JAMA Internal Medicine | Original Investigation

Comparison of Physician Visual Assessment With Quantitative Coronary Angiography in Assessment of Stenosis Severity in China

Haibo Zhang, MD; Lin Mu, BS; Shuang Hu, PhD; Brahmajee K. Nallamothu, MD, MPH; Alexandra J. Lansky, MD; Bo Xu, MD; Georgios Bouras, MD; David J. Cohen, MD, MSc; John A. Spertus, MD, MPH; Frederick A. Masoudi, MD, MSPH; Jeptha P. Curtis, MD; Runlin Gao, MD; Junbo Ge, MD, PhD; Yuejin Yang, MD, PhD; Jing Li, MD, PhD; Xi Li, MD, PhD; Xin Zheng, MD, PhD; Yetong Li, BS; Harlan M. Krumholz, MD, SM; Lixin Jiang, MD, PhD; for the China PEACE Collaborative Group

IMPORTANCE Although physician visual assessment (PVA) of stenosis severity is a standard clinical practice to support decisions for coronary revascularization, there are concerns about its accuracy.

OBJECTIVE To compare PVA with quantitative coronary angiography (QCA) as a means of assessing stenosis severity among patients undergoing percutaneous coronary intervention (PCI) in China.

DESIGN, SETTING, AND PARTICIPANTS A cross-sectional study (2012-2013) of a random subset of 1295 patients from the China Patient-centered Evaluative Assessment of Cardiac Events (PEACE) Prospective PCI Study was carried out. The PEACE Prospective PCI study recruited a consecutive sample of patients undergoing PCI at 35 hospitals in 18 provinces of China. The coronary angiograms of this subset of participants were reviewed using QCA by 2 independent core laboratories blinded to PVA readings.

MAIN OUTCOMES AND MEASURES Differences between PVA and QCA assessments of stenosis severity for lesions for which PCI was performed and variation of these differences among hospitals and physicians, stratified by the diagnosis of acute myocardial infarction (AMI).

RESULTS In patients without AMI, the mean (SD) age was 62 (10) years, and 217 (31.5%) were women; in patients with AMI, the mean (SD) age was 60 (11) years, and 153 (25.2%) were women. The mean (SD) percent diameter stenosis by PVA was 16.0% (11.5%) greater than that by QCA in patients without AMI and 10.2% (12.3%) in those with AMI ($P < .001$ for both comparisons). In patients without AMI, of 837 lesions with 70% or more stenosis by PVA, 427 (50.6%) were less than 70% by QCA; in patients with AMI, similar patterns were observed to a lesser extent. Among patients without AMI, only 4 (0.47%) lesions were additionally assessed with fractional flow reserve. Among 30 hospitals, the difference between PVA and QCA readings of stenosis severity varied from 7.6% (95% CI, 0.4%-14.7%) to 21.3% (95% CI, 17.1%-24.9%) among non-AMI patients. Across 57 physicians, this difference varied from 6.9% (95% CI, −1.4%-15.3%) to 26.4% (95% CI, 21.5%-31.4%).

CONCLUSIONS AND RELEVANCE For coronary lesions treated with PCI in China, PVA reported substantially higher readings of stenosis severity than QCA, with large variation across hospitals and physicians. These findings highlight the need to improve the accuracy of information used to guide treatment decisions in catheterization laboratories.

JAMA Intern Med. 2018;178(2):239-247. doi:10.1001/jamainternmed.2017.7821
Published online January 16, 2018.

Editor's Note page 247

Supplemental content

Author Affiliations: Author affiliations are listed at the end of this article.

Group Information: The China PEACE Collaborative Group members are listed at the end of this article.

Corresponding Author: Lixin Jiang, MD, PhD, National Clinical Research Center of Cardiovascular Diseases, Fuwai Hospital, 167 Beilishi Rd, Beijing 100037, People's Republic of China (jiangl@fwoxford.org).

Coronary angiography is performed to determine the presence and severity of coronary stenosis, thus guiding the treatment for patients with coronary artery disease. Physician visual assessment (PVA) of stenosis severity remains the standard method for guiding revascularization. The 2017 American College of Cardiology and American Heart Association Appropriate Use Criteria for revascularization for patients with stable angina defines a significant coronary stenosis as 70% or more luminal diameter narrowing by visual assessment or 40% to 70% with an abnormal fractional flow reserve (FFR) of 0.80 or less.[1]

Over the past 2 decades, the decision to perform percutaneous coronary intervention (PCI) has typically occurred at the time of angiography (ie, ad hoc PCI),[2] which makes the accuracy of operator assessment particularly crucial.[3,4] Limitations in PVA accuracy have been described for decades, with substantial, well-documented interobserver and intraobserver variability compared with computer-assisted methods.[5-8] A US study[9] in 2013 identified marked differences in diagnostic angiographic interpretation between PVA and quantitative coronary angiography (QCA), a highly reproducible computer-assisted technique that is commonly used in research settings.[10] However, the findings of the study were not definitive because it included only 175 angiograms from 7 high-volume centers. Furthermore, it is not known whether this phenomenon is unique to the United States (possibly related to its health care financing system) or is present in other countries. This is important because many treated lesions were much less severe by QCA than PVA, and an adjunctive functional assessment of lesion severity, such as FFR, was rarely employed despite its proven benefits with respect to decision-making.[11,12] If PVA is not consistently reliable when compared with more objective measures like QCA, then that would highlight the need to incorporate methods to achieve more accurate and reproducible measures of ischemia or lesion severity into routine clinical care.

Understanding angiographic quality in China is important because procedural volumes are growing rapidly, despite limited health care resources. In China, the PCI volume has increased more than 20-fold in the past decade, nearly 90% of which are performed as ad hoc PCIs at the time of diagnostic angiography.[13] To date, no national efforts have been undertaken to identify the accuracy and variation of PVA of coronary angiograms compared with QCA. Such insights can inform clinicians as to the accuracy of their interpretations and potentially spur strategies to improve angiographic interpretations in China and other countries.

In this study, we compared interpretations of PCI-treated lesions by PVA vs QCA for clinical interpretation of coronary stenosis severity using a diverse contemporary sample of patients in China. Specifically, we randomly selected coronary angiograms from patients participating in the China Patient-centered Evaluative Assessment of Cardiac Events (PEACE) Prospective PCI Study.[14] Among those lesions treated with PCI, we compared QCA assessment that was performed independently by trained analysts in 2 core laboratories blinded to the clinical readings by site operating physicians.

Key Points

Question How much does physician visual assessment differ from quantitative coronary angiography in the interpretation of coronary stenosis severity among adults undergoing percutaneous coronary intervention in China?

