Fractional Flow Reserve-Guided Versus Angiography-Guided

Coronary Artery Bypass Graft Surgery

Running title: Toth et al.; FFR-guided vs. Angio-guided CABG

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Abstract

Background—Fractional Flow Reserve (FFR) is well established for patients (pts) undergoing percutaneous coronary intervention, yet little is known for candidates to coronary artery bypass graft surgery (CABG).

Methods and Results—From 2006 to 2010, we retrospectively included in this registry 627 consecutive pts treated by CABG having at least one angiographically intermediate stenosis. In 429 pts, CABG was solely based on angiography (Angio-guided group). In 198 pts, at least one intermediate stenosis was grafted with FFR ≤ 0.80 or deferred with FFR > 0.80 (FFR-guided group). Endpoint was major adverse cardiovascular events (MACE) at 3 years, defined as the composite of overall death, myocardial infarction and target vessel revascularization. Rate of angiographic multivessel disease was similar in Angio-guided group vs. FFR-guided group (404 [94.2%] vs. 186 [93.9%), p=0.722). In FFR-guided group, this was significantly down-graded after FFR measurements to 86.4% (p<0.001 vs. before FFR), and it was associated with lower number of anastomoses (3[2-3] vs. 3 [2-4], p<0.001) and rate of on-pump surgery (49% vs. 69%, p<0.001). At 3 years, MACE was not different between Angio-guided and FFR-guided group (12% vs. 11%, HR: 1.030, 95% CI: 0.627 to 1.692, p=0.908). Yet, FFR-guided group compared with Angio-guided group presented significantly lower rate of angina (CCS class II-IV: 31% vs. 47%, p<0.001).

Conclusions—FFR-guided CABG was associated with lower number of graft anastomoses and rate of on-pump surgery as compared with Angio-guided CABG. This did not result into a higher event rate up to 36-month follow-up and was associated with lower rate of angina.

Key words: corin diagnosis coronary artery disease, bypass surgery, coronary angiography, fractional flow reserve
Introduction

Myocardial revascularization is recommended to improve symptoms and clinical outcome, following the latest joint guidelines of the European Society of Cardiology and the European Association of Cardio-thoracic Surgery. Improvement of clinical outcome, in particular, has been associated to the revascularization of the underlying ischemic burden. The latter if not demonstrated by non-invasive functional testing should be confirmed at the time of the diagnostic coronary angiography by the measurement of fractional flow reserve (FFR). FFR, in fact, allows the identification with unequal spatial resolution of the coronary stenosis responsible of reversible ischemia. In addition, percutaneous revascularization performed in the presence of an abnormal FFR (i.e. FFR < 0.80) results into an improved clinical outcome as compared with a revascularization strategy guided solely by the angiographic severity of the coronary stenosis.

Nevertheless only scarce data supporting the role of FFR in the guidance of surgical revascularization are available. Botman et al. showed a significant relationship between functionally significant coronary stenosis as demonstrated by FFR and graft patency at one year. The aim of our retrospective study is to investigate the impact of FFR measurement at the time of the pre-operative diagnostic coronary angiography on surgical revascularization and its related clinical outcome as compared with conventional angiographic guidance.

Methods

Population

In this study we investigated retrospectively patients who underwent CABG in our Institution between January 2006 and December 2010. Inclusion criterion was the presence of at least one intermediate stenosis at the coronary angiography, defined as diameter stenosis (DS) between
50% and 70% by visual estimation. Patients with a recent myocardial infarction (< 30 days) or needing associated valve surgery were excluded.

Patients were divided into 2 groups: angiography-guided (Angio-guided) and FFR-guided groups. The Angio-guided group consisted of patients, where no FFR was measured at the time of the pre-operative coronary angiography, and coronary artery by-pass graft (CABG) was indicated solely on the basis of the angiographic severity of the coronary stenosis. The FFR-guided group consisted of patients, in whom at least one intermediate stenosis was measured by FFR, and grafted in the presence of FFR ≤ 0.80 or deferred with FFR > 0.80.

