Evaluation of gastroepiploic arterial grafts to right coronary artery using transit-time flow measurement

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Abstract

OBJECTIVES: The objective of this study was to analyse the relationship between the intraoperative transit-time flow measurement (TTFM) parameter values and the postoperative angiographic results of gastroepiploic arterial (GEA) grafts to the right coronary artery (RCA). We investigated whether the intraoperative TTFM parameter values are reliable indicators of early patency in GEA grafts to the RCA.

METHODS: Patients undergoing off-pump coronary artery bypass surgery with GEA grafts were included in this study. Eighty-three GEA grafts were individually anastomosed and examined by angiography 1 week after surgery. The quality of each graft was graded using FitzGibbon grading (Study 1) and graft-flow grading (Study 2).

RESULTS: Study 1: Seventy-two grafts were determined as Grade A and 11 as Grades B or O. There were no significant differences in the average of mean graft flow (MGF), pulsatility index or diastolic filling percentage between Grade A and Grades B or O grafts. Study 2: Sixty-two grafts were graded as good-graft dominant, 16 as bidirectional and 5 as occlusion including string. The average of the MGF, pulsatility index and diastolic filling percentage in the grafts graded as bidirectional and occlusion including string were not significantly different from those of grafts graded as good-graft dominant.

CONCLUSIONS: Previously reported cut-off values for intraoperative TTFM parameters could not be adapted for the early patency of GEA grafts to the RCA. However, the smoothness of the graft-flow curve may be a reliable predictor of postoperative graft patency.

Keywords: Adult • Cardiology • Coronary artery disease • Off-pump surgery • Cardiac Surgery

INTRODUCTION

Transit-time flow measurement (TTFM) is a widely used technique for assessing intraoperative graft quality [1]. TTFM can be used to obtain values for the following parameters: mean graft flow (MGF, ml/min), pulsatility index (PI) and diastolic filling percentage (DF, %). Several retrospective studies have provided data to show that TTFM is useful for detecting impaired grafts [2–6]. However, these reports generally refer to the internal mammary artery (IMA) or saphenous vein (SV) grafts to the left coronary artery (LCA). There have been few reports concerning gastroepiploic arterial (GEA) grafts to the right coronary artery (RCA).

We have performed a number of coronary bypass surgeries involving GEA grafts to RCA. In this study, we analysed the relationship between TTFM parameters (MGF, PI and DF) and postoperative angiographic results of the GEA grafts and determined whether these TTFM parameters are reliable intraoperative measures of graft quality in coronary artery bypass surgery involving the GEA grafts to RCA.

PATIENTS AND METHODS

This study was approved by the institution’s Ethics Committee.

Patients

One hundred and sixty-nine patients underwent off-pump coronary artery bypass surgery (OPCABG) with GEA grafts for RCA bypass. The surgical designs were as follows: GEA–posterior descending artery (PD; n = 73), GEA–atrioventricular branch (AV; n = 24), GEA–PD–AV (n = 14), GEA–PD–left circumflex artery (LCX; n = 4) and GEA–AV–LCX (n = 3). In total, 97 patients underwent
individual GEA–PD or the GEA–AV anastomoses. In 83 patients, the following conditions were observed: TTFM parameters (MGF, PI and DF) and the graft-flow waveforms were intraoperatively recorded; the patients displayed stable vital signs, without catecholamines, during the perioperative period; and an angiogram was taken 1 week after the surgery. This report is based on the data obtained from these 83 patients.

**Surgical details**

Our standard strategy for coronary artery bypass is to perform OPCABG employing the no-touch aorta technique with in situ arterial grafts. We used the bilateral IMAs for LCA and GEA for RCA. Three 'Lima sutures' were made to move the cardiac apex upward. We used a shunt tube during every anastomosis. In this study, all surgeries described were performed following this style.

The IMA was harvested using a hook-type ultrasonic scalpel (Harmonic scalpel, TH®, Ethicon, Japan), and GEA was harvested using a scissor-type ultrasonic scalpel (Harmonic scalpel, CS-14C®, Ethicon, Japan). GEA was harvested starting distally and ending proximal to the pylorus.

After systemic heparinization, both IMA and GEA were distally transected. Free flow in the conduits was not measured. Diluted milrinone (1 ml; 0.5 mg/ml) was intraluminally injected into IMA and GEA. They were wrapped in gauze soaked in papaverine hydrochloride solution until each anastomosis was started. GEA was passed through a hole in the diaphragm to reach the target coronary artery. The anastomoses were made using a running 8–0 polypropylene suture.

**Transit-time flow measurement assessment**

Intraoperative flow measurements for all grafts were performed immediately before sternal closure using a TTFM device (BF1001; Medi-Stim AS, Oslo, Norway) on the mid-portion of the graft body. Systolic blood pressure and mean arterial blood pressure were maintained at 100–150 and 70–90 mmHg, respectively.

