use angiography to measure atherosclerosis severity, it is important to determine the relationship between IVUS and angiographic assessment of CAD burden. Therefore, using a comprehensive coronary angiographic database, we sought to 1) compare different angiographic CAD burden scores with each other, and 2) determine which scoring systems most accurately estimate IVUS-derived plaque burden and area.

Methods

Study Population

Analysis was performed in 3600 consecutive patients enrolled in the Emory Cardiology Biobank prior to undergoing elective or emergent cardiac catheterization across three Emory Healthcare sites, between 2003 and 2009. Patients were interviewed to collect information on demographic characteristics, medical history and behavioral habits. Risk factor prevalence was determined by physician diagnosis and/or treatment for associated medical conditions such as hypertension, dyslipidemia, and diabetes mellitus. Medical records were reviewed to confirm self reported history as well as to document previous angiographic findings and prior coronary revascularization. Laboratory data was collected at the time of enrollment. The study was approved by the Institutional Review Board of Emory University, Atlanta, GA and all subjects provided written informed consent.

Coronary Angiography Image Acquisition and Analysis

All patients underwent coronary angiography interpreted by two independent clinical observers with lesions recorded using a 17 segment modified AHA model.¹⁵ Angiographic

scoring systems were applied to all values using a formulaic approach. Patients with prior percutaneous coronary intervention (PCI) or coronary artery bypass grafting (CABG) were scored based on pre-procedural disease. Inter-observer agreement with lesion scoring was determined using an intra-class correlation coefficient. The authors (I.J.N and R.S.P.) independently examined 25 randomly chosen angiograms, visually estimated lesion scores, and calculated Gensini and Sullivan Extent scores. The intra-class correlation coefficients were estimated at 0.88 (95% CI 0.74-0.95) and 0.90 (0.77-0.96) for Gensini and Sullivan Extent scores, respectively, indicating good inter-observer agreement.¹⁶

Angiographic Scoring Systems

A literature search was performed in the MEDLINE electronic database using the search terms “coronary angiography score” and the individual score name. A separate search was also performed in the Google Scholar electronic database using the title of the original paper reporting the score. The most commonly used angiographic scoring systems from the literature were then selected for analysis based on the frequency of citations in MEDLINE and Google Scholar (Table 1). All scores were systematically evaluated on three points: 1) number of epicardial vessels with associated branches incorporated into the score, with higher weight given to scores with more inclusive criteria, 2) detailed assessment of lesion severity with higher weight given to scores incorporating varying degrees of lesion stenosis and recognition of accepted criteria for hemodynamic or interventional significance (i.e.

50%), and 3) quantification of the functional significance of myocardium affected by stenotic lesions, with higher weight given to scores incorporating a greater number of epicardial and associated branch vessels. The ten scoring systems most frequently cited in the literature and most widely applicable were then chosen for inclusion in the final analysis. A detailed description of each angiographic scoring system is provided in the **Supplementary Appendix**.

Intravascular Ultrasound Image Acquisition and Analysis

Fifty patients enrolled in the Biobank were also enrolled in an IVUS sub-study with inclusion and exclusion criteria and image acquisition methods as previously described.¹⁷ In brief, IVUS image acquisition in this patient subset was performed in the non-obstructed left anterior descending (LAD) coronary artery after administration of 200µg intracoronary nitroglycerin using a phased-array 20 MHz Eagle Eye® Gold Catheter and s5™ Imaging System (Volcano Corp., Rancho Cordova, California). Automated continuous pullback at a rate of 0.5 mm/s was performed in the proximal 60 mm of the LAD to acquire an average of 120 IVUS frames per patient. IVUS measurements of external elastic membrane (EEM), plaque (EEM - lumen), and lumen cross-sectional areas were performed for every recorded IVUS frame at 0.5 mm intervals, and were averaged over the entire studied segment. Plaque area was calculated as EEM area minus lumen area (reported in mm²) averaged over the imaged vessel and plaque burden was calculated as plaque area divided by EEM area (reported as a percentage).¹⁸ Intra-observer analysis was performed by an experienced analyst in random samples of 10 patients (n=886 IVUS frames) at least 2 weeks apart, demonstrating good reproducibility for plaque area (concordance correlation coefficient = 0.968 [95% CI: 0.965-0.971]).