**Coronary angiography and FFR measurement**

Coronary angiography was performed by a standard percutaneous femoral or radial approach with 6 or 7 Fr diagnostic- or guiding catheters. After the administration of 200-300 μg intracoronary isosorbide dinitrate (ISDN), the angiogram was repeated in the projection allowing the best possible visualization of the stenosis. Experienced operators not involved in the analysis of the data assessed stenosis severity. Multivessel disease was defined in the presence of stenosis in 2 or more major coronary arteries.

Performance of FFR measurement was left at the operator’s discretion. FFR was measured as previously described. Briefly, a pressure monitoring guide wire (Certus PressureWire™, St. Jude Medical Inc., St. Paul, Minnesota, US) was advanced distal to the coronary artery stenosis. After the administration of intracoronary ISDN (200 μg), hyperemia was obtained with either intravenous infusion (140 μg/kg/min) or intracoronary bolus (70-100 μg) adenosine. An FFR value lower or equal to 0.80 indicated an ischemia-producing coronary stenosis.

**Coronary artery bypass surgery**
Type of surgery, namely on-pump or off-pump, number and type of grafts were left to the surgeon’s discretion.

**Study endpoints**

Primary endpoint of the study was the rate of major adverse cardiac events (MACE), defined as overall death, myocardial infarction (MI) and target vessel revascularization (TVR) up to 3 years clinical follow-up. Secondary endpoints were all the individual endpoints included in MACE, plus the number of graft anastomoses, and the symptoms at the last clinical follow-up available. MI was defined as previously described.\(^{13,14}\) TVR was defined as any percutaneous or surgical revascularization performed at the follow-up either to the index study vessel or to the related vascular graft conduit.

In a group of patients undergoing a clinically indicated coronary angiography during the follow-up, graft patency rate was evaluated. Here, a sub-analysis was performed on a graft level. In particular, in the Angio-guided graft group we included all the grafts implanted on coronary arteries with intermediate stenosis and no FFR available at the time of the baseline angiogram; in the FFR-guided graft group we included all grafts implanted on coronary arteries with intermediate stenosis and FFR\(\leq 0.80\), measured at the time of the baseline angiogram.

The Institutional Medical Ethical Committee approved the use of clinical data for this study, and patients provided their informed consent.

**Statistical Analysis**

All analyses were performed with Prism GraphPad 5.0 (GraphPad Software Inc., California, US) and SPSS 20.0 (IBM Inc., New York, US). Continuous variables are expressed as mean \(\pm\) SD or as median [interquartile range], as appropriate. Categorical variables are reported as frequencies and percentages. Normal distribution was tested with the D’Agostino-Pearson omnibus K2 test.
Comparisons between continuous variables were performed using the Student’s t test or Mann-Whitney test. Comparisons between categorical variables were evaluated using the Fisher exact test or the Pearson chi-square test, as appropriate. Presence of multivessel disease before and after FFR-measurement was compared with McNemar test. Linear regression analysis was performed to assess the relationship between FFR-guidance and number of anastomoses performed. Clinical variables (male gender, and previous percutaneous coronary intervention [PCI]) that showed a significant univariable association with number of anastomoses entered the multivariable linear regression model. Logistic regression analysis was performed to assess the relationship between arterial or venous anastomoses and presence/absence of angina CCS class II-IV. Difference in survival was calculated by applying the Kaplan-Meier curves. Cox-proportional Hazard analysis was performed to analyze clinical endpoints at the follow-up. In the subgroup of patients undergoing the angiographic follow-up, clinical variables like age and diabetes entered the multivariable model. A probability value of p<0.05 (two-tailed) was considered as statistically significant.

Results

Clinical characteristics

We included 627 patients: 429 in the Angio-guided group, and 198 in the FFR-guided group. Clinical characteristics are summarized in Table 1. There were no significant differences in baseline characteristics between the 2 groups except that Angio-guided patients were older, more frequently female and diabetic. FFR-guided patients had more frequently PCI in the past.

