

# Role of Invasive Functional Assessment in Surgical Revascularization of Coronary Artery Disease

**ABSTRACT:** In patients with stable coronary artery disease, percutaneous coronary intervention is associated with improved outcomes if the lesion is deemed significant by invasive functional assessment using fractional flow reserve. Recent studies have shown that a revascularization strategy using instantaneous wave-free ratio is noninferior to fractional flow reserve in patients with intermediate-grade stenoses. The decision to perform coronary artery bypass grafting surgery is usually based on anatomic assessment of stenosis severity by coronary angiography. The data on the role of invasive functional assessment in guiding surgical revascularization are limited. In this review, we discuss the diagnostic and prognostic significance of invasive functional assessment in patients considered for coronary artery bypass grafting. In addition, we critically discuss ongoing and future clinical trials on the role of invasive functional assessment in surgical revascularization.

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Coronary artery bypass grafting (CABG) is a class I indication for revascularization of patients with multivessel or left main coronary artery disease (CAD).<sup>1</sup> The decision to perform CABG is usually based on the anatomic assessment of CAD severity by coronary angiography. Although coronary angiography has good spatial and temporal resolution, it does not provide information about the functional significance of CAD. Studies using fractional flow reserve (FFR) in patients with stable CAD with an intermediate degree of stenosis have shown that the benefit of percutaneous coronary intervention (PCI) applies only to those patients with significant ischemia on invasive functional evaluation by FFR.<sup>2-4</sup> These studies have underlined the importance of an integrated anatomic and functional evaluation of intermediate-grade lesions in patients undergoing PCI to achieve better outcomes. The instantaneous wave-free ratio (iFR) is another physiological technique for the invasive functional assessment of CAD that has shown good reproducibility and agreement with FFR.<sup>5</sup>

The role of invasive functional assessment in patients referred for CABG has not been well elucidated. Some of the lesions that are deemed significant based on anatomic assessment by angiography may not be functionally significant on invasive assessment, and this might have important clinical implications on the number and type of grafts, procedure time, graft patency rates, and, ultimately, clinical outcomes. Integration of functional evaluation could also change the revascularization strategy (ie, PCI versus CABG) by reclassifying disease severity.<sup>6</sup>

In this review, we discuss the role of the physiological assessment of coronary artery lesions with invasive functional modalities in patients referred for CABG and the important implications it may have on patient selection and surgical strategy.

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**Key Words:** coronary angiography  
■ coronary artery bypass ■ coronary artery disease ■ fractional flow reserve ■ percutaneous coronary revascularization

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## ASSOCIATION OF FUNCTIONAL SIGNIFICANCE OF CORONARY STENOSES WITH GRAFT PATENCY AND PROGRESSION OF NATIVE CAD

Graft patency is affected by multiple factors, which are summarized in Table 1. Some of these factors, such as patient comorbidities and target vessel size, are not modifiable. The severity of angiographic stenosis of the native coronary artery clearly impacts graft patency. The presence of competitive flow in a native artery in the setting of an anatomically intermediate stenosis has been shown to be associated with higher rates of graft occlusion.<sup>7–11</sup> Computational fluid dynamics studies provided important insight into the complex interactions between coronary grafts and native vessels in the context of competitive flow.<sup>12</sup> In an elegant study using near-infrared fluorescence angiography, patent bypass conduits did not improve myocardial perfusion, suggesting that the degree of native artery stenosis, although anatomically noteworthy, was not functionally significant.<sup>7</sup> Taken together, these studies raise the concern that coronary grafts to physiologically nonsignificant lesions do not augment myocardial perfusion, run

a risk of failure because of competitive flow, and confer questionable clinical benefit. Consequently, physiological assessment of multivessel CAD appears to meaningfully impact the grafting strategy, including the decision to graft or not, and the use of arterial versus venous grafts, as well.