TTFM provides values for the following three parameters [7]:

- **MGF**, which is defined by the equation $(MGF; \text{ml/min}) = (\text{aortic pressure} – \text{distal myocardial pressure/distal vascular resistance});$
- **PI**, which is defined according to the equation $(PI) = (\text{maximum flow volume} – \text{minimum flow volume/mean flow volume});$ and
- **diastolic filling (DF, %)**, which is defined by the equation $(DF) = (\frac{\text{total diastolic flow}}{\text{total diastolic flow} + \text{total systolic flow}})$. An appropriately fitted probe, with acceptable contact between the probe and the graft, was used.

**Coronary angiography**

Angiograms were evaluated by two distinct patterns of classification. In one pattern, anastomotic stenosis (i.e. the patency of graft anastomosis) was evaluated with the FitzGibbon grading system (Study 1) (Table 1) [8]. In the other pattern, the graft flow was graded (Study 2). Graft-flow grading focused on the direction of the graft-blood flow and assigned the following grades: good-graft dominant, bidirectional flow or occlusion including string. Good-graft dominant condition was defined as a situation in which the target vessel was fully opacified from the GEA graft injection, and the GEA graft was barely filled by retrograde flow from the native coronary injection. Bidirectional flow was defined as a situation in which the target vessel was distally opacified from the GEA graft injection, and the GEA graft was reflected by retrograde flow from the native coronary injection. Occlusion including string was defined as a situation in which the target vessel was barely reflected from the GEA graft injection and the GEA graft was barely reflected from the native coronary injection (Table 2).

**Statistical analysis**

Statistical analysis was performed using the IBM SPSS statistics 21 software (SPSS, Inc., Chicago, IL, USA). The Shapiro–Wilk W-test was used to test for normality. Each of the TTFM parameters is expressed as mean ± standard deviation (SD). In Study 1, F-values were obtained using Levene’s test. If the assumption of homogeneity of variance was met, we used Student’s t test for comparison of the two independent groups. If the assumption of homogeneity of variance was not met, we used the Mann–Whitney U-test. In Study 2, Dunnett’s test was used for multiple comparisons. A P-value of <0.05 was considered to be statistically significant.

**RESULTS**

**Study 1**

All grafts were assessed 1 week after coronary surgery and were classified using the FitzGibbon grading system. Definitions of grades included in the FitzGibbon system are summarized in

<table>
<thead>
<tr>
<th>Table 1: Definitions of graft grade assessed by FitzGibbon classification</th>
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<tr>
<td><strong>Grade</strong></td>
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<td>A</td>
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<td>B</td>
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<td>O</td>
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Table 2: Definitions of graft-flow grading

<table>
<thead>
<tr>
<th>Grade</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good-graft dominant</td>
<td>Target vessel was fully opacified from the GEA graft injection, and the GEA graft was barely filled by retrograde flow from the native coronary injection</td>
</tr>
<tr>
<td>Bidirectional flow</td>
<td>Distal anastomosis of target vessel was opacified from the GEA graft injection and the GEA graft was reflected by retrograde flow from the native coronary injection</td>
</tr>
<tr>
<td>Occlusion including string</td>
<td>Target vessel was barely reflected from the GEA graft injection and the GEA graft was barely reflected from the native coronary injection</td>
</tr>
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</table>

GEA: gastroepiploic arterial.
Table 1. Of the 83 grafts, 72 were determined as Grade A and 11 grafts as Grades B or O postoperatively. A comparison of intraoperative TTFM parameters between the two groups (Grade A grafts and Grades B or O grafts) is given in Table 3. Although Grade A grafts had a relatively higher DF scores than Grade B or O grafts, there were no significant differences in MGF ($P = 0.905$), PI ($P = 0.482$) or DF ($P = 0.269$) between Grade A grafts and Grades B or O grafts. Therefore, there was no correlation between the early quality of the GEA graft anastomoses and the intraoperative TTFM parameter values.

**Study 2**

All grafts were classified using the graft-flow grading system summarized in Table 2. In total, 62 grafts were graded as good-graft dominant, 16 as bidirectional flow and 5 as occlusion including string. Table 4 shows the averages of the TTFM parameters MGF, PI and DF classified by the graft-flow grading. Grafts graded as occlusion including string had the lowest MGF value (7.8 ± 1.5 ml/min) and the highest PI (6.5 ± 2.3). However, each bidirectional flow value showed no significant difference when compared with each good-graft dominant value (MGF, $P = 0.06$; PI, $P = 0.09$; DF, $P = 0.29$). Furthermore, none of the TTFM parameter values for grafts graded as occlusion including string showed a significant difference when compared with the values for grafts graded as good-graft dominant (MGF, $P = 0.07$; PI, $P = 0.18$; DF, $P = 0.06$). Although there was no significant difference among the three groups, the data showed that MGF and PI values have a tendency to reflect the graft-flow grading.