Angiographic and surgical characteristics

Rate of multi-vessel disease (MVD) at coronary angiography was similar between the 2 groups.
(404 [94.2%] in Angio-guided vs. 186 [93.9%] in FFR-guided group, p=0.722) (**Figure 1, panel A**). After FFR measurement, rate of MVD was significantly down-graded in the FFR-guided group (171 [86.4%], p<0.001 vs. before FFR-measurement, p=0.002 vs. Angio-guided group) (**Figure 1, panel B**).

After CABG, total anastomoses per patient (3[2-3] vs. 3 [2-4], p<0.001) and venous anastomoses per patient (1[0-1] vs. 1[1-2], p<0.001) were significantly lower in the FFR-guided as compared with the Angio-guided group, while only a trend was observed for arterial anastomoses (2[1-2] vs. 2[1-2], p=0.068)(**Table 2**). This resulted into higher arterial-venous anastomosis ratio in the FFR-guided versus the Angio-guided group (71/29% vs. 55/45%, respectively, p<0.001). In addition, a significant overall difference was observed in the rate of single, 2 to 3, and 4 or more anastomoses per patient between the Angio-guided and the FFR-guided group (**Figure 1, panel C**). At multivariable linear regression analysis, FFR-guidance was significantly associated with the number of anastomoses performed (Beta [95% C.I.]: -0.20[-0.74;-0.33], p<0.001). Grafted coronary arteries were equally distributed between the 2 groups with the exception of lower rate of right coronary artery grafted in the FFR-guided group (**Table 2**). In addition, a lower rate of on-pump surgery was observed in the FFR-guided versus the Angio-guided group (49% vs. 69%, p<0.001), while only a trend was found toward lower pump time in the FFR-guided group.

**Clinical follow-up**

Clinical follow-up was available in 419 (98%) patients in the Angio-guided group and in 193 (97%) patients in the FFR-guided group at a median of 33.1 [21.7-36.0] months. Kaplan Meier (**Figure 2**) and Cox-regression (**Table 3**) analysis did not show any significant difference between the FFR-guided and the Angio-guided group with respect to overall death, myocardial
infarction, TVR, and MACE at 36 months.

At baseline, no significant difference was observed between the Angio-guided and the FFR-guided group in the rate of CCS class II-IV. At follow-up, rate of CCS class II-IV was significantly lower in the FFR-guided as compared with the Angio-guided group (Figure 3). A trend toward an association between arterial anastomoses and CCS class II-IV (OR: 0.836 [0.689–1.014], p=0.069) was found, while no significant association was observed between venous anastomoses and CCS class II-IV (OR: 1.063 [0.917–1.232], p=0.418).

**Angiographic follow-up**

A subgroup of 155 (25%) pts underwent a clinically indicated coronary angiography during the follow-up. Clinical characteristics of these pts did not significantly differ from that of the overall group (data not shown). Out of 234 grafts implanted on coronaries with intermediate stenosis, 174 were included in the Angio-guided graft group, and 60 were included in the FFR-guided graft group. Median time to angiographic follow-up was similar between these 2 groups: 22 [9-36] vs. 21 [12-36] months, respectively, p=0.790. Compared with the Angio-guided graft group, higher overall graft occlusion-free survival (Figure 4, panel A) and significantly fewer grafts (36 [21%] vs. 3 [5%], respectively; adjusted HR: 0.523 [0.290-0.944], p=0.031) were found occluded in the FFR-guided graft group. Only a trend toward higher arterial graft occlusion-free survival was observed in the FFR-guided group (Figure 4, panel B), with similar rate between the 2 groups in terms of occluded arterial graft (15 [14%] vs. 2 [4%], unadjusted HR: 0.522 [0.249-1.091], p=0.101).

**Discussion**

In the present study, patients undergoing FFR-measurement at the time of the diagnostic pre-
operative coronary angiogram (FFR-guided CABG) received less grafts, less anastomoses, and a lower rate of on-pump surgery as compared with patients with no FFR-measurement (Angio-guided CABG). Importantly, this lower number of grafts did not result into an excess hazard up to 36-month follow-up and was associated with lower rate of angina.

