Accurate characterization of the degree of risk entailed in performing interventional procedures is the key to optimal clinical decision making. It has been recognized since the inception of percutaneous coronary intervention (PCI) that lesion morphology is a major determinant of both clinical and technical success and a predictor of complications. It is intuitive that the way a lesion appears angiographically reflects its specific composition, which would suggest its likely response to mechanical manipulation and catheter-based treatment. In addition to identifying individual morphological factors that predict success, a risk prediction model can be developed by combining these factors to facilitate quantification of risk. Risk models are useful in offering a realistic assessment to the patient and family, assisting the operator to evaluate technical concerns, and providing an objective framework for benchmarking and quality assurance.

In this article, the history of angiography-based risk assessment models for coronary interventions is reviewed in depth. The limitations inherent in a morphologic approach to PCI risk assessment are considered, and the appropriate use of lesion classification in modern practice is described. Finally, we address the importance the practicing interventionist should place on existing analytic systems, which includes both morphologic characterization and clinical factors.

**THE AHA/ACC TASK FORCE CRITERIA**

In the early days of balloon angioplasty, when complication rates were significantly higher than in contemporary practice, deciding which patients and stenoses to avoid and which to preferentially treat was a complex problem rendered even more difficult by the apparent randomness of relatively frequent adverse events. Initially, balloon angioplasty had complication rates of 10% to 15%; in modern practice, PCI is associated with mortality and emergency bypass rates of less than 1%. This marked improvement in PCI outcomes is primarily the consequence of advancements in technique, devices, adjuvant medical therapy, and improved case selection, all of which were developed to a large extent specifically to treat the difficult lesion types identified early in the angioplasty experience. The many innovations in PCI technique and the resultant delivery of predictable and durable results are testaments to the historical value of these classification schemes.

The first systematic attempt to identify angiographic factors predictive of increased risk was made by the National Heart, Lung, and Blood Institute Registry in 1984. Faxon and coworkers found that circumflex artery location, lesion calcification, proximal tortuosity, eccentric geometry, and a severe stenosis were associated with reduction in success, which was defined as ≥20% improvement in stenosis diameter. The severity of the lesion and its geometry were especially critical in the early experience; keep in mind that in 1983, a balloon could traverse a lesion in just 75% of cases when it was attempted. Hence, a subtotal lesion had just a 59% likelihood of success in that registry, and the success rate was only 37% for total occlusions. This background is important; improvements in technique throughout the evolution of PCI substantially altered the factors that predict success, producing the “moving target” recognized today.
Combining this experience and the published work of Gruentzig and others, the American College of Cardiology (ACC) and the American Heart Association (AHA) devised a lesion classification system intended to predict PCI outcomes. The system grouped the individual criteria into three large categories based on anticipated rates of success (Table 1). Originally, it was expected that low-risk type A lesions would have a success rate of >85%, moderate-risk type B lesions were predicted to have a 60% to 85% success rate, and high-risk type C lesions had a <60% success rate. The characteristics of each lesion class differed by degree of proximal tortuosity, angulation of the stenosed segment, the length of the lesion, and the presence of total occlusion, bifurcation lesions, or thrombus or friable vein graft lesions. Notably, this classification system was never validated or tested empirically for its accuracy or utility before its publication as a guideline.

Ellis et al evaluated these criteria in more than 1,000 lesions from the Multivessel Angioplasty Prognostic study. They found that angulated stenosis, high-grade stenosis, chronic total occlusion lesions, bifurcation stenosis, and male gender were associated with reduced success rates; the other factors in the AHA/ACC system were not predictive. Overall angiographic success occurred in just 82.6% of patients, reflecting the state of the art of that era. They confirmed the usefulness of the ACC/AHA classification for predicting success in general but found that actual rates of success ranged from 92% for type A lesions to 60% for type C lesions. To improve the clinical utility of the system, they introduced a modification to the B lesion class, adding a class B2 for patients who had more than one B criterion.

Other investigators also found that the AHA/ACC classification was not especially accurate as a predictor of outcomes and identified several critical limitations. Moushmoush et al found, in cases of multivessel angioplasty, that there was no significant difference in outcomes between types A and B1 lesions, or B lesions generally. The main distinction was with type C lesions, in which inability to cross the lesion, rather than the occurrence of complications, was the determining feature. Certain morphologies predicted lack of success, whereas others were associated with more complications. Myler et al found that angioplasty of grafts was especially risky and unpredictable, reflecting the unpredictability of the occurrence of “no reflow” related to distal embolization. They also noted that lesions containing two or more type C lesions were especially hazardous. Tan et al performed a careful prospective evaluation of 729 patients using two independent observers unaware of PCI outcome at the time of the lesion review. These procedures, performed from 1990 to 1993, had an overall success rate of 91%, with major complications in 3.3%. In a careful comparison of the ACC/AHA lesion subclasses, they found no difference between classes A and B1. Although there was a statistically significant difference between B1 and B2 lesions, the absolute difference in success rate was not nearly as substantial as predicted. Abrupt closure occurred in 2.1%, 2.6%, and 5% of type A, B, and C lesions, respectively; again, only the C class was significantly lower. They also evaluated the success and failure rates of individual criteria within a class and found that the impact of individual criteria varied considerably. Type B characteristics had a success rate ranging from 74% to 95% and an abrupt closure rate ranging from 2.2% to 14%. Type C characteristics had a success rate ranging from...
57% to 88% and an abrupt closure rate ranging from 0% to 16%. Longer lesions, calcified lesions, diameter stenosis of 80% to 99%, and presence of thrombus were predictive of a lower success rate. Longer lesions, angulated lesions, diameter stenosis of 80% to 99%, and calcified lesions were predicted an abrupt closure. The investigators concluded that the AHA/ACC classification scheme was “outdated and needs to be changed for application in current angioplasty practice.”

The introduction of stents and other devices in the late 1990s represents the beginning of the modern era of intervention. Two studies evaluated whether lesion morphology remained predictive in this era. Zaacks et al.9,10 showed that success rates in the A, B1, and B2 classes were similar, ranging from 96.3% to 95.1%, whereas the success rate with class C lesions was 88.2% (P < .0001). They found that total occlusion and vessel tortuosity, both criteria for C classification, predicted procedure failure but not complications, whereas thrombus, bifurcation lesions, inability to protect a major side branch, and degenerated vein grafts were strongly associated with increased complications. Ellis et al.11 also tested the relationship between lesion characteristics and complications in the early stent era. After evaluating 27 candidate variables, nine were found to be useful to predict complications, most of which were present in the AHA/ACC classification. However, several variables not included in the AHA/ACC criteria were predictive (eg, filling defects), whereas others that are in the classification system were not valuable.

THE SCAI SIMPLIFIED CLASSIFICATION SCHEME

Based on these publications, it was clear 15 to 20 years ago that the B and C lesion categories as originally proposed were quite heterogeneous and required amendment based on clinical practice.12 Furthermore, it placed together disparate forms of lesion complexity and vessel anatomy that were not based on clinical experience or intuition. It was suggested widely that analyzing specific lesion morphologic characteristics, rather than applying a general lesion classification score, might be more useful in assessing risk. Yet the AHA/ACC did not adjust the classification system significantly in subsequent updates,13,14 despite its increasing obsolescence. This was potentially catastrophic because it ignored the markedly improved outcomes that new interventional devices, superior pharmacologic adjuncts, and improved catheter and guidewire technology had made possible. It also threatened the potential of developing a sound statistical method to predict adverse events.

Consequently, the data from the Society of Coronary Angiography and Interventions Registry (SCAI), collected in 41,071 single-vessel interventions performed from 1993 to 1996, were used to evaluate the predictive ability of the ACC/AHA lesion classification system and to determine if an improved predictive model could be developed.15 It was demonstrated that vessel patency has a profound influence on success rates: when classes B and C are divided into patent and occluded within each class, no other variable was nearly as predictive. Additionally, it was confirmed that both B and C classes are rather diverse with regard to risk. There is no difference in success rates between the A class lesion and the patent B class lesion, whereas the success rate of the patent C class lesion is actually better than the occluded B class lesion. As a result, the classification system was restructured into four groups, distinguishing only the C or non-C classification and whether or not the lesion was patent or occluded. The SCAI classification retains its predictive value in the stent era, as shown in a subsequent evaluation with nearly contemporary PCI techniques in the ACC-National Cardiovascular Data Registry.
The ACC/AHA lesion classification was applied to 61,926 patients undergoing single-vessel PCI: it was found to be less accurate in predicting major complications compared with the SCAI lesion classification (Figures 1 through 4). The c-statistic for major complications after PCI, however, was modest for all systems (0.599 for original ACC/AHA, 0.624 for modified ACC/AHA, and 0.665 for SCAI lesion classification). Conversely, the predictive accuracy was better for predicting success, especially with the SCAI modification (0.69, 0.708, 0.75 for original, modified ACC/AHA lesion classification, and SCAI classification, respectively).

The SCAI simplified classification scheme is therefore far superior as a predictive model of coronary intervention than the AHA/ACC classification system and is a powerful tool. It produces a better prediction of procedure success and a somewhat improved prediction of complications than the more complex ACC/AHA lesion classification system. In addition, the categories are more homogeneous, hierarchical stratifications of risk of complications and procedural success. It has remained the standard tool to evaluate lesion morphology both in clinical trials and interventional practice.

**OPTIMAL RISK STRATIFICATION OF CORONARY INTERVENTION**

Nevertheless, the NCDR study\(^6\) made obvious that any risk prediction model based entirely on lesion morphology has a substantial inherent weakness. The ability of lesion morphology to predict the major complications of myocardial infarction, urgent coronary artery bypass grafting, or hospital death in the contemporary PCI era is limited.\(^1\) Furthermore, although the SCAI lesion classification predicts complications to a moderate degree, a critical relationship exists that cannot be overlooked: complex lesion morphology is associated with acuity of presentation. As is intuitive, the more complex the lesion, the more acutely ill the patient. Because complications are related to patient acuteness, especially the presence of acute myocardial infarction, lesion classification is only a weak independent predictor for complications. In multivariate analysis, after entering clinical status, the lesion class adds little to the model in predicting complications. For patients with a myocardial infarction, death is more likely in those with initially occluded vessels, regardless of non-C or C class (SCAI class III or IV), although the emergency CABG rate is highest in patients with patent class C lesions. These findings confirmed those of Harrell et al, who demonstrated definitively that clinical factors are preeminent in predicting complications.\(^17\) With the weak exception of type C lesions, anatomic parameters added no further information to that provided by clinical status, such as cardiogenic shock, acute myocardial infarction, renal failure, or congestive heart failure.

It was therefore apparent that developing a solely morphologic-based method to predict PCI risk was not possible. Hence, for optimal risk stratification, the SCAI scheme has to be used in association with clinical parameters. This was the concept behind its inclusion in the NCDR model of mortality risk.\(^18\) C lesions are also incorporated as one factor in the Mayo Clinic model.\(^19\) However, lesion morphology is not included in either the New York State\(^20\) or the Michigan\(^21\) models. The constitution of these well-validated models shows the particular value, and its relative lack, of lesion morphology in the current interventional era.

For example, Singh and colleagues compared the Mayo Clinic model to the original AHA/ACC classification.\(^19\) They found that the Mayo Clinic risk score provides significantly better prediction for cardiovascular complications, but the ACC/AHA classification is a better predictor of angiographic success.

**BENEFITS AND CHALLENGES OF RISK PREDICTION MODELS**

The original concept of a simple score based on lesion morphology was to reflect the technical difficulty of the procedure and consequently the likelihood of success or complications; it was intended to be a resource to the operator in the prudent selection of patients. In contemporary practice, few if any operators calculate such scores routinely. However, familiarity with those lesion morphologies imparting increased risk is widespread, and reference to these schemes, either informally or directly in specific cases, is still a valuable tool. Additionally, many physicians use the general concepts to explain to patients and their families when risk...
is increased and what can be done to minimize the consequences.

The most important current use is as a benchmarking tool for operators and programs. The overall performance of the individual laboratory or operator can be evaluated according to the difficulty of the cases selected. Objective classification of risk permits comparison of the individual operator and laboratory with a general experience obtained from registry data. It also permits stratification of patients in large studies to account for, or control for, the complexity of the actual procedures.

In practice, however, the goal of accurately predicting PCI results in individual cases has proven elusive. Coronary intervention has proven to be a dynamic field in which success and complication rates present a moving target, sometimes so fast that the procedure has been improved before the original data can be published. The initially expected wide range of performance in lesions of differing complexity, as predicted by the original 1988 classification, has been compressed substantially due to improved technology and operator skills. In addition, developments in adjunctive pharmacology have further reduced the risks and improved success rates. Furthermore, specific lesion characteristics, which limit successful intervention by standard techniques, are targeted by device manufacturers as challenges to overcome. Thus, balloons have become smaller to aid in crossing tighter lesions, more flexible to negotiate tortuous vessels, and stronger to permit use of higher pressures in calcified lesions. Devices to remove atheromas or burr through calcified lesions have been developed and, of course, stents have been perfected to protect against vessel collapse, dissection, and acute occlusion.

A critical challenge to any classification system involving morphology assessment is reproducibility of sometimes highly subjective appearances. The Angiographic Core Lab of the Bypass and the Angioplasty Investigation (BARI) incorporated second interpretations by an experienced investigator blinded to his first reading. The reproducibility of the intraobserver interpretation of individual features of the lesions was evaluated. There was an excellent ability to separate C lesions from A and B lesions, but only moderate reproducibility separating A lesions from B from C lesions, and moderate reproducibility identifying angulation. There was fair to poor correlation for the other lesion characteristics that were evaluated. Kleiman and colleagues reported interobserver variability of classifying lesions into the ACC/AHA ABC system. Two experienced operators each evaluated 150 lesions and compared their results. There was agreement in classification as A, B, or C lesions in only 61% of patients. The distinction between C and non-C lesions was reproducible at an acceptable level; agreement in differentiating C from non-C was 81%. Still, this does show significant interobserver variability even among experienced operators as part of a research study; in actual practice, when evaluation of operator skill is partly tied to such interpretations and the PCI outcome is not blinded, the capability for “gaming the system” is apparent.

A major problem that has never been formally addressed is that certain lesion types that remain significant challenges can be classified in a much more sophisticated manner than the existing classification schemes allow. Bifurcation lesions can be classified in several effective ways that surpass those developed 20 years ago. Complete occlusions, thrombus, and vein grafts still remain impressive challenges to the interventionist and each has a dedicated body of investigation detailing methods of preventing and protecting against complications specific to those lesion types. PCI in the setting of cardiogenic shock and in elderly patients poses significant risks that are not fully recognized by morphologic-based methods as currently constructed.

Yet another concern is that nearly all currently validated risk stratification scores are essentially mortality prediction models. Because mortality is an uncommon outcome relative to other adverse events of PCI, perhaps emphasis on only this outcome is misplaced. Although the Mayo Clinic and NCDR models have been shown to be effective in predicting all major adverse cardiac events, they are not optimized for this purpose.

Furthermore, although these scores are accurate in predicting procedural complications, no predictive model can ameliorate the effect of chance and unanticipated circumstances innately encountered in invasive treatments. Finally, although current models accurately evaluate procedural risk, they do not address the potential benefit; consequently, they cannot substitute for clinical judgment in the absence of an accurate risk-benefit cal-
culation. Perhaps this flaw can be addressed as appropriateness criteria for revascularization are developed.

CONCLUSION

The value of the original AHA/ACC classification system was substantial as a general guide to the relatively inexperienced operators of 2 decades ago. Its publication as part of the first PCI guideline encouraged the development of techniques specific for certain high-risk morphologies and succeeded in reducing the risks in those circumstances. However, it probably was never highly predictive of outcomes—its intended purpose. Its utility is even further ambiguous today with further advancement in procedural techniques, operator experience, and availability of stents. The SCAI simplified classification retains some usefulness as both a clinical and investigational tool. However, morphologic assessment is no longer a central predictor of PCI outcomes. Major limitations are its reliance on subjective angiographic lesion assessment with considerable interobserver variability and exclusion of important clinical and acuity of presentation variables that have considerable influence on the outcome of a PCI procedure. These systems have been supplanted by and assimilated into a series of statistically validated risk assessment models that incorporate patient-related conditions, acuteness of presentation, and angiographic- and procedure-related characteristics. There remains a need for more detailed models that include sophisticated morphologic characterization derived from large experiences in specific settings that remain particularly high risk, such as acute myocardial infarction, vein graft lesions, bifurcations, and thrombus.

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