Findings In this cross-sectional study that included 1295 adults, the mean percent diameter stenosis by physician visual assessment was 16.0% greater than that by quantitative coronary angiography in patients without acute myocardial infarction, and 10.2% greater in those with acute myocardial infarction. Results were significant in both comparisons.

Meaning The accuracy of coronary stenosis interpretation by physician visual assessment requires improvement to better inform treatment decisions in catheterization laboratories.

Methods

Data Sources and Study Sample

The design of China PEACE-Prospective PCI Study has been described previously.[14] In brief, it is a national study to assess long-term clinical outcomes, cardiovascular risk factor control, and the appropriate use of PCI procedures. From 2012 to 2013, 4225 consecutive patients undergoing PCI for ischemic heart disease and requiring implantation of at least 1 coronary stent were enrolled at 40 hospitals in 18 provinces in China. The central ethics committee at the China National Center for Cardiovascular Disease/Fuwai Hospital, local internal ethics committees at all sites, and the Yale University institutional review board approved this study. All patients provided written informed consent. The study is registered at clinicaltrials.gov (NCT01624922).

Patient demographic and clinical data were collected through central medical chart abstraction, including information on lesion location and stenosis severity before PCI. We obtained coronary angiograms from patients who underwent PCI and selected a random subset for QCA reviews by 2 independent angiographic core laboratories: the Core Laboratory of the Company of Cardiovascular Research Foundation (Fuwai Core Laboratory; Beijing, China), which reviewed 981 angiograms, and the Yale Angiographic Core Laboratory (Yale Core Laboratory; New Haven, CT), which reviewed 402 angiograms. To compare readings between core laboratories, both laboratories reviewed the same angiograms from 105 patients, corresponding to 127 treated lesions. This comparison showed a high consistency between laboratories (eTable 1 in the Supplement).

We excluded patients who had previously undergone coronary artery bypass grafting, because revascularization thresholds in this group may differ from those with a native coronary disease. We included and separately analyzed patients with acute myocardial infarction (AMI), which was defined as an increase in cardiac biomarker levels (ie, troponin or creatine kinase) with at least 1 value above the ninety-ninth percentile of the upper reference limit with other clinical evidence of myocardial ischemia (ie, symptoms of ischemia or electrocardiographic changes indicative of new ischemia).

Quantitative Coronary Angiography

Trained analysts at core laboratories independently reviewed all films blinded to all other clinical information, including the clinical interpretation by the site operating physicians. Quantitative assessments were performed using the same validated software in both laboratories, Cardiovascular Measurement System (QAngio XA 7.2, MEDIS), a personal computer-based system, for offline quantitative angiographic analysis. Specific features of this system include 2-point user-defined path line (centerline) identification, arterial contour detection with a minimal-cost matrix algorithm, and an interpolated reference vessel diameter. The interpolated reference vessel diameter is a broadly accepted and well-validated method of measuring reference diameter by QCA; it is obtained at the site of minimal lumen diameter and derived by an iterative linear regression technique that is operator-independent and accounts for vessel tapering.[15] The minimal lesion diameter was used to calculate the percent diameter stenosis relative to the interpolated reference vessel diameter of the lesion of interest. The core laboratories assessed the reference and minimal lesion diameters from the single-best-available projection with the least foreshortening that best demonstrated the stenosis as selected by the analyst.

Statistical Analysis

We first reported the descriptive statistics of our study population and then compared the percent diameter stenosis by PVA vs QCA by means of analysis of variance (ANOVA) across subgroups, which were defined by lesion stenosis severity, location, length, reference vessel diameter, and the use of FFR or intravascular ultrasound (IVUS).

We further evaluated concordance between these 2 assessment methods for assessing percent stenosis, first as continuous variables by means of Pearson correlation and simple linear regression, and then as categorical variables by means of Cohen's weighted κ at a priori cutoffs (<50%, 50% to <70%, 70% to <90%, 90% to <100%, and 100%).[9] In patients with multiple lesions, all treated lesions were included. For angiograms reviewed by both core laboratories, the results from the Fuwai Core Laboratory were used for the main analysis. In sensitivity analyses, we assessed correlation and concordance by PVA vs QCA using results from each of the 2 core laboratories separately. We also restricted analyses of the lesions to only those without thrombus or extensive calcium deposits by QCA. Considering the clinical differences between elective and acute PCI, we analyzed patients with and without AMI separately.

Last, we fitted a mixed model to assess the variation among hospitals and physicians in coronary stenosis diameter in patients with and without AMI. In assessing these variations, we only included hospitals that had at least 5 cases in the study sample of angiograms. All analyses were conducted using SAS statistical software (version 9.3, SAS Institute Inc).

Results

Study Population

The study sample included 1295 patients who underwent PCI of 1548 lesions by 176 physicians at 35 hospitals in 18 provinces of China. This included 689 patients (844 treated lesions) without AMI and 606 patients (704 treated lesions) with AMI. Among patients without AMI, 674 (97.8%) underwent ad hoc PCI (ie, PCI at the same time as angiography). A total of 31 (4.5%) reported no symptoms of ischemia before admission. Among patients with AMI, 452 (74.6%) had ST-segment elevation myocardial infarction (STEMI). **Table 1** shows patients' demographic and clinical characteristics.

Table 1. Baseline Characteristics of Patients Undergoing PCI by AMI Status

Characteristic	No. (%) Patients Without AMI	No. (%) Patients With AMI
Total patients, No.	689	606
Age, y		
<50	79 (11.5)	111 (18.3)
50-59	175 (25.4)	180 (29.7)
60-69	254 (36.9)	203 (33.5)
70-79	162 (23.5)	93 (15.3)
≥80	19 (2.8)	19 (3.1)
Age, mean (SD), y	62 (10)	60 (11)
Women	217 (31.5)	153 (25.2)
Comorbidities and cardiovascular risk factors		
Diabetes mellitus	214 (31.1)	165 (27.2)
Hypertension	495 (71.8)	356 (58.7)
Dyslipidemia	325 (47.2)	209 (34.5)
Current smoker	264 (38.3)	341 (56.3)
eGFR on admission, mean (SD)	80.9 (21.6)	87.8 (25.1)
Medical history		
Myocardial infarction	115 (16.7)	53 (8.7)
PCI	123 (17.9)	50 (8.3)
Heart failure	242 (35.1)	55 (9.1)
Stroke	112 (16.3)	91 (15.0)
No symptoms of ischemia before admission	31 (4.5)	2 (0.3)
Multivessel disease[a]	392 (56.9)	358 (59.1)
Mean SYNTAX score for angiographic complexity (by core laboratory), Mean (SD)	12.3 (8.4)	15.8 (9.3)
Ad hoc PCI	674 (97.8)	NA
Stress test performed	21 (3.0)	1 (0.2)

Abbreviations: AMI, acute myocardial infarction; eGFR, estimated glomerular filtration rate; NA, not applicable; SYNTAX, synergy between percutaneous coronary intervention with TAXUS and cardiac surgery; PCI, percutaneous coronary infarction; QCA, quantitative coronary angiography.