The type of graft is another determinant of graft patency. Arterial grafts, such as internal mammary arteries or radial arteries, exhibit longer patency<sup>13–15</sup> and likely confer long-term survival benefit<sup>16</sup> in comparison with venous grafts. The radial artery, because of its muscular nature, is particularly vulnerable to competitive flow, and current guidelines recommend its use in coronary targets with severe stenoses.<sup>17</sup> The surgical technique also plays an important role in graft patency. A recent longitudinal randomized controlled trial showed a mean 16-year patency of saphenous vein grafts harvested with a fat pedicle and no-touch technique, comparable to that of the left internal mammary artery.<sup>18</sup> Collectively, the type of graft and the grafting technique tailored to the functional assessment of coronary artery stenosis may confer long-term advantage and should be considered when determining the surgical strategy.

Another factor to consider with surgical revascularization is the progression of native disease over time in the context of its functional significance. If intermediate stenoses are expected to progress in the short term, one might reasonably seek to bypass these. Conversely, if an intermediate stenosis is likely to be stable over time, one might reasonably refrain from bypassing that vessel, in particular if the graft is unlikely to increase myocardial perfusion and is at risk for failure because of competitive flow. A study showed the acceleration of native vessel disease in patients who receive bypass grafts to coronary arteries with moderate stenoses, in particular in the right coronary distribution.<sup>19</sup> In contrast, moderate lesions in the right coronary distribution that were not bypassed were quite stable over time. These findings raise the concern that bypassing coronary arteries with intermediate lesions may have unintended negative consequences in accelerating native vessel disease and that these same lesions, if left alone, may be quite stable. Therefore, a technique that could identify intermediate stenoses with functional significance might help guide revascularization in these cases.

**Table 1. Factors Affecting Graft Patency**

Patient-related factors
Diabetes mellitus
Peripheral artery disease
Hyperlipidemia
Smoking
Graft-related factors
Internal mammary artery
Alternate arterial graft (radial, gastroepiploic)
Vein grafts
Length of graft
Graft diameter
Angulation
Shear stress in graft
Surgical technique
Target vessel–related factors
Degree of proximal stenosis
Size of native artery
Presence of distal stenosis
Distal bed vascular resistance
Thrombosis-related factors
Time from surgery
Vessel diameter mismatch
Pinch and angulation of proximal anastomosis
Pinch of distal anastomosis
Low shear stress at anastomotic site

## LIMITATIONS OF ANATOMIC AND NONINVASIVE IMAGING AND EMERGENCE OF INVASIVE FUNCTIONAL ASSESSMENT IN GUIDING REVASCUARIZATION

In clinical practice, the severity of CAD is usually assessed by invasive angiography, which has several limitations itself. The interpretation of angiography with

eyeballing suffers from high inter- and intraobserver variability, and even though quantitative coronary angiography could potentially limit those variabilities, it is not commonly used in daily practice.<sup>20,21</sup> Even if angiographic stenosis is accurately assessed, it does not always correlate well with the functional significance of a given lesion.<sup>22</sup>

Functional (ischemic) evaluation of CAD is commonly performed by using noninvasive imaging (ie, echocardiography, nuclear imaging, magnetic resonance imaging) achieving a sensitivity and specificity that ranges between 70% and 90%.<sup>23,24</sup> The COURAGE substudy (Clinical Outcomes Utilizing Revascularization and Aggressive Drug Evaluation) demonstrated a benefit with PCI only in patients with >10% myocardial ischemic burden determined by nuclear stress testing.<sup>25</sup> The benefit of PCI was not seen in the absence of severe ischemia.<sup>25</sup> This observation formed the basis for the use of noninvasive testing to guide revascularization, but such noninvasive testing has limitations, in particular in patients with multivessel and left main CAD. In a study comparing FFR with nuclear perfusion imaging in patients with multivessel disease, 32% of patients with discordance between FFR and nuclear imaging had normal perfusion when the FFR was abnormal in >1 vascular territory,<sup>26</sup> likely attributed to the so-called balanced ischemia, which is a notable and well-recognized limitation of nuclear stress imaging.