Statistical analysis

Continuous variables are presented as means (standard deviation) or medians (interquartile range) as appropriate and categorical variables are presented as proportions (%). Spearman's rank correlation coefficients were used to correlate the discontinuous and non-normally distributed score data. Angiographic scores were correlated with each other and with IVUS average percent plaque burden and average plaque area. Spearman's multiple rho rank

correlation between all IVUS measures and the angiographic score, representing the square root of the R-square from a multiple linear regression model predicting the rank of the angiographic score from multiple IVUS predictors, was also calculated for each scoring system. Two-sided p values <0.05 were designated as statistically significant. SAS 9.2 software (SAS, Inc., Cary, North Carolina) was used for the statistical analysis.

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Results

A total of 3600 consecutive patients with complete angiographic data were included in the analysis. The cohort consisted of 66% males, median age 63 (interquartile range 55 to 71) years, the majority of whom were Caucasian (79.7%) (Table 2). The prevalence of traditional risk factors was high and 62% of patients had prior PCI or CABG.

Angiographic Scoring Systems and Inter-Score Correlations

Ten scoring systems were included in the final analysis: CASS-50,² CASS-70,² Gensini,³ Duke Jeopardy,¹⁹⁻²⁰ Duke CAD Severity Index,²¹ Friesinger,²²⁻²³ Sullivan Vessel, Sullivan Stenosis, Sullivan Extent,²⁴ and Jenkins²⁵ scores (Table 3). Correlation analysis demonstrated that scoring systems were highly linearly correlated with each other (range for ρ : 0.79-0.98, $p<0.0001$ for all correlations, Table 4). The two most widely used scores in the literature, Gensini and CASS-70, had a correlation of $\rho = 0.90$, $p<0.0001$ (Figure 1).

Angiographic Scores and IVUS

Angiographic scoring systems were all highly correlated with atherosclerotic plaque burden (range for ρ : 0.56-0.78, $p<0.0001$ for all correlations) and moderately correlated with plaque area (range for ρ : 0.43-0.62, $p<0.01$ for all correlations, Table 5). The CASS-50 score had the strongest correlation with both plaque burden and plaque area (ρ : 0.78 and 0.62, $p<0.0001$, Figure 2) and the highest correlation with all IVUS parameters in a multiple linear regression model (Spearman's multiple rho rank correlation: 0.76, $p<0.0001$, Table 5). The Duke Jeopardy score had the weakest correlation with both parameters (ρ : 0.56 and 0.43, $p<0.01$).

Discussion

In a large registry of patients carefully phenotyped for angiographic CAD, we demonstrate that commonly used angiographic scoring systems are 1) strongly correlated with each other and 2) strongly correlated with IVUS derived measures of atherosclerotic plaque burden in the LAD artery, even in the absence of significant luminal stenosis.

Since the advent of coronary angiography, multiple scoring systems have been devised for the quantification of CAD burden. Although previous studies have examined the association of scores with outcomes such as mortality and disease progression, there is little data on how different scores relate to each other.^{5,16,26} Our results demonstrate that, regardless of the degree of heterogeneity among systems, scores are highly and consistently correlated with each other. The high degree of correlation between scores indicates that the measured proportion of intra-individual disease burden remains consistent despite increasing

complexity of scoring systems. However, we observed progressively greater inter-score variability as scores increased (e.g., Gensini scores at a CASS score of 4), suggesting that simple scoring systems have limited discriminative ability compared with more complex systems at higher levels of CAD burden. Overall, our findings support the validity of direct comparisons and interpretation of scores between studies.

Despite its many limitations, coronary angiography remains the gold standard for the diagnosis of CAD. Angiographic assessment of disease burden, however, is limited to visualization of luminal narrowing. In contrast, IVUS provides visualization of intramural plaque and assessment of plaque contents. Previous studies have compared coronary angiographic and IVUS assessment of plaque burden in specific patient populations and in specific arterial segments but there is no data comparing overall angiographic assessment of CAD burden with IVUS using validated angiographic scoring systems.^{14,27} In addition, prior comparisons have shown only modest correlations for measures of lumen size, very weak correlations for plaque volume, and almost no correlation between quantitative coronary angiography for all arterial segments and single vessel IVUS.²⁷⁻²⁸ However, in a cohort of patients undergoing angiographic assessment of CAD, we demonstrate better correlations between IVUS-derived estimates of plaque burden in the LAD artery (both as individual parameters of plaque burden and area, and as a composite from multiple linear regression) and global angiographic CAD burden scores. Our data suggests that up to 61% of the variability in IVUS-derived plaque burden in a single vessel can be explained by the total angiographic burden. In contrast to a previous study²⁷ we also found a moderate correlation with plaque area. It is hypothesized that the lower correlation with plaque area may be due to preservation of luminal dimensions despite outward arterial remodeling and externally directed intramural plaque growth.²⁹ Importantly, our findings of a strong association between overall angiographic burden and IVUS-derived estimates of plaque burden in the LAD artery suggest that patients with a greater total burden of atherosclerosis in a single non-critically narrowed coronary artery by IVUS may also have a sum total greater degree of luminal compromise throughout the coronary tree. This association may explain why the angiographic burden³⁰ and IVUS plaque burden³¹ are consistently more important than single lesion angiographic stenosis in prediction of future adverse cardiac events.