[a] Defined as percent diameter stenosis by physician visual assessment 50% or greater in left main or 70% or greater in other major coronary vessels.

Comparison of PVA and QCA

Of the 1548 treated lesions, the mean (SD) stenosis severity reported by PVA was 87.7% (8.7%) among patients without AMI and 93.7% (8.0%) among patients with AMI. In contrast, the mean (SD) stenosis severity by QCA was 71.7% (14.8%) and 83.6% (16.5%), respectively.

Table 2 lists the mean difference in coronary stenosis severity between PVA and QCA among subgroups of different lesion characteristics, stratified by AMI status. The mean (SD) difference in percent diameter stenosis between PVA and QCA was 16.0% (11.5%) in non-AMI patients and 10.2% (12.3%) in

Table 2. Mean Difference (PVA minus QCA) in Stenosis Severity Between PVA and QCA Across Subgroups by AMI Status

	Lesions From Patients Without AMI			Lesions From Patients With AMI		
Category	No. (%)	Mean Difference, % (SD)	*P* Value[a]	No. (%)	Mean Difference, % (SD)	*P* Value[a]
All lesions	844 (54.5)	16.0 (11.5)		704 (45.5)	10.2 (12.3)	
Lesion location			.21			.16
Left main	6 (0.7)	0.2 (19.6)		1 (0.1)	25.6 (0.0)	
Left anterior descending	350 (41.5)	16.6 (11.9)		286 (40.6)	10.7 (12.5)	
Left circumflex	201 (23.8)	15.9 (10.5)		157 (22.3)	11.0 (12.6)	
Right	287 (34.0)	15.7 (11.3)		260 (36.9)	9.0 (11.9)	
Percent diameter stenosis by QCA			<.001			<.001
<50%	7 (0.8)	36.9 (10.5)		2 (0.3)	43.3 (3.3)	
50% to <70%	420 (49.8)	23.3 (7.8)		174 (24.7)	25.5 (8.7)	
70% to <90%	286 (33.9)	12.2 (8.0)		205 (29.1)	12.8 (8.6)	
90% to <100%	68 (8.1)	0.8 (6.2)		45 (6.4)	1.2 (4.9)	
100%	63 (7.5)	−0.90 (4.5)		278 (39.5)	−0.1 (1.4)	
Percent diameter stenosis by PVA			<.001			<.001
50% to <70%	7 (0.8)	−3.9 (14.4)		2 (0.3)	−11.3 (4.7)	
70% to <90%	349 (41.4)	17.7 (10.7)		116 (16.5)	14.0 (12.0)	
90% to <100%	415 (49.2)	17.3 (11.0)		291 (41.3)	17.4 (11.4)	
100%	73 (8.6)	2.8 (6.9)		295 (41.9)	1.7 (6.8)	
Lesion reference vessel diameter by QCA, mm			.03			.10
<2.5	253 (30.0)	15.1 (11.6)		223 (31.7)	8.9 (11.4)	
2.5 to <3	321 (38.0)	16.0 (11.1)		253 (35.9)	11.2 (13.6)	
3 to <3.5	195 (23.1)	16.2 (12.6)		180 (25.6)	9.6 (11.6)	
≥3.5	75 (8.9)	19.0 (9.5)		48 (6.8)	12.5 (11.9)	
Lesion length by QCA, mm			<.001			.01
<10	170 (20.1)	18.0 (10.9)		102 (14.5)	12.5 (13.1)	
10 to <20	351 (41.6)	17.3 (10.9)		309 (43.9)	11.0 (12.3)	
20 to <30	178 (21.1)	16.3 (11.3)		173 (24.6)	8.0 (11.6)	
≥30	140 (16.6)	10.5 (12.0)		115 (16.3)	9.6 (12.6)	
Unrecorded	5 (0.6)	7.1 (15.9)		5 (0.7)	0	
Use of a FFR/IVUS			.56			.23
Yes	12 (1.4)	14.5 (9.0)		6 (0.9)	17.9 (14.1)	
No	832 (98.6)	16.1 (11.5)		698 (99.1)	10.1 (12.3)	

Abbreviations: AMI, acute myocardial infarction; FFR, fractional flow reserve; IVUS, intravenous ultrasound; PVA, physician visual assessment; QCA, quantitative coronary angiography.

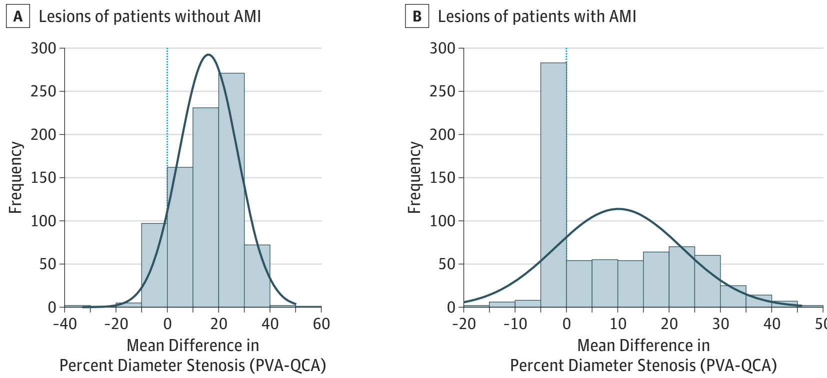
[a] *P* values represent significance for the *t* statistic in the overall population and *F* statistics for the analysis of variation across subgroups.

patients with AMI. In both groups, stenosis severity as determined by PVA was significantly higher than stenosis severity by QCA ($P < .001$ for both comparisons); the difference between PVA and QCA defined stenosis severity was greater among non-AMI patients compared with patients with AMI ($P < .001$). There was no significant difference in accuracy according to the vessel. In non-AMI patients, the difference was greater with shorter lesions and larger reference vessel diameters, but this pattern was not seen among patients with AMI (Table 2). Of 837 lesions assessed as 70% or greater by PVA in non-AMI patients, 427 (50.6%) were less than 70% by QCA and 203 (24.3%) were less than 60%.

eTable 2 in the Supplement shows a comparison between PVA and QCA after categorization according to a priori cutoffs, showing a weighted κ of 0.20 (95% CI, 0.17-0.23) in patients without AMI and 0.46 (95% CI, 0.42-0.49) in patients with AMI. Among patients without AMI, the most commonly calculated percent diameter stenosis by QCA was between 50% and less than 70% with 420 (49.8%) lesions in this category, and 7 (0.8%) lesions were calculated to be less than 50% by QCA. Among 7 lesions with a percent diameter stenosis less than 70% by PVA, only 1 IVUS was performed and no patient had documentation of a stress test or FFR prior to PCI. Among 42 lesions between 40% and 70% by PVA, the mean (SD) difference between PVA and QCA was 6.4% (13.6%). Among 423 lesions between 40% and 70% by QCA, 388 (91.7%) lesions were assessed as greater than 70% by PVA.