Invasive functional testing has emerged as a strategy to overcome the limitations of anatomic and noninvasive imaging. Several techniques have been studied, including FFR, iFR, resting ratio of distal pressure to aortic pressure, and contrast ratio of distal pressure to aortic pressure.<sup>27–31</sup> FFR is calculated as the ratio of mean pressure distal to the stenosis, measured by the pressure wire, over the mean aortic pressure, measured at the tip of the guiding catheter under hyperemic conditions.<sup>32</sup> iFR is an instantaneous wave-free ratio of the pressure across a stenosis during diastole.<sup>33</sup> In comparison with anatomic imaging, the invasive functional modalities provide an assessment of the physiological significance of CAD that directly correlates with outcomes.<sup>2,3</sup>

Computerized tomography–derived FFR is an emerging technique for noninvasive functional assessment of CAD that integrates the anatomic severity of a given stenosis with its hemodynamic significance using an algorithm based on computational fluid dynamics.<sup>34,35</sup> In a recent multicenter study in patients with suspected CAD, use of coronary computed tomography angiography followed by selective use of computerized tomography–derived FFR was associated with similar clinical outcomes at 1 year in comparison with the usual care of noninvasive or invasive testing planned by the clinician.<sup>36</sup> Overall, computerized tomography–derived FFR is a promising modality, but clinical studies with longer follow-up and hard end points are warranted.

## FUNCTIONALLY DRIVEN REVASCULARIZATION

### Role of Invasive Functional Assessment in PCI

FFR has evolved to a well-validated clinical tool to assess the functional significance of intermediate or equivocal coronary artery stenoses.<sup>37</sup> Initial clinical validation of FFR came from the DEFER study (Deferral of Percutaneous Coronary Intervention), which showed that, in patients with stable CAD, deferral of intervention in angiographically intermediate stenoses with  $FFR > 0.75$  was associated with excellent 5-year outcomes, emphasizing the lack of prognostic or clinical benefit with PCI in functionally nonsignificant CAD.<sup>38</sup> It is noteworthy that this effect was noted at 24 months, 5 years, and 15 years of follow-up.<sup>38–40</sup> The FAME trial (Fractional Flow Reserve versus Angiography for Multivessel Evaluation) randomly assigned patients with multivessel CAD to an FFR-guided PCI group (FFR cutoff  $< 0.80$ ) and an angiography-guided PCI group. At 2 years, the FFR-guided group had a significantly lower rate of death and myocardial infarction (MI).<sup>4</sup> The FAME 2 trial (Fractional Flow Reserve versus Angiography for Multivessel Evaluation 2) randomly assigned patients with stable CAD to FFR-guided PCI (FFR cutoff  $< 0.80$ ) plus optimal medical therapy versus optimal medical therapy only. The recruitment of patients in this study was terminated prematurely because of the significant difference in the primary end point between the 2 study groups, primarily driven by the high rate of urgent revascularization in the medical therapy group.<sup>2</sup> Further subgroup analysis showed a trend toward lower rates of death or MI in the FFR-guided PCI group 7 days after the randomization in comparison with the medical therapy group.<sup>2</sup> The beneficial effects of PCI in the FFR-guided PCI group could have been more noticeable with an extended duration of follow-up.<sup>2</sup>

The role of iFR in functional assessment of CAD was investigated in 2 large multicenter clinical trials. The DEFINE-FLAIR study (Functional Lesion Assessment of Intermediate Stenosis to Guide Revascularisation) showed that the risk of major adverse cardiac events in the iFR-guided revascularization group ( $iFR < 0.90$ ) was noninferior to FFR-guided strategy ( $FFR < 0.80$ ) at 1 year of follow-up in patients with stable CAD or acute coronary syndrome with angiographically intermediate stenosis. Approximately 80% of the patients in each group had stable CAD and 20% had recent MI.<sup>41</sup> The iFR-SWEDEHEART study (Evaluation of iFR vs FFR in Stable Angina or Acute Coronary Syndrome) showed similar results at 1 year of follow-up.<sup>42</sup> The iFR group in both studies had lower procedural time than FFR. These 2 studies validated the iFR as an easy and reproducible invasive tool to assess the functional significance of CAD in the catheterization laboratory.<sup>43</sup>