**Role of FFR in patients selected to CABG**

Myocardial revascularization is recommended when a large territory of reversible myocardial ischemia is present.\(^1\)\(^2\) Of note, patients undergoing surgical revascularization usually present with complex coronary artery disease, like left main stenosis or multivessel disease. In these conditions, non-invasive functional testing has demonstrated limited accuracy and poor spatial resolution in detecting reversible ischemia.\(^15\) At the variance, FFR has high spatial resolution as it allows to interrogate each stenotic coronary artery and to unmask possible ischemia-producing stenoses.\(^16\) This was particularly evident in our study. Rate of multivessel disease, in fact, was not significantly different between the 2 groups at baseline angiography. Yet, after FFR measurement, rate of multivessel disease was significantly downgraded in patients of the FFR-guided group, suggesting that several coronary stenosis deemed angiographically significant turned out to be not ischemia producing at the invasive functional evaluation.\(^17\) A significant independent interaction was found between FFR measurement at the time of the diagnostic coronary angiography and surgical revascularization eventually adopted as confirmed by the inverse relationship found between FFR-guidance and number of anastomoses. As a consequence, the number of grafts and the total number of anastomoses, the venous anastomoses in particular, were significantly reduced in the FFR-guided group. The number of arterial anastomoses was similar between the 2 groups, with a higher arterial-venous anastomosis ratio in the FFR-guided group. In addition, rate of 4 or more anastomoses and on-pump surgery were
significantly reduced, with a trend toward a reduced pump time, suggesting overall a less complex surgical protocol performed in the FFR-guided group.

Grafted coronary arteries were equally distributed between the 2 groups with the exception of lower rate of right coronary artery grafted in the FFR-guided group. This is of no surprise if considering that intermediate stenosis of the RCA can be found more frequently with a non-significant FFR value, and can be attributed to the more limited subtended myocardial territory of the RCA as compared with the left coronary artery.

**FFR-guided CABG and clinical outcome**

An FFR-guided percutaneous revascularization has been associated with a significant clinical benefit into different clinical and anatomical settings compared to a percutaneous revascularization strategy guided solely by the angiographic severity of the coronary stenosis. In addition, deferral of coronary stenosis with non-significant FFR to optimal medical therapy has shown a favorable outcome. In our patients of the FFR-guided group, we did not observe any signal of excess hazards during the follow-up. In addition, patients of the FFR-guided group presented improved symptoms, considering that rate of CCS class II-IV was significantly reduced as compared with patients of the Angio-guided group. This is particularly remarkable if considering that patients of the FFR-guided group underwent a more limited revascularization in terms of anastomoses and grafts implanted. We don’t have a definitive explanation for the lower rate of angina in patients of the FFR-guided group. We can only speculate that: 1) on one side, the lack of FFR-guidance might have left some of the functionally significant stenosis un-grafted in patients of the Angio-guided group; 2) on the other side, in patients of the FFR-guided group, the higher arterial to venous anastomosis ratio might have either limited the clinical impact of potential venous graft failure or warranted longer graft patency rate due to the predominance of
the arterial bypasses. The latter is also suggested by the trend toward an association between arterial anastomoses and CCS class II-IV.

**FFR-guided CABG and graft patency**

In a prospective registry, Botman et al. showed a significant relationship between functionally significant coronary stenosis as demonstrated by FFR and graft patency at one year. In particular, compared with grafts implanted on stenotic vessels with pathologic FFR, the occlusion rate was nearly 3 times higher in those grafts implanted in stenotic vessels with non-significant FFR at the pre-operative coronary angiography. Our findings in the subgroup of patients with angiographic follow-up confirm and further extend to a longer time-period these previous observations. In fact, we found that rate of graft occlusion was 4 times lower in the FFR-guided group up to 3 years follow-up as compared with the Angio-guided group.