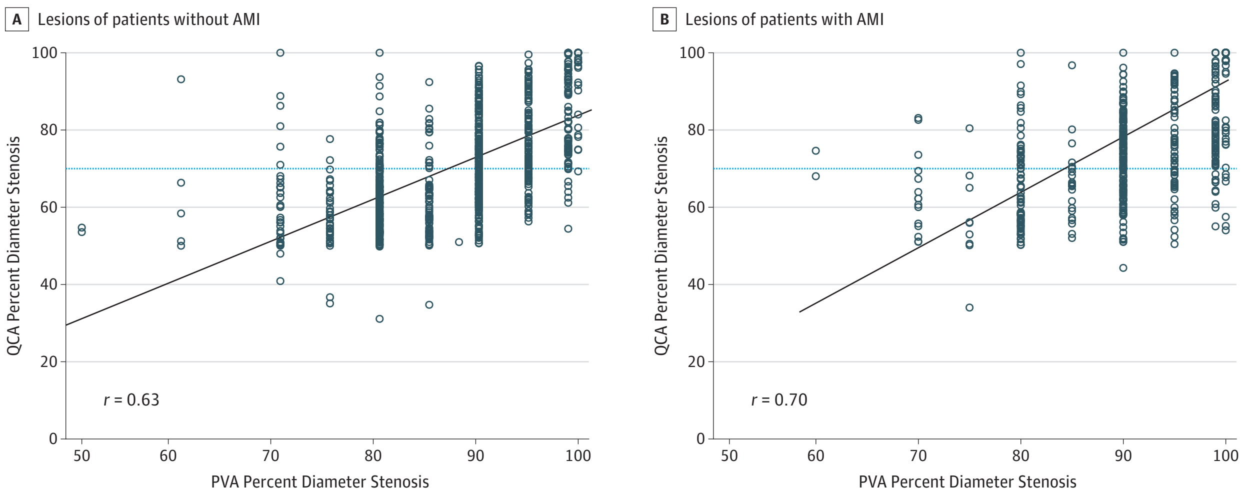
Figure 1 shows the distribution of the difference between PVA and QCA by AMI status. Stenosis severity defined by PVA was at least 20% greater than QCA in 346 (41.0%) of the lesions among non-AMI patients and in 178 (25.3%) of the lesions among patients with AMI. The correlation of percentages of stenosis between PVA and QCA (**Figure 2**) demonstrated a Pearson *c* of 0.63 ($P < .001$) in non-AMI patients and 0.70

Figure 1. Distribution of the Mean Difference in Percent Diameter Stenosis Between PVA and QCA by AMI Status



AMI indicates acute myocardial infarction; PVA, physician visual assessment; QCA, quantitative coronary angiography.

Figure 2. Comparison of the Percent Diameter Stenosis Between PVA and QCA by AMI Status



AMI indicates acute myocardial infarction; PVA, physician visual assessment; QCA, quantitative coronary angiography.

($P < .001$) in patients with AMI. In patients with AMI, among 409 lesions less than 100% by PVA, the mean (SD) difference between PVA and QCA was 16.3% (11.8%), and comparisons between PVA and QCA show a Pearson c of 0.42 ($P < .001$) and a weighted κ of 0.04 (95% CI, 0.02-0.06).

When the analyses were conducted using only results from each of the QCA laboratories, respectively, the results were qualitatively similar (eTable 3 in the Supplement). After excluding lesions with thrombus or extensive calcium deposits by QCA, we observed a similar pattern (795 patients without AMI: Pearson c = 0.63; $P < .001$; weighted κ = 0.20; 95% CI, 0.16-0.23; 553 patients with AMI: Pearson c = 0.68; $P < .001$; weighted κ = 0.41; 95% CI, 0.38-0.45).

Hospital and Physician Variation

In non-AMI patients, the overall mean difference between PVA and QCA readings of stenosis severity among all 30 hospitals was 16.0%, and hospital-specific differences ranged from 7.6% (95% CI, 0.4-14.7) to 21.3% (95% CI, 17.1-24.9); 9 (30.0%) hospitals differed significantly from the mean difference (**Figure 3**).

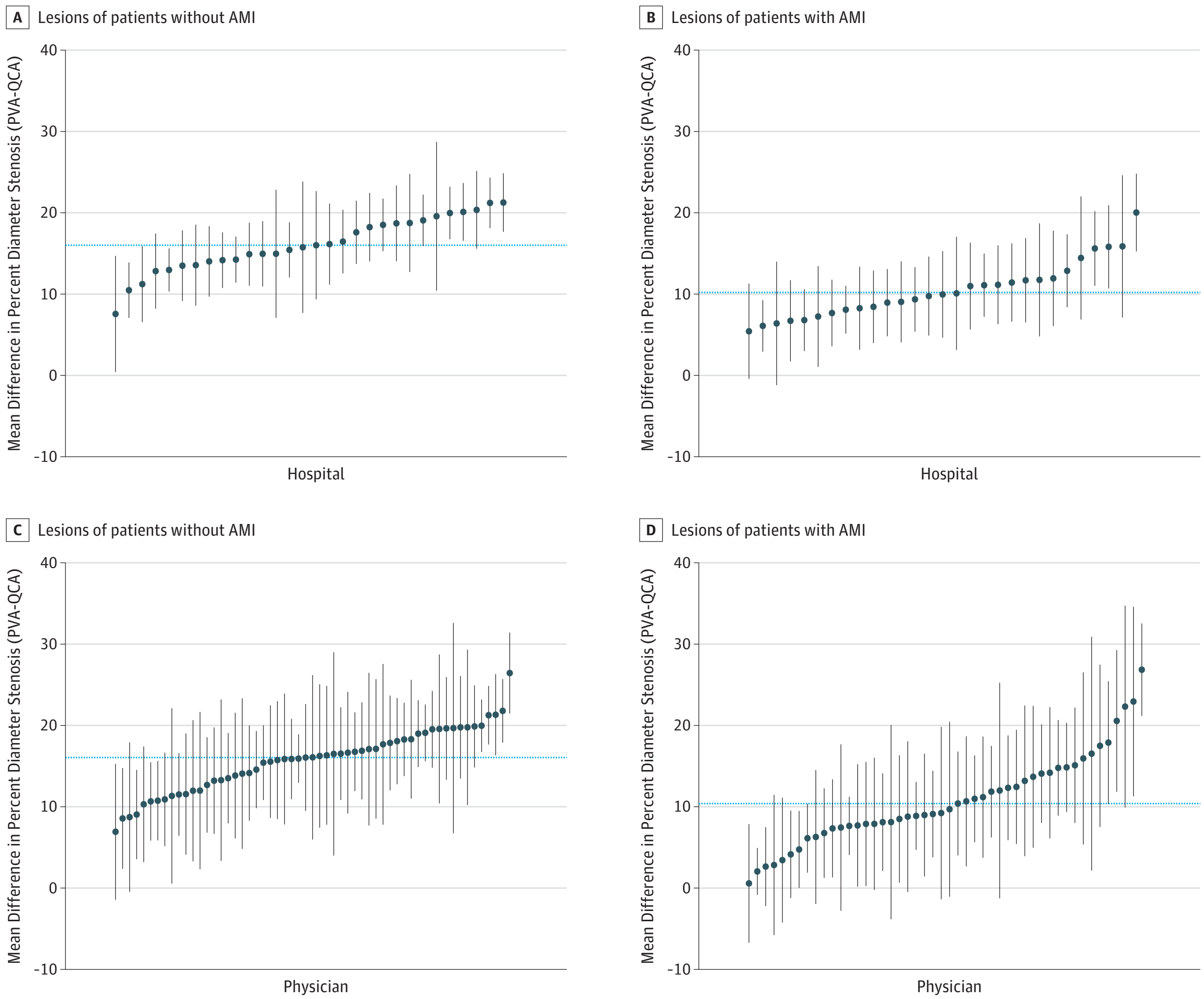
In patients with AMI, the overall mean difference among all 29 hospitals was 10.2%, and hospital-specific differences ranged from 5.4% (95% CI, −0.4 to 11.3) to 20.0% (95% CI, 15.2 to 24.8), with 4 (13.8%) hospitals significantly different from the overall mean difference (Figure 3).