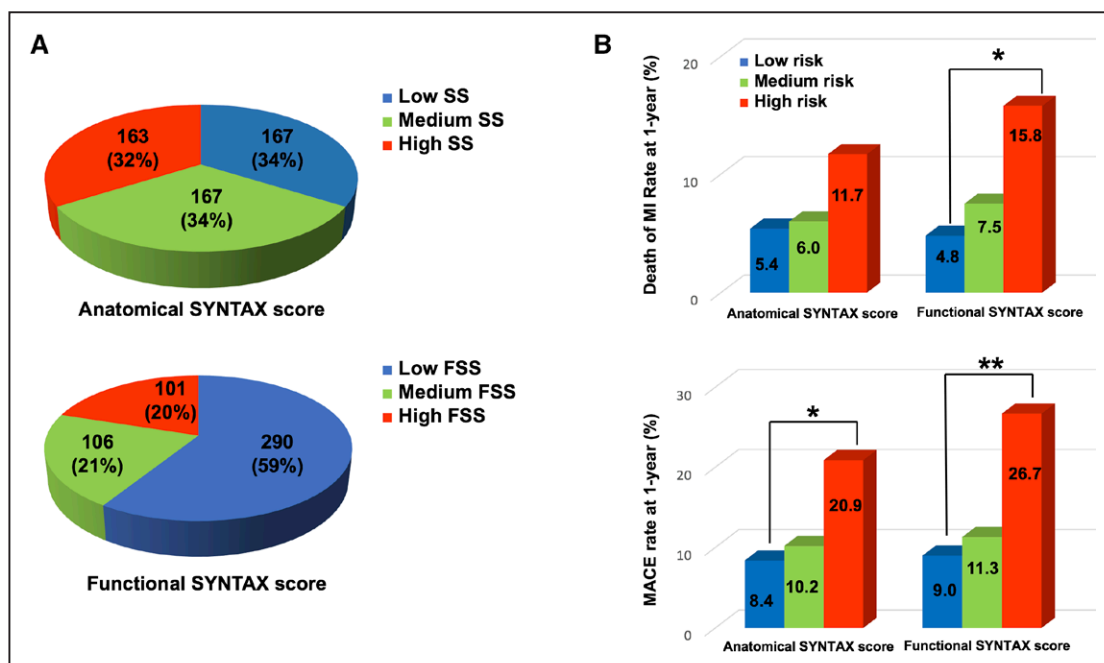
The incremental prognostic value of invasive functional assessment of CAD over anatomic imaging was further highlighted in a subsequent study by the FAME investigators, which showed that integrating FFR into the conventional SYNTAX score (Synergy between PCI with Taxus and Cardiac Surgery), ie, functional SYNTAX score, reclassified >30% of the cases in comparison with the conventional anatomic SYNTAX score<sup>44</sup> (Figure 1A). Patients in the highest tertiles of the functional SYNTAX score had higher rates of death or MI and major adverse cardiovascular events at 1 year in comparison with patients in the lowest tertiles (Figure 1B).<sup>44</sup> Data from the FAME investigators demonstrated that functionally insignificant lesions after PCI had favorable prognosis, even if they appeared to be anatomically significant on angiography.<sup>2</sup> In the same fashion, the residual SYNTAX score derived from the degree of angiographic stenosis after PCI of all functionally significant lesions was not associated with an adverse prognosis,<sup>45</sup> further strengthening the argument of complete functional revascularization versus angiography-guided complete anatomic revascularization.

Even though most of the data on invasive functional tests refer to stable CAD, the role of those tests appears to be important in acute coronary syndromes as well. The

COMPARE-ACUTE (Comparison Between FFR Guided Revascularization Versus Conventional Strategy in Acute STEMI Patients With MVD) and DANAMI-3 PRIMULTI investigators (Primary PCI in Patients With ST-elevation Myocardial Infarction and Multivessel Disease: Treatment of Culprit Lesion Only or Complete Revascularization) demonstrated the feasibility, safety, and efficacy of FFR-guided complete revascularization of patients with ST-segment-elevation myocardial infarction (STEMI) in comparison with revascularization of the infarct-related artery only, findings that, if replicated, have the potential to significantly impact the management of patients with STEMI.<sup>46,47</sup> A study investigating the efficacy of iFR-guided complete revascularization in STEMI is now underway (SAFE STEMI for SENIORS [Study of Access Site for Enhancing PCI in STEMI for Seniors] [NCT02939976]).

