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Fractional Flow Reserve and Coronary Bifurcation Anatomy

A Novel Quantitative Model to Assess and Report the Stenosis Severity of Bifurcation Lesions

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ABSTRACT

OBJECTIVES The aim of this study was to develop a new model for assessment of stenosis severity in a bifurcation lesion including its core. The diagnostic performance of this model, powered by 3-dimensional quantitative coronary angiography to predict the functional significance of obstructive bifurcation stenoses, was evaluated using fractional flow reserve (FFR) as the reference standard.

BACKGROUND Development of advanced quantitative models might help to establish a relationship between bifurcation anatomy and FFR.

METHODS Patients who had undergone coronary angiography and interventions in 5 European cardiology centers were randomly selected and analyzed. Different bifurcation fractal laws, including Murray, Finet, and HK laws, were implemented in the bifurcation model, resulting in different degrees of stenosis severity.

RESULTS A total of 78 bifurcation lesions in 73 patients were analyzed. In 51 (65%) bifurcations, FFR was measured in the main vessel. A total of 34 (43.6%) interrogated vessels had an FFR ≤0.80. Correlation between FFR and diameter stenosis was poor by conventional straight analysis ($\rho = -0.23$, $p < 0.001$) but significantly improved by bifurcation analyses: the highest by the HK law ($\rho = -0.50$, $p < 0.001$), followed by the Finet law ($\rho = -0.49$, $p < 0.001$), and the Murray law ($\rho = -0.41$, $p < 0.001$). The area under the receiver-operating characteristics curve for predicting FFR ≤0.80 was significantly higher by bifurcation analysis compared with straight analysis: 0.72 (95% confidence interval: 0.61 to 0.82) versus 0.60 (95% confidence interval: 0.49 to 0.71; $p = 0.001$). Applying a threshold of ≥50% diameter stenosis, as assessed by the bifurcation model, to predict FFR ≤0.80 resulted in 23 true positives, 27 true negatives, 17 false positives, and 11 false negatives.

CONCLUSIONS The new bifurcation model provides a comprehensive assessment of bifurcation anatomy. Compared with straight analysis, identification of lesions with preserved FFR values in obstructive bifurcation stenoses was improved. Nevertheless, accuracy was limited by using solely anatomical parameters. (J Am Coll Cardiol Intv 2015;8:564–74) © 2015 by the American College of Cardiology Foundation.

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Assessing the severity of coronary bifurcation lesions is a frequently faced challenge. The pitfalls and limitations of the conventional quantitative coronary angiography (QCA) approach—the straight (single segment) analysis—have been widely recognized (1,2). Three-dimensional (3D) reconstruction on the basis of 2 angiographic projections might improve assessment of bifurcation lesions (3). However, the greatest challenge of bifurcation analysis remains to define the true reference vessel size of the main vessel (MV) and the side branch (SB), and, in particular, the true size of the bifurcation core, or the polygon of confluence (i.e., where the MV and the SB merge upstream into a single branch). Several bifurcation models have been developed to incorporate the step-down phenomenon in calculating the reference vessel size for quantitative assessment of bifurcation lesions (2,4,5). However, these models have not completely addressed the physical interpretation of the reference vessel size at the bifurcation core, which hampers the comprehensive assessment of the entire bifurcation lesion that extends from the proximal MV into the distal MV and/or the SB. Development of dedicated quantitative bifurcation models could assist in: 1) understanding the relation between bifurcation anatomy and fractional flow reserve (FFR), a standard of reference for inducible myocardial ischemia (6); and 2) assessing interventional devices aiming at this complex clinical scenario.

This study aims to present a new quantitative bifurcation model for comprehensive assessment of anatomical severity in the entire bifurcation lesion including its core. The model constructs a number of bent oval planes for measurement in the bifurcation core. This resolves the ambiguity in defining stenosis severity in the core and seamlessly integrates lesion assessment at the 2 sides of the lateral wall opposite to the carina. The accuracy of this model, empowered by 3D QCA to predict the functional significance of coronary bifurcation stenosis, was evaluated using FFR as the reference standard.

METHODS

STUDY POPULATION. This retrospective, observational, and analytical study randomly selected patients who were admitted in 5 European hospitals (Hospital Clinico San Carlos, Madrid, Spain; Thoraxcentrum Twente at Medisch Spectrum Twente, Enschede, the Netherlands; Aarhus University Hospital, Skejby, Denmark; OLV Clinic, Aalst, Belgium; and Paul Stradins Clinical Hospital, Riga, Latvia) in the context of clinical FFR studies including bifurcation lesions (TWENTE trial [7], Nordic-Baltic Bifurcation Study III [8], Tryton kissing balloon investigation [9], and Echavarria-Pinto et al. [10]). Inclusion criteria were: 1) bifurcation lesions with >40% diameter stenosis (DS%) by visual estimation in the main coronary arteries; 2) absence of coronary artery bypass graft to the interrogated vessel; 3) measurement of FFR in the MV prior to revascularization or in the SB if no stent was implanted in the SB; and 4) 2 angiographic projections ≥25° apart recorded by flat-panel systems.

Exclusion criteria were: 1) excessive overlap or foreshortening (>90%); 2) poor angiographic images quality for delineation of lumen contours; and 3) presence of a third branch with diameter >1 mm at the interrogated bifurcation, forming a trifurcation structure.

Diagnostic angiography was obtained after intracoronary nitrates in all cases, and FFR interrogation was performed as part of the clinical evaluation of patients or according to the corresponding study protocol. Written informed consent was obtained from all patients according to institutional regulations.

THE NEW QUANTITATIVE BIFURCATION MODEL. A bifurcation is associated with 3 segments: the proximal MV, the distal MV, and the SB. They are connected by the bifurcation core, where the distal

ABBREVIATIONS AND ACRONYMS

3D = 3-dimensional

AUC = area under the receiver-operating characteristics curve

CI = confidence interval

DS% = percent diameter stenosis

FFR = fractional flow reserve

MLA = minimum lumen area

MV = main vessel

QCA = quantitative coronary angiography

RDF = reference diameter function

SB = side branch

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