In non-AMI patients, the overall mean difference among all 57 physicians was 16.0%, and the physician-specific difference ranged from 6.9% (95% CI, −1.4 to 15.3) to 26.4% (95% CI, 21.5 to 31.4). In AMI patients, the overall mean difference among all 48 physicians was 10.4%, and the physician-specific difference ranged from 0.6% (95% CI, −6.7 to 7.9) to 26.9% (95% CI, 21.2 to 32.5) (Figure 3).

Discussion

In a large population of patients and lesions treated with PCI in China, we found that PVA resulted in more severe stenosis determinations than those calculated using a core laboratory-derived QCA. Among non-AMI patients, nearly half of treated

Figure 3. Variations Across Hospitals and Among Physicians in the Mean Percent Diameter Stenosis Difference Between PVA and QCA by AMI Status



AMI indicates acute myocardial infarction; PVA, physician visual assessment; QCA, quantitative coronary angiography.

lesions were less than 70% by QCA, with a substantial proportion of lesions being less than 60%. These angiographic studies, which encompass a diverse group of procedures at these hospitals, rarely included FFR to assess functional severity of anatomical lesions. The discrepancies between PVA and QCA varied substantially at the hospital and physician level.

This study extends the existing literature in several important ways. First, to our knowledge it is the largest study to date to evaluate the interpretation of percent diameter coronary stenosis by PVA and QCA. It also demonstrates that the concerns raised in previous US-based studies also apply to China, where half a million PCIs are performed each year. Finally, owing to its large sample size, this study is the first to examine the variation between PVA- and QCA-defined stenosis severity across hospitals and physicians.

In China, the volume of PCI procedures performed has increased markedly in the past decade, accompanied by a rapid increase in the number of PCI-capable hospitals and interventional cardiologists.[16] Since 2009, the Chinese government has made considerable efforts toward PCI standardization, including certification of institutions and individuals and implementation of training requirements and quality controls.[17] Nevertheless, few efforts have been directed toward verifying the accuracy of the interpretation of angiograms, despite the pivotal importance of these interpretations in the decision to perform revascularization. Although panel readings have been shown to improve the accuracy of angiogram interpretation,[18,19] the proportion of ad hoc PCIs in China has increased rapidly,[13] thereby expanding the influence of inaccurate interpretations by individuals. Incorporating the accuracy of stenosis severity into quality assurance systems at the hospital and physician level may help to increase the accuracy of visual interpretation and minimize variations.

The study has several important implications. The assumption of accurate and reproducible assessment of coronary stenosis severity serves as the foundation for current clinical decisions regarding revascularization. Despite being challenged as long as 40 years ago,[7,20] owing to its convenience, efficiency, and ease of implementation, visual assessment is still the main method used to determine percent diameter stenosis in China and other countries. Given that the clinical standard, PVA, frequently resulted in an overestimate of lesion severity compared with the less subjective QCA, it is possible that revascularization would not have been pursued in some lesions—an implication that is similar to findings from the United States.

Our findings are particularly important in China, where functional assessments are rarely used and decisions about interventions rely heavily on PVA. Yet, this phenomenon is not unique to China; for example, in the US Medicare population, only 44.5% of patients underwent stress testing within the 90 days prior to elective PCI.[21] Moreover, health care resources in China are limited with respect to PCI capability relative to the growth of cardiovascular need and the population size, so there is a need to concentrate procedures where they are most needed. Also, many patients, despite national insurance, may have considerable out-of-pocket costs associated with these procedures, highlighting the need for prudent use of the procedures.

For our study, we employed methods similar to those used in a 2013 study in the United States[9] to permit a comparison of findings. Importantly, the mean difference between PVA and QCA interpretations of stenosis severity in non-AMI patients in China was twice as large as in the previous study (16% vs 8%). Using only the data from the same core laboratory as the US study, this mean difference was 17%, suggesting that PVA accuracy may be even lower in China than the United States. Among those lesions undergoing PCI, one-half of the PVA measurements were less than 70% by QCA in China, compared with approximately one-fourth of lesions in the United States.

There is a question about whether QCA should represent a gold standard against which to measure PVA. Quantitative coronary angiography has been widely used for decades in clinical research and, in selected cases, in clinical practice, owing to its reproducibility and validity.[10] Nevertheless, QCA has limitations, including a dependency on image quality and challenges in assessing complex lesions, such as those with thrombus or calcification. However, our findings remained robust when we excluded complex lesions. Furthermore, based on the 2017 Appropriate Use Criteria, angiographic determination of stenosis severity remains a cornerstone in revascularization decisions.[1]

There are potential remedies to the limitations of QCA. There is evidence that group reading can improve the accuracy of interpretations. Moreover, there may be ways to easily incorporate some of the principles of QCA into real-time practice, such as a standardized calibration process using specific catheters. Also, feedback to practitioners, enabling calibration of their interpretations, might be useful—as might be computerized training programs. In addition, the development of machine-learning techniques[22] may provide tools to help physicians interpret coronary stenosis more accurately. Finally, FFR may be estimated with techniques such as computational fluid dynamics.