## Role of Invasive Functional Assessment in CABG

Historically, the goal of CABG in patients with multivessel CAD has been to achieve complete revascularization. Studies have shown that complete revascularization with CABG is more beneficial in terms of symptoms and long-term survival than incomplete revascularization.<sup>48–54</sup> These



**Figure 1. Functional versus anatomical SYNTAX score.**

**A**, Functional reclassification of anatomic severity of coronary artery disease by integrating FFR. Proportions of the study population across the tertiles of the anatomical SYNTAX score (SS) and functional SYNTAX score (FSS). After incorporating FFR into the SS to calculate FSS, 32% of patients moved from a higher-risk group to a lower-risk group (38% of the highest SS tertile moved to the medium- or lowest-risk FSS group, whereas 59% of the medium-risk SS tertile moved to the lowest-risk FSS group). **B**, Clinical outcomes across anatomical and functional SYNTAX score. Higher rates of death, MI, and major adverse cardiovascular events in the highest tertiles of functional SYNTAX score group in comparison with the other tertiles within this group. \* $P < 0.01$ , \*\* $P < 0.001$ . FFR indicates fractional flow reserve; MACE, major adverse cardiovascular event; MI, myocardial infarction; and SYNTAX, Synergy between PCI with Taxus and Cardiac Surgery. Adapted with permission from Nam et al.<sup>44</sup> Copyright © 2011, Elsevier.

studies were based on anatomic assessment, leaving the role of functionally complete revascularization unclear.

There have been limited studies evaluating the functional significance of anatomic stenoses of coronary arteries before CABG. In a prospective study of 164 patients eligible for CABG with at least 1 intermediate-grade lesion, FFR was performed in all lesions before grafting. In this study, the FFR cutoff was  $<0.75$  and the surgeon was blinded to the FFR findings. One year later, it was noted that 21.4% of the grafts (arterial and venous) to functionally nonsignificant lesions were occluded in comparison with 8.9% of the grafts to functionally significant lesions.<sup>55</sup> There was no difference in clinical outcomes or repeat revascularization between the 2 groups, but this could be attributed to the relatively short follow-up period of only 1 year. It is noteworthy that there was a linear relationship between the FFR values and the rates of graft occlusion.<sup>55</sup>

In a retrospective study in patients with at least 1 intermediate stenosis, the lesions were grafted if the FFR was  $\leq 0.80$  or deferred if the FFR was  $>0.80$ . FFR-guided (functional) CABG was associated with a lower number of grafts and lower rates of on-pump surgery in comparison with angiography-guided CABG.<sup>56</sup> The FFR group was noted to have higher overall graft occlusion-free survival on angiographic follow-up. After 3 years, there was no difference in terms of the rate of death, MI, or the combined outcomes of major adverse cardiac events between groups, but the FFR-guided CABG group was associated with lower rates of angina.

An interesting nonrandomized study assessed the long-term clinical outcomes of FFR-assisted CABG of angiographically equivocal left main disease and determined the relationship between quantitative coronary angiography and FFR.<sup>57</sup> At 5-year follow-up, patients with left main disease and  $\text{FFR} \geq 0.80$  who did not have surgery had outcomes similar to patients with  $\text{FFR} < 0.80$  who underwent surgery. There was a poor correlation between angiographic lesion severity and FFR. It is noteworthy that 23% of the patients with left main coronary artery stenosis  $<50\%$  had a hemodynamically significant lesion as measured by FFR, underscoring the potential role of FFR in assessing the surgical candidacy of patients with left main disease.