**Study limitations**

Several limitations should be acknowledged in our study. First, this is an observational study limited by its retrospective design. Second, we should acknowledge the wide confidence intervals observed for MACE, reflecting the limited sample size of our study. The sample size that would be needed to limit the 95% confidence interval to approximately 15% corresponds to 3800 patients per group. Although based on these figures, a clinically-driven prospective randomized study would be of difficult performance, we believe our study is valuable in that it provides other surrogate endpoints to design prospective studies: i.e. pump time, number of anastomosis, patency rate of grafts, etc. Third, coronary stenosis severity was not assessed by an independent angiographic core-lab. Likewise, some disease of secondary coronary branches might have not been captured in our analysis. Although this limitation equally affected both groups, we cannot exclude an unbalance in favor of the FFR-guided group: i.e. less severe
overall disease. Fourth, the sub-analysis performed in the group of patients with angiographic follow-up, although in line with previous findings,\textsuperscript{10,19} should be considered speculative and only hypothesis-generating. Here, we acknowledge a possible selection bias derived by the fact that only patients with a clinically indicated coronary angiography were analyzed.

In 29 patients of the FFR-guided group, an additional stenosis in another vessel was measured with FFR and not intervened accordingly: i.e. grafted in the presence of FFR > 0.80 (n=19) or deferred despite an FFR ≤ 0.80 (n=11). Since these patients had at least one stenosis treated according to the FFR value, they were kept in the FFR-guided group. We believe they had only limited impact (if any, this impact was not favorable to the FFR-guided group) on our analysis and interpretation of the results for the following reasons: 1) Baseline clinical characteristics of these patients were not significantly different from that of the overall population of the FFR-guided group (data not shown); 2) Among these 29 patients, only 2 presented with TVR at clinical follow-up both in the non-index vessels. In one patient, LIMA was implanted on the LAD, despite the FFR value of the native stenotic vessel was 0.84 at pre-CABG coronary angiography: PCI of the LIMA was performed at the follow-up. In the other patient, a stenotic LCX was not grafted despite the FFR value was 0.54 at pre-CABG diagnostic angiogram: PCI of the LCX was performed at the follow-up.

Conclusions
An FFR-guided CABG was associated with lower number of graft anastomoses, with a lower rate of on-pump surgery as compared with Angio-guided CABG. This did not result into a higher event rate up to 36-month follow-up and was associated with lower rate of angina.
Conflict of Interest Disclosures: WW and BDB are consultants for St. Jude Medical Inc. The other authors have no conflict of interest to disclose.

References:


**Table 1.** Clinical characteristics.

<table>
<thead>
<tr>
<th></th>
<th>Angio-guided (n=429)</th>
<th>FFR-guided (n=198)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, years</td>
<td>69 (63-76)</td>
<td>65 (56-72)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Male gender, n (%)</td>
<td>309 (72)</td>
<td>162 (82)</td>
<td>0.010</td>
</tr>
<tr>
<td>BMI, kg/m²</td>
<td>27 (24-30)</td>
<td>28 (25-30)</td>
<td>0.066</td>
</tr>
<tr>
<td>Hypertension, n (%)</td>
<td>338 (79)</td>
<td>155 (78)</td>
<td>0.917</td>
</tr>
<tr>
<td>Hypercholesterolemia, n (%)</td>
<td>287 (67)</td>
<td>128 (65)</td>
<td>0.587</td>
</tr>
<tr>
<td>Diabetes, n (%)</td>
<td>128 (30)</td>
<td>43 (22)</td>
<td>0.034</td>
</tr>
<tr>
<td>Previous PCI, n (%)</td>
<td>102 (24)</td>
<td>97 (49)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Smoking habit, n (%)</td>
<td>177 (41)</td>
<td>84 (42)</td>
<td>0.794</td>
</tr>
<tr>
<td>Family history, n (%)</td>
<td>103 (24)</td>
<td>48 (24)</td>
<td>1.000</td>
</tr>
<tr>
<td>PVD, n (%)</td>
<td>73 (17)</td>
<td>27 (14)</td>
<td>0.293</td>
</tr>
<tr>
<td>LVEF, %</td>
<td>71 (60-80)</td>
<td>71 (61-79)</td>
<td>0.931</td>
</tr>
</tbody>
</table>

BMI: body mass index; MI: myocardial infarction; PCI: percutaneous coronary intervention; PVD: peripheral vascular disease; LVEF: left ventricular ejection fraction.