Despite methodological concerns over coronary angiography as a tool for use in clinical trials, our data supports its clinical and investigative utility as a measure of CAD burden. Although we cannot extrapolate our findings to progression of CAD, our study helps validate the use of cross-sectional angiographic burden scores for both clinical and research purposes since they are both accurate (correlative with IVUS plaque burden) and precise (correlative with each other). Angiographic scoring systems may be used as valid estimates of CAD burden for use in future studies when IVUS is not available.

Strengths and Limitations

Strengths of this study include a large sample size, use of a variety of commonly cited angiographic scoring systems, and availability of detailed IVUS measurements for use in correlation analysis. There are also some important limitations of our study. First, IVUS was only available in a small subset of the cohort and only in the LAD artery. Second, angiograms were scored by visual estimate alone albeit by two experienced investigators; no quantitative coronary angiography scoring software was used in this study. Third, the subjects in whom IVUS was performed represent a distinct population of patients undergoing angiographic assessment for symptomatic CAD and our findings are not necessarily generalizable to the general population with obstructive CAD. Third, our data do not necessarily support the use of one score over another since the correlation coefficients between plaque burden and scores were similar. Further investigation is needed to determine

which score (if any) has the most reproducible and comprehensive utility for estimation of CAD burden in clinical investigation. Importantly, these data do not address the performance of angiographic scoring systems with respect to functional or physiologic significance of coronary lesions.

In conclusion, our study demonstrates that angiographic CAD burden scoring systems used in the literature are 1) strongly correlated with each other and 2) strongly correlated with IVUS plaque burden and moderately correlated with IVUS plaque area, and therefore may be used to provide valid assessments of CAD burden for use in clinical practice and research investigation.

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Abbreviations

CAD	Coronary Artery Disease
IVUS	Intravascular Ultrasound
LAD	Left Anterior Descending
PCI	Percutaneous Coronary Intervention
CABG	Coronary Artery Bypass Grafting

Figure 1. Distribution of Gensini scores with CASS-70 scores
 $\rho = 0.90, p < 0.0001$

Figure 2. Distribution of Average Percent Plaque Burden with CASS-50 scores
 $\rho = 0.78, p < 0.0001$

Table 1

Angiographic Scoring Systems

Scoring System	No. of Citations in MEDLINE/GOOGLE SCHOLAR	No. of Vessels Involved	Severity of Lesion	Functional Significance of Lesion	Comments
Gensini*	962	+++	+++	+++	Most widely used
CASS*	181	++	++	+	Oldest scoring system
Duke CAD Severity Index*	286	++	+++	++	Prognostic value
Syntax	783	+++	+++	+	Requires computer algorithm
Duke Jeopardy*	317	+++	++	++	Widely used, well validated
BARI Jeopardy Index	100	+++	++	++	Requires computer algorithm
Jenkins*	212	+++	+++	+	Uses proximal disease only
Friesinger*	273	+	+++	+	Modifies CASS score
Sullivan*	149	+++	+++	+++	3 separate scores
Approach	45	+++	++	+++	Varies with coronary anatomy

* = used in data analysis

Abbreviations: CAD, Coronary Artery Disease; CASS, Coronary Artery Surgery Study; BARI, Bypass Angioplasty Revascularization Investigation

Key:

No. of Vessels Involved: +++ : Includes all epicardial and branch vessels

++ : Includes all epicardial vessels only

+

Severity of Lesion : +++ : Includes varying degrees of stenosis; recognizes significance of stenosis per accepted criteria

++ : Includes one degree of stenosis only; recognizes significance of stenosis per accepted criteria

+

Functional Significance: +++ : Quantifies the functional significance of myocardium affected by stenotic lesions for the major epicardial and branch vessels