The impact of FFR assessment on revascularization strategy was studied in a small cohort of patients with multivessel disease.<sup>58</sup> The study showed that the revascularization procedure of choice was altered in 36% of patients. In addition, FFR altered the surgical strategy, including the number of grafts and placement of grafts, and revealed unsuspected left main disease in 3 patients. Similarly, in the FAMOUS-NSTEMI trial (Fractional Flow Reserve Versus Angiographically Guided Management to Optimise Outcomes in Unstable Coronary Syndromes), the FFR altered the treatment between medical therapy, PCI, or CABG in 21.6% of patients.<sup>59</sup>

The role of iFR on multivessel and left main CAD reclassification and surgical revascularization has not been studied yet, but appears promising. Large clinical trials are warranted. Coronary flow reserve, defined as the ratio of coronary blood flow at maximal hyperemia to the flow at baseline, may also play a role in guiding surgical revascularization.<sup>60,61</sup> Similarly, computerized tomography-derived FFR may be useful in CABG planning by evaluating the functional significance of different stenoses and guiding the selection of graft sites and targets.

## ONGOING STUDIES AND FUTURE DIRECTIONS

Studies on functional assessment of CAD to guide surgical revascularization have been limited and have mostly examined patency rates and short-term outcomes. Many questions remain unanswered: Would a revascularization strategy focused on functionally significant lesions, possibly with changing strategy to PCI or fewer bypass grafts, improve or adversely affect long-term outcomes? The current strategy of angiographically-guided CABG has resulted in favorable long-term results and should not be cast aside without the appropriate diligence.<sup>62,63</sup> Nevertheless, the appeal of physiological assessment is intuitive and warrants further study if there is a possibility of decreasing periprocedural risk or improving long-term outcomes as already evidenced in the setting of functionally-guided PCI.

There are several ongoing trials investigating the role of FFR in CABG (Table 2). The FAME 3 study (A Comparison of Fractional Flow Reserve-Guided Percutaneous Coronary Intervention and Coronary Artery Bypass Graft Surgery in Patients With Multivessel Coronary Artery Disease) is a multicenter, prospective, randomized trial with a noninferiority design. Patients with 3-vessel disease not involving the left main artery are randomly assigned to FFR-guided PCI or angiography-guided CABG. The study aims to demonstrate that FFR-guided PCI is noninferior to CABG in patients with 3-vessel coronary disease not involving the left main coronary artery. A major limitation of this trial is that it does not assess the direct role of FFR in the CABG cohort. Randomization is based on anatomic assessment alone, and FFR is used to guide percutaneous revascularization only. An additional concern is the relatively short duration of follow-up given the incremental benefit of surgical revascularization over PCI with time.<sup>62</sup>

The GRAFFITI study (Graft Patency After FFR-guided Versus Angio-guided CABG Trial) is designed to study FFR-guided versus angiography-guided CABG in patients with multivessel disease. The study end points include graft patency rates after 1 year by coronary computed tomography angiography or invasive coronary angiography. The study has the potential to as-

**Table 2. Ongoing Clinical Studies on Invasive Functional Assessment Using FFR in Patients Referred for CABG**

Clinical Trial	ClinicalTrials.gov Identifier	Study Design	No. of Patients	Primary Outcome	Follow-up	Study Limitations
FAME 3 (A Comparison of Fractional Flow Reserve-Guided Percutaneous Coronary Intervention and Coronary Artery Bypass Graft Surgery in Patients with Multivessel Coronary Artery Disease)	NCT02100722	Randomized, open label	1500	Death, MI, stroke, and any repeat revascularization	1 y	No direct assessment of role of FFR in CABG
GRAFFITI (Graft Patency After FFR-guided Versus Angio-guided CABG Trial)	NCT01810224	Prospective, randomized (1:1), multicenter, international study	206	Graft patency	1 y	No clinical outcomes Short follow-up
FARGO (Fractional Flow Reserve Versus Angiography Randomization for Graft Optimization Trial)	NCT02477371	Prospective, randomized (1:1), multicenter study	168	Graft patency	6 mo	No clinical outcomes
Impact of Preoperative FFR on Arterial Bypass Graft Functionality: Toward a New CABG Paradigm	NCT02527044	Efficacy study, open label	120	FFR	16 mo	Absence of comparator arm Short follow-up (6 mo) for graft patency Only qualitative of clinical outcome

CABG indicates coronary artery bypass grafting; FFR, fractional flow reserve; and MI, myocardial infarction.

sess the role of FFR in CABG; however, it is severely limited by the duration of follow-up and end points because it only assesses graft patency up to 1 year. One of the arguments in favor of grafting vessels with moderate stenoses is the possibility of native disease progression over time. It is conceivable that FFR-guided CABG may yield short-term equivalency, or even superiority, but may be associated with poorer results in the long term because of native vessel progression, and GRAFFITI most likely will not be able to tease out these differences.