As seen in Figs 1–3, the three figures of TTFM parameter values show different graft-flow curve shapes. Each panel displays data from a graft representative of those of a particular grade, i.e. good-graft dominant (Fig. 1), bidirectional (Fig. 2) or occlusion including string (Fig. 3). It is difficult to determine whether the grafts require revision in cases of Figs 2 and 3 on the basis of TTFM parameter values alone.

**DISCUSSION**

A successful coronary bypass surgery is the first step towards a successful career for cardiovascular surgeons. However, the quality of the grafts used is directly linked to the patient’s surgical outcome; therefore, several methods have been used to...
intraoperatively detect graft failure [9–12]. TTFM is the most common intraoperative method for assessing graft function. This device displays a flow curve and calculates values for parameters MGF, PI and DF.

Several studies have correlated graft quality (technical problems such as a conduit twisting, kinking or dissection; anastomosis of the intimal flap; thrombus; stenosis and occlusion) with intraoperative TTFM parameter values (MGF, PI and DF). D’Ancona et al. [13] surgically revised 41 (3.5%) of 1145 grafts based on an unsatisfactory flow curve, PI or both and suspected that failing grafts showed a PI value of >5. Leong et al. [14] commented that a graft could be assumed to be patent if it was assessed using MGF (>15 ml/min) and PI (<5). According to Gregory [15], the DF value should be >50% and ideally >65%. Furthermore, if both PI and DF display good values, the graft quality and distal coronary perfusion must be accurate.

These studies have demonstrated the usefulness of intraoperative TTFM as a method to improve graft patency by identifying and revising failed grafts. According to these articles, a graft is likely to be patent if the MGF value is >15 ml/min, the PI value is <5 and the DF value is >50%.

In our hospital, we have used not only both IMAs but also GEA as a third arterial graft. As stated above, it is clear that TTFM is useful for detecting a graft failure intraoperatively. However, these articles discussed only IMA or SV grafts, and not GEA grafts.

From our impression, some GEA grafts were patent despite displaying low MGF values and high PI values and some GEA grafts were occluded despite displaying high MGF values and low PI values. The IMAs used in the patients who had GEA were almost all patent grafts, and we could not verify TTFM data of IMAs. Therefore, we studied the relation between the GEA graft patency and TTFM parameter values.

In Study 1, there was no correlation between the quality of GEA anastomoses and TTFM parameter values. In contrast, in Study 2, grafts graded as bidirectional or occlusion including string tended to have lower MGF values and higher PI values compared with those graded as good-graft dominant. However, the grafts in Study 2 showed non-significant difference in their mean parameter values, MGF, PI and DF among the three grading groups. Therefore, we suggest that the cut-off TTFM parameter values mentioned above should not be adopted for GEA grafts in RCA bypass.

The MGF value is dependent on the following factors: size, length and quality of the graft, the native coronary artery, run-off quality of the coronary bed, mean arterial pressure, competitive flow, viscosity of the blood and quality of the anastomosis. Janne et al. reported that the average MGF value of IMA grafts was 42 ml/min [16]. The average MGF value of our patent GEA grafts was relatively lower than the value obtained with IMA or SV grafts. Because GEA is a visceral artery and the fourth branch of the aorta (abdominal aorta, coeliac artery, common hepatic artery, gastroduodenal artery, right GEA), its diameter and flow volume are smaller than both IMA and SV grafts. Therefore, it is difficult to determine the GEA anastomosis quality using a cut-off MGF value of 15 ml/min.

In general, the PI value reflects, or is proportional to, the vascular resistance. Therefore, a high PI value is an indicator of poor graft quality or poor anastomosis. When the graft flow was competitive, PI showed a high value because the minimal flow volume was negative. Moreover, we believe that the occurrence of anastomotic stenosis leading to flow resistance and increasing PI value is rare. High PI is most often caused by competitive flow, distal coronary resistance and graft resistance. Some authors have suggested using a PI value of 3 or higher as the cut-off criterion to predict a higher incidence of early IMA or SV graft failure [16]. In our study, patent GEA grafts displayed PI values higher than those quoted by other studies.

GEA is different from IMA when viewed from the anatomical, embryological and physiological perspectives [17]. From the anatomical perspective, GEA is classified into splanchic (visceral) arteries, i.e. splenic or superior mesenteric artery. IMA is classified into somatic arteries located in the body wall such as the intercostal artery. Thus, GEA is a physiologically reactive artery. We skeletonized all GEAs using an ultrasonic scalpel (harmonic scalpel); therefore, we believe it is difficult for GEAs to become spastic. However, it is true that GEAs tend to be more spastic than IMAs even if they are skeletonized. For these reasons, GEAs typically display peripheral arterial flow, with the highest flow during cardiac systole and the flow close to zero at the cardiac end-diastole before coronary anastomosis [18].

Furthermore, posterior and inferior wall circulation from RCA has decreased intramural compressive forces that develop during cardiac systole compared