++ : Quantifies the functional significance of myocardium affected by stenotic lesions for select vessels only

+

: Does not quantify functional significance of myocardium (i.e. assigns same significance to all vessels and their targets)

Table 2
Patient Characteristics

Patient Characteristics	
Male (%)	66.0
Age (years)	63 (55-71)
African-American (%)	16.3
Caucasian (%)	79.7
Diabetes (%)	32.4
Hypertension (%)	69.6
Ever Smoked (%)	59.5
Hyperlipidemia (%)	68.8
Prior PCI (%)	40.8
Prior CABG (%)	22.2
Systolic Blood Pressure (mmHg)	135 (120-150)
Diastolic Blood Pressure (mmHg)	76 (68-84)
BMI (kg/m ²)	28.7 (25.4-33.1)
LDL-C (mg/dL)	93 (72-119)
HDL-C (mg/dL)	40 (33-48)
Glucose (mg/dL)	108 (97-129)
GFR (ml/min/1.73m ²)	84.6 (63.3-108.0)
Angiographic stenosis in LAD artery (%)	35 (10-50)
IVUS Average Plaque Burden in LAD artery (%)	41.1 (34.2-51.5)
IVUS Average Plaque Area in LAD artery (mm ²)	6.4 (4.7-8.5)

Data are presented as median (25th-75th percentile) or proportion (%) where indicated

Abbreviations: PCI, percutaneous coronary intervention; CABG, coronary artery bypass grafting; BMI, body mass index; LDL-C, low-density lipoprotein cholesterol; HDL-C, high-density lipoprotein cholesterol; GFR, glomerular filtration rate; LAD, left anterior descending; IVUS, intravascular ultrasound

Table 3**Angiographic Scores**

Score	Median (IQR)	Mean (SD)
Gensini	10.5 (0-44)	36.8 (57.1)
CASS-50	1 (0-2)	1.4 (1.2)
CASS-70	1 (0-2)	1.2 (1.2)
Duke Jeopardy	2 (0-6)	3.1 (3.6)
Duke CAD Severity Index	23 (0-48)	25.4 (25.9)
Friesinger	2 (0-6)	3.8 (4.1)
Sullivan Vessel	1 (0-2)	1.0 (1.1)
Sullivan Stenosis	4 (0-9)	5.1 (4.7)
Sullivan Extent	14.9 (0-31.5)	19.4 (19.2)
Jenkins	4 (0-8)	4.7 (4.6)

Abbreviation: IQR, interquartile range; SD, standard deviation

Table 4

Inter-Score Correlation Coefficients (ρ)

	Gensini	
CASS-50	0.89*	CASS-50
CASS-70	0.90*	0.94*
		CASS-70
Duke Jeopardy	0.90*	0.83*
		Duke Jeopardy
Duke CAD Severity Index	0.93*	0.87*
		Duke CAD Severity Index
Friesinger	0.92*	0.86*
		Friesinger
Sullivan Vessel	0.88*	0.88*
		Sullivan Vessel
Sullivan Stenosis	0.94*	0.95*
		Sullivan Stenosis
Sullivan Extent	0.90*	0.88*
		Sullivan Extent
Jenkins	0.94*	0.93*
		Jenkins

* $p < 0.0001$

Table 5
Correlation Coefficients (ρ) of Angiographic Scores with IVUS Plaque Burden and Plaque Area in the LAD artery

Scoring System	Correlation with Average Percent Plaque Burden (%)	Correlation with Average Plaque Area (mm ²)	Multiple Rho Rank Correlation with Plaque Burden and Plaque Area
Gensini	0.76 [*]	0.58 [*]	0.75 [*]
CASS-50	0.78 [*]	0.62 [*]	0.76 [*]
CASS-70	0.71 [*]	0.49 [*]	0.67 [*]
Duke Jeopardy	0.56 [*]	0.43 [*]	0.50 [†]
Duke CAD Severity Index	0.71 [*]	0.53 [*]	0.67 [*]
Friesinger	0.65 [*]	0.44 [*]	0.66 [*]
Sullivan Vessel	0.67 [*]	0.44 [*]	0.65 [*]
Sullivan Stenosis	0.78 [*]	0.58 [*]	0.74 [*]
Sullivan Extent	0.69 [*]	0.49 [*]	0.66 [*]
Jenkins	0.77 [*]	0.59 [*]	0.75 [*]

^{*}
 $p < 0.0001$

[†]
 $p = 0.003$

Abbreviation: LAD, left anterior descending