Limitations

Certain limitations should be considered in the interpretation of this study. First, hospitals participating in the study represented a select group of tertiary care facilities, so we may have underestimated the magnitude of misinterpretation had less sophisticated hospitals been included. Second, owing to the small number of physicians in each hospital, we were unable to assess the between-physician variation in a hospital. Third, this is a pragmatic study of actual practice and we do not have details on how they produced their estimates of lesion severity. Finally, we did not evaluate cases where PCI was not performed and were unable to assess when angiographically severe stenoses were underappreciated.

Conclusions

In this large study of patients undergoing contemporary PCI in China, we found that PVA significantly overestimated coronary stenosis severity compared with independent measurements by QCA, supporting the need for greater use of functional assessments prior to the performance of PCI. Large variations across hospitals and among physicians suggest that efforts are urgently needed to improve the accuracy of interpretations of coronary angiograms and to optimize the selection of patients for PCI in current clinical practice.

ARTICLE INFORMATION

Accepted for Publication: November 3, 2017.

Published Online: January 16, 2018. doi:10.1001/jamainternmed.2017.7821

Author Affiliations: National Clinical Research Center of Cardiovascular Diseases, State Key Laboratory of Cardiovascular Disease and Division of Cardiology, Fuwai Hospital, National Center for Cardiovascular Diseases, Chinese Academy of Medical Sciences and Peking Union Medical College, Beijing, People's Republic of China (Zhang, Hu, Xu, Gao, Yang, J. Li, X. Li, Zheng, Y. Li, Jiang); Yale University School of Medicine, New Haven, Connecticut, United States (Mu); Center for Outcomes Research and Evaluation, Yale-New Haven Hospital, New Haven, Connecticut (Mu, Curtis, Krumholz); Ann Arbor VA Center for Clinical Management and Research and University of Michigan Health System, Ann Arbor, Michigan (Nallamothu); Yale University Medical Center, New Haven, Connecticut (Lansky, Bouras); Saint Luke's Mid America Heart Institute/University of Missouri-Kansas City, Kansas City, Missouri (Cohen, Spertus); Division of Cardiology, University of Colorado Anschutz Medical Campus, Aurora, Colorado, United States (Masoudi); Section of Cardiovascular Medicine and Robert Wood Johnson Clinical Scholars Program, Department of Internal Medicine, Yale University School of Medicine, New Haven, Connecticut (Curtis, Krumholz); Shanghai Institute of Cardiovascular Diseases, Zhongshan Hospital, Fudan University, Shanghai, People's Republic of China (Ge); Department of Health Policy and Management, Yale School of Public Health, New Haven, Connecticut (Krumholz).

Author Contributions: Dr Jiang had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis. Drs Zhang and Mu contributed equally to the study. Drs Krumholz and Jiang contributed equally to the study and are joint senior authors.
Study concept and design: Zhang, Mu, Lansky, Cohen, Ge, J. Li, Jiang.
Acquisition, analysis, or interpretation of data: Zhang, Mu, Hu, Nallamothu, Lansky, Xu, Bouras, Spertus, Masoudi, Curtis, Gao, Ge, Yang, J. Li, X. Li, Zheng, Y. Li, Krumholz.
Drafting of the manuscript: Zhang, Mu, Lansky, Y. Li.
Critical revision of the manuscript for important intellectual content: Zhang, Mu, Hu, Nallamothu, Lansky, Xu, Bouras, Cohen, Spertus, Masoudi, Curtis, Gao, Ge, Yang, J. Li, X. Li, Zheng, Krumholz, Jiang.

Statistical analysis: Mu, Hu, Lansky, X. Li, Y. Li.
Administrative, technical, or material support: Zhang, Bouras, Gao, Ge, Yang, J. Li, Zheng.
Study supervision: Lansky, Ge, Jiang.

Conflict of Interest Disclosures: Dr Krumholz is a recipient of research agreements from Medtronic and from Johnson & Johnson (Janssen), through Yale University, to develop methods of clinical trial data sharing; is the recipient of a grant from the Food and Drug Administration and Medtronic to develop methods for postmarket surveillance of medical devices; works under contract with the Centers for Medicare & Medicaid Services to develop and maintain performance measures; chairs a cardiac scientific advisory board for UnitedHealth; is a participant/participant representative of the IBM Watson Health Life Sciences Board; and is the founder of Hugo, a personal health information platform. Dr Spertus is supported by grants from Gilead, Genentech, Lilly, Amorcyte, and EvaHeart, and has a patent for the Seattle Angina Questionnaire with royalties paid. Dr Masoudi has a contract with the American College of Cardiology for his role as the Chief Science Officer of the NCDR. Dr. Cohen receives research grant support from Medtronic, Boston Scientific, and Abbott Vascular, and consulting fees from Medtronic. No other disclosures are reported.

Funding/Support: This project was supported by the Research Special Fund for Public Welfare Industry of Health (201202025, 201502009) from the National Health and Family Planning Commission of China, the National Key Technology R&D Program (2015BAI12B01, 2015BAI12B02) from the Ministry of Science and Technology of China, and the 111 Project (B16005).

Role of the Funder/Sponsor: The funding agencies had no role in the design and conduct of the study; collection, management, analysis, and interpretation of the data; preparation, review, or approval of the manuscript; and decision to submit the manuscript for publication.

Additional Contributions: We appreciate the multiple contributions made by study teams at the China Oxford Centre for International Health Research and the Yale-New Haven Hospital Center for Outcomes Research and Evaluation in the realms of study design and operation, particularly the data collection by Li Li, MD, Jiamin Liu, MD, Wenchi Guan, MD, PhD, Xiaofang Yan, MS, Ying Sun, BS, Siying Niu, BS, Qian Xiao, BS, Xuekun Wu, MS, Yuan Yu, MD, Fang Feng, MPH, Ning Zhang, BS, Qiulan Xie, BS, Jia Li, BS, Jianxin Zhang, BS, Hao Dai, MS, Hui Zhong, BS, Liping Zhang, BS, Yang Yang, BS, Yan Gao, MS, Siming Wang, BS, Xueke Bai, MS, Xiqian Huo, MD, and Bin Wang, MD. We appreciate the advice from Yun Wang, PhD, Department of Biostatistics, Harvard T.H. Chan School of Public Health. We are grateful for the support provided by the Chinese government.