The FARGO trial (Fractional Flow Reserve Versus Angiography Randomization for Graft Optimization Trial) is a prospective, randomized, multicenter study that aims to evaluate graft patency in patients randomly assigned to FFR-guided versus angiography-guided CABG. Similar to GRAFFITI, one of the major limitations of this trial is the assessment of graft patency up to 6 months only.

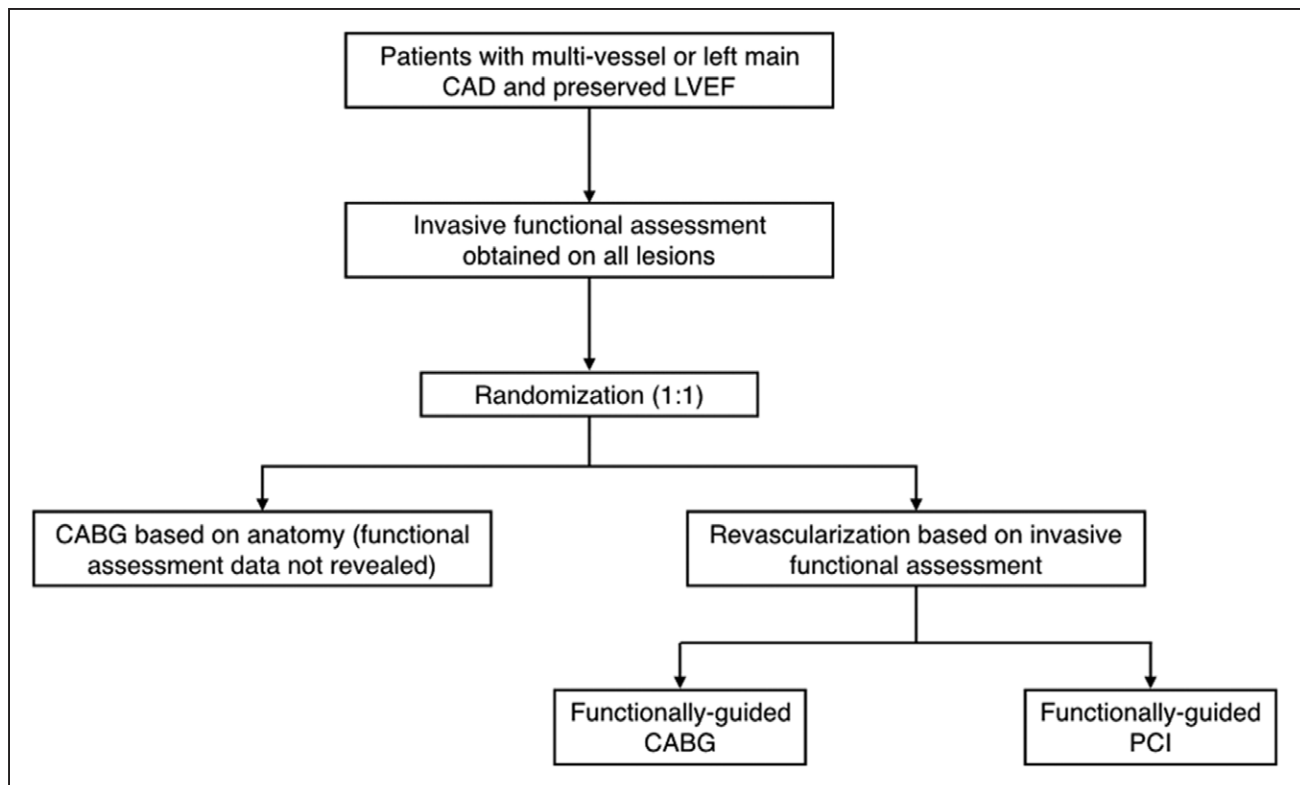
The study Impact of Preoperative FFR on Arterial Bypass Graft Functionality: Toward a New CABG Paradigm is designed to assess the role of preoperative FFR on arterial bypass graft functionality 6 months following surgical revascularization. In this study, FFR is measured as a scale and with 0 (worst) to 1 (best) regarding blood flow. This study is limited by the lack of a comparator arm and the short duration in assessing graft patency.