**Table 2.** Procedural characteristics of coronary artery bypass graft surgery.

<table>
<thead>
<tr>
<th></th>
<th>Angio-Guided</th>
<th>FFR-Guided</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anastomosis per patient, median (IQR)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arterial</td>
<td>2 (1-2)</td>
<td>2 (1-2)</td>
<td>0.068</td>
</tr>
<tr>
<td>Venous</td>
<td>1 (1-2)</td>
<td>1 (0-1)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Anastomosis per group, n (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arterial</td>
<td>751/1373 (55)</td>
<td>367/518 (71)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Venous</td>
<td>622/1373 (45)</td>
<td>151/518 (29)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Grafted Coronary Arteries, n (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LAD</td>
<td>425 (99)</td>
<td>196 (99)</td>
<td>1.000</td>
</tr>
<tr>
<td>LCX</td>
<td>380 (89)</td>
<td>170 (86)</td>
<td>0.575</td>
</tr>
<tr>
<td>RCA</td>
<td>346 (81)</td>
<td>130 (66)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Rate of On-pump Surgery, n (%)</td>
<td>269 (69)</td>
<td>97 (49)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Pump time (min), median (IQR)</td>
<td>95 (89-112)</td>
<td>89 (73-106)</td>
<td>0.067</td>
</tr>
</tbody>
</table>
Table 3. Clinical endpoints at 36-month follow-up.

<table>
<thead>
<tr>
<th></th>
<th>Angio-guided (n=429)</th>
<th>FFR-guided (n=198)</th>
<th>HR (95% CI)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Death, n (%)</td>
<td>31 (7)</td>
<td>7 (4)</td>
<td>1.712 (0.843 to 3.475)</td>
<td>0.137</td>
</tr>
<tr>
<td>MI, n (%)</td>
<td>25 (6)</td>
<td>12 (6)</td>
<td>0.913 (0.453 to 1.841)</td>
<td>0.780</td>
</tr>
<tr>
<td>TVR, n (%)</td>
<td>14 (3)</td>
<td>9 (5)</td>
<td>0.671 (0.276 to 1.630)</td>
<td>0.378</td>
</tr>
<tr>
<td>MACE, n (%)</td>
<td>52 (12)</td>
<td>22 (11)</td>
<td>1.030 (0.627 to 1.692)</td>
<td>0.908</td>
</tr>
</tbody>
</table>

MI: myocardial infarction; TVR: target vessel revascularization; MACE: major adverse cardiovascular event.

Figure Legends:

Figure 1. Rate of patients with multivessel disease before (Panel A) and after (Panel B)
Fractional flow reserve measurement; rate of patients with 1, 2 to 3, and 4 or more anastomoses (Panel C).

Figure 2. Clinical events in the Angio-guided and FFR-guided group during 36-month follow-up. Panel A: overall survival (Log Rank 2.216, p=0.137); Panel B: myocardial infarction (MI)-free survival (Log Rank 0.064, p=0.780); Panel C: target vessel revascularization (TVR)-free survival (Log Rank 0.777, p=0.378); Panel D: major adverse cardiac event (MACE)-free survival (Log Rank 0.013, p=0.908).

Figure 3. Rate of patients with symptoms (Canadian Cardiovascular Society class II-IV) at baseline and at last clinical follow-up.

Figure 4. Occlusion-free survival of grafts with angiographic follow-up. Panel A: occlusion-free survival of all grafts (Log Rank 6.297, p=0.012); Panel B: occlusion-free survival of arterial grafts only (Log Rank 3.458, p=0.063).
Figure 1
Figure 2
Figure 3
Figure 4

A. Overall occlusion-free graft survival

- Angio-guided
- FFR-guided

Log Rank 6.297, p=0.012

Follow-up (months)

Patency rate (%)

B. Occlusion-free graft survival of arterial grafts

- Angio-guided
- FFR-guided

Log Rank 3.458, p=0.063

Follow-up (months)

Patency rate (%)

Angio-guided: 174 128 83 39
FFR-guided: 60 47 26 16

Angio-guided: 110 75 49 24
FFR-guided: 51 39 22 15
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