The China PEACE Collaborative Group: Air Force General Hospital: PLA, Jianchang Wang, MD, Haitao Zhang, MD, Congchun Huang, MD; Anhui Provincial Hospital: Likun Ma, MD,Hao Hu, MD, Xiangyong Kong, MD; Baotou Central Hospital: Ruiping Zhao, MD, Wei Du, MD, Hongyu Li, MD; China-Japan Union Hospital of Jilin University: Ping Yang, MD,PhD, Zhaohui Feng, BN, Cuiying Mao, MD, Bing Li, MD; First Hospital of Shanxi Medical University: Qinghua Han, MD, PhD, Liqin Duan, MD, Chunrong Jin, MD; Fujian Provincial Hospital: Yansong Guo, MD, Xinjing Chen, MD, Feng Lin, MD; Fuwai Hospital, CAMS&PUMC (Ward 22): Yongjian Wu, MD, PhD, Yanmeng Tian, MD; Fuwai Hospital CAMS&PUMC (Ward 25B): Jianjun Li, MD, PhD, Chenggang Zhu, MD, Qian Dong, BN; General Hospital of China FAW Group Corporation: Hongtao Pan, MD, Peng Gao, MD, Lei Sun, MD; Guilin People's Hospital: Wei Zhang, MD, Shuyun Xie, MD, Yanni Zhuang, MD, Wei Li, MD; Inner Mongolia Baogang Hopital, Zhiping Ge, MD, Huihua Wen, MD, Qiaoling Liu, MD, Yongdong Li, MD; Inner Mongolia People's Hopsital: Yajun Han, MD, Ping Zhao, MD, Weiyi Zhao, MD; Jiangxi Provincial People's Hospital: Lang Hong, MD, Linfeng Li, MD, Lihua Yuan, MN, Yun Li, BN; Jinghai County Hospital: Peihua Zhao, MD, Jingsheng Sun, MD, Rengui Chai, MD; Nanyang Central Hospital: Shouzhong Yang, MD, Yudong Li, MD, Jianbu Gao, MD, Songyu Zhang, MD; Qingdao Fuwai Hospital: Ying Yang, MSPH, Guixin Wu, MD, Jiajia Mao, MN, Cheng Zheng, BS; Qinghai Cardiovascular and Cerebrovascular Hospital: Huiping Bian, MD, Bo Chen, MD, Jiandong Cao, MD; Qinzhou Second People's Hospital: Hua Yan, MD, Liyuan Chen, MD, Qiuxia Liu, MD, Lin Chen, MD; Shangxi Cardiovascular Hospital: Bao Li, MD, Bin Yang, MD, Jianhua Li, MD, Jianhong Wang, MD; Suzhou Kowloon Hospital, Shanghai Jiao Tong University School of Medicine: Feng Liu, MD, Xiangfei Meng, MD, Bo Shao, MD, Zhanling Liao, MD; TEDA International Cardiovascular Hospital: Zhigang Liu, MD, PhD, Wenbin Jing, MD, Zhipeng Guo, MD; The Affiliated Hospital of Qingdao University: Changyong Zhou, MD, Yini Wang, MD, Tao Yu, MD; The Affiliated Hospital of Xuzhou Medical College: Dongye Li, MD, Yuanyuan Luo, MD, Hong Zhu, MD; The First Affiliated Hospital of Fujian Medical University: Jinxiu Lin, MD, Dajun Chai, MD, Wenxiang Zhao, MD; The First Hospital of Jilin University: Yang Zheng, MD, PhD, Zhaoxi Liu, MD, Wenqian Zhou, MD, Lin Zou, MD; The Fourth Affiliated Hospital of China Medical University: Yuanzhe Jin, MD, Xiaohong Zhang, MD, Xueying Zhang, MD; The People's Hospital of Liaoning Province: Zhanquan Li, MD, Ying Liu, MD, Qian Yu, MD, Yan Xing, MD; The Second Affiliated Hospital of Xuzhou Medical College: Weiheng Wu, MD, Li Li, MD, Jianqi Feng, MD; The Second Affiliated Hospital of Zhengzhou University: Xianen Fa, MD, Lihua Zhang, MD, Liqiang Sun, MD Lei Liu, MD; The Second Hospital of Dalian Medical University: Peng Qu, MD, PhD, Hongyan Wang, MD, PhD, Dayuan Lou, MD, Dajun Yuan, MD, PhD; Tongji Hospital, Tongji Medical College, Huangzhong University of Science&Technology: Daowen Wang, MD, PhD, Xiaoqing Shen, MD, Jiangang Jiang, MD; Xiangtan Central Hospital: He Huang, MD, Jianping Zeng, MD, Mingxing Wu, MD, Yi Zhou, MD; Xinqiao Hospital, Xuzhou First People's Hospital: Hongju Zhang, MD, Liuxiao Jun, MD, Ming Hu, MD, Wei Li, MD; Zhengzhou Central Hospital: Lin Zhang, MD, Yumei Guo, MD, Huiling Sun, MD.

REFERENCES

1. Patel MR, Calhoon JH, Dehmer GJ, et al. ACC/AATS/AHA/ASE/ASNC/SCAI/SCCT/STS 2017 Appropriate Use Criteria for Coronary Revascularization in Patients With Stable Ischemic Heart Disease: A Report of the American College of Cardiology Appropriate Use Criteria Task Force, American Association for Thoracic Surgery, American Heart Association, American Society of Echocardiography, American Society of Nuclear Cardiology, Society for Cardiovascular Angiography and Interventions, Society of Cardiovascular Computed Tomography, and Society of Thoracic Surgeons. *J Am Coll Cardiol*. 2017;69(17):2212-2241.

2. Smith SC Jr, Dove JT, Jacobs AK, et al; American College of Cardiology/American Heart Association task force on practice guidelines (Committee to revise the 1993 guidelines for percutaneous transluminal coronary angioplasty); Society for Cardiac Angiography and Interventions. ACC/AHA guidelines for percutaneous coronary intervention (revision of the 1993 PTCA guidelines)-executive summary: a report of the American College of Cardiology/American Heart Association task force on practice guidelines (Committee to revise the 1993 guidelines for percutaneous transluminal coronary angioplasty) endorsed by the Society for Cardiac Angiography and Interventions. *Circulation*. 2001;103(24):3019-3041.

3. Nallamothu BK, Krumholz HM. Putting ad hoc PCI on pause. *JAMA*. 2010;304(18):2059-2060.

4. Leape LL, Park RE, Bashore TM, Harrison JK, Davidson CJ, Brook RH. Effect of variability in the interpretation of coronary angiograms on the appropriateness of use of coronary revascularization procedures. *Am Heart J*. 2000;139(1 Pt 1):106-113.

5. Raphael MJ, Donaldson RMA. A "significant" stenosis: thirty years on. *Lancet*. 1989;1(8631):207-209.

6. Marcus ML, Skorton DJ, Johnson MR, Collins SM, Harrison DG, Kerber RE. Visual estimates of percent diameter coronary stenosis: "a battered gold standard". *J Am Coll Cardiol*. 1988;11(4):882-885.