Results from the COMPARE-ACUTE study are an argument for expanding the use of FFR in the setting of STEMI.<sup>46</sup> It is crucial that the study design did not include the use of CABG as a revascularization modality despite a substantial portion of patients having 3-vessel disease. This omission of CABG in the design limits our understanding of the best mode of revascularization for patients with multivessel disease presenting with STEMI and needs to be addressed in future studies.

Although the FAME 3 and GRAFFITI trials attempt to further delineate the role of FFR in surgical revascularization, they will still leave unanswered key clinical questions. What is the role of the functional syntax score in the revascularization mode of multivessel disease? Should the reclassified patients be revascularized based on reclassification (possibly with PCI) or would they be better served in time with a multivessel CABG? A large clinical trial with long-term follow-up in which patients with multivessel or left main disease are randomly assigned to functionally (FFR or iFR)-guided PCI, functionally (FFR or iFR)-guided CABG, or anatomically-guided CABG would be necessary to shed light on the role of functional assessment in surgical revascularization (Figure 2). Graft patency could be evaluated using coronary computed tomography angiography or invasive angiography after bypass surgery. This study would have the advantage of comparing the functionally-guided complete revascularization strategy with CABG or PCI with anatomically complete revascularization with CABG.

## CONCLUSIONS

There is a wealth of data supporting the beneficial role of ischemia-guided (functional) over angiography-guided (anatomic) percutaneous revascularization in patients with stable CAD. Current knowledge does not adequately address the role of the functional assessment of CAD in CABG. Early data suggest that such an approach may reduce the number of coronary grafts required, while improving outcomes, but these data are hypothesis-generating and not sufficient to change current management guidelines of patients with multivessel or left main CAD. Well-designed rigorous clinical



**Figure 2. Conceptual study design with long-term clinical and angiographic follow-up.**

CABG indicates coronary artery bypass grafting; CAD, coronary artery disease; LVEF, left ventricular ejection fraction; and PCI, percutaneous coronary intervention.

cal trials to define the role of functional assessment in guiding surgical revascularization are warranted.

## ARTICLE INFORMATION

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### Disclosures

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HMP Communications (Editor in Chief, *Journal of Invasive Cardiology*), *Journal of the American College of Cardiology* (Guest Editor; Associate Editor), Population Health Research Institute (clinical trial steering committee), Slack Publications (Chief Medical Editor, *Cardiology Today's Intervention*), Society of Cardiovascular Patient Care (Secretary/Treasurer), WebMD (CME steering committees); other: *Clinical Cardiology* (Deputy Editor), National Cardiovascular Data Registry - Acute Coronary Treatment and Intervention Outcomes Network Registry Steering Committee (Chair), Veteran Affairs - Clinical Assessment, Reporting and Tracking Research and Publications Committee (Chair); research funding: Abbott, Amarin, Amgen, AstraZeneca, Bristol-Myers Squibb, Chiesi, Eisai, Ethicon, Forest Laboratories, Ironwood, Ischemix, Lilly, Medtronic, Pfizer, Roche, Sanofi Aventis, The Medicines Company; royalties: Elsevier (Editor, *Cardiovascular Intervention: A Companion to Braunwald's Heart Disease*); site co-investigator: Biotronik, Boston Scientific, St. Jude Medical (now Abbott); trustee: American College of Cardiology; unfunded research: FlowCo, Merck, PLx Pharma, Takeda.

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