7. Zir LM, Miller SW, Dinsmore RE, Gilbert JP, Harthorne JW. Interobserver variability in coronary angiography. *Circulation*. 1976;53(4):627-632.

8. Campbell PT, Mahmud E, Marshall JJ. Interoperator and intraoperator (in)accuracy of stent selection based on visual estimation. *Catheter Cardiovasc Interv*. 2015;86(7):1177-1183.

9. Nallamothu BK, Spertus JA, Lansky AJ, et al. Comparison of clinical interpretation with visual assessment and quantitative coronary angiography in patients undergoing percutaneous coronary intervention in contemporary practice: the Assessing Angiography (A2) Project. *Circulation*. 2013;127(17):1793-1800.

10. Garrone P, Biondi-Zoccai G, Salvetti I, et al. Quantitative coronary angiography in the current era: principles and applications. *J Interv Cardiol*. 2009;22(6):527-536.

11. Toth GG, Toth B, Johnson NP, et al. Revascularization decisions in patients with stable angina and intermediate lesions: results of the international survey on interventional strategy. *Circ Cardiovasc Interv*. 2014;7(6):751-759.

12. Douglas PS, Pontone G, Hlatky MA, et al; PLATFORM Investigators. Clinical outcomes of fractional flow reserve by computed tomographic angiography-guided diagnostic strategies vs. usual care in patients with suspected coronary artery disease: the prospective longitudinal trial of FFR(CT): outcome and resource impacts study. *Eur Heart J*. 2015;36(47):3359-3367.

13. Zheng X, Curtis JP, Hu S, et al; China PEACE Collaborative Group. Coronary catheterization and percutaneous coronary intervention in China: 10-year results from the China PEACE-Retrospective CathPCI Study. *JAMA Intern Med*. 2016;176(4):512-521.

14. Du X, Pi Y, Dreyer RP, et al; China PEACE Collaborative Group. The china patient-centered evaluative assessment of cardiac events (PEACE) prospective study of percutaneous coronary intervention: study design. *Catheter Cardiovasc Interv*. 2016;88(7):E212-E221.

15. Reiber JH, Serruys PW, Kooijman CJ, et al. Assessment of short-, medium-, and long-term variations in arterial dimensions from computer-assisted quantitation of coronary cineangiograms. *Circulation*. 1985;71(2):280-288.

16. Gao R. Current status of percutaneous coronary intervention in China. *Heart*. 2010;96(6):415-418.

17. Huo Y. Current status and development of percutaneous coronary intervention in China. *J Zhejiang Univ Sci B*. 2010;11(8):631-633.

18. Kussmaul WG III, Popp RL, Norcini J. Accuracy and reproducibility of visual coronary stenosis estimates using information from multiple observers. *Clin Cardiol*. 1992;15(3):154-162.

19. Beauman GJ, Vogel RA. Accuracy of individual and panel visual interpretations of coronary arteriograms: implications for clinical decisions. *J Am Coll Cardiol*. 1990;16(1):108-113.

20. DeRouen TA, Murray JA, Owen W. Variability in the analysis of coronary arteriograms. *Circulation*. 1977;55(2):324-328.

21. Lin GA, Dudley RA, Lucas FL, Malenka DJ, Vittinghoff E, Redberg RF. Frequency of stress testing to document ischemia prior to elective percutaneous coronary intervention. *JAMA*. 2008;300(15):1765-1773.

22. Kohli M, Prevedello LM, Filice RW, Geis JR. Implementing machine learning in radiology practice and research. *AJR Am J Roentgenol*. 2017;208(4):754-760.

Editor's Note

Overuse of Percutaneous Coronary Interventions

Rita F. Redberg, MD, MSc

Related article page 239

Since Gruentzig first used a balloon to inflate the left anterior descending of a young man with angina in 1977, there have been hundreds of millions of percutaneous coronary interventions (PCI) done worldwide. Most PCI are performed on patients who are asymptomatic or who have not had a trial of optimal medical therapy,[1] which is equally effective in preventing myocardial infarction or death. Furthermore, in symptomatic patients there is no benefit to PCI in reducing symptoms or improving quality of life compared with a placebo procedure.[2] This carefully performed analysis[3] from the China PEACE study adds to the concern of overuse of PCI. It documents yet another commonly known but little discussed contributor to inappropriate PCI—the inaccuracy of angiographic readings. Visual assessments tend to systematically overestimate the magnitude of the stenosis, meaning that patients will get an intervention on a lesion that is not hemodynamically significant. In a painstaking analysis of 1295 patients who underwent PCI in China, Zhang et al[3] compared physician visual assessment with quantitative coronary angiography (QCA). They found systematic overestimation of angiographic stenosis by 10% for patients with acute myocardial infarction (AMI), and 16% for patients without AMI.

For patients in need of cardiac catheterization, visual assessment should be supplemented with a more quantitative method for questionable stenosis. However, the more important intervention is to initiate medical therapy for all patients with coronary artery disease; there is no reason to have a diagnostic cardiac catheterization first. I routinely start antiischemic medications and follow patients clinically for resolution of angina and ability to resume and continue all activities, including work and athletics. As has been amply documented, the oculostenotic reflex takes over in the catheterization laboratory. This enthusiasm for use of PCI, whether motivated by our love for technology, feeling like we are doing something when we open a stenosis, or related to our fee-for-service health care system, is hard to resist once a patient reaches the catheterization laboratory.[4] The best approach is not to refer these stable patients to the catheterization laboratory in the first place, but rather to start medical therapy and follow the patient clinically.

Author Affiliations: Department of Medicine, University of California, San Francisco, California; Editor, *JAMA Internal Medicine*.

Corresponding Author: Rita F. Redberg, MD, MSc, University of California San Francisco Medicine, 505 Parnassus, M1180, San Francisco, CA 94143-0124 (rita.redberg@ucsf.edu).

Conflict of Interest Disclosures: None reported.

1. Borden WB, Redberg RF, Mushlin AI, Dai D, Kaltenbach LA, Spertus JA. Patterns and intensity of medical therapy in patients undergoing percutaneous coronary intervention. *JAMA*. 2011;305(18):1882-1889.

2. Al-Lamee R, Thompson D, Dehbi HM, et al; ORBITA investigators. Percutaneous coronary intervention in stable angina (ORBITA): a double-blind, randomised controlled trial. *Lancet*. 2017;pii:S0140-6736(17):32714, 32719.

3. Zhang H, Mu L, Hu S, et al. Comparison of physician visual assessment with quantitative coronary angiography in assessment of stenosis severity in China [published online January 8, 2018]. *JAMA Intern Med*. doi:10.1001/jamainternmed.2017.7821

4. Lin GA, Dudley RA, Redberg RF. Cardiologists' use of percutaneous coronary interventions for stable coronary artery disease. *Arch Intern Med*. 2007;167(15):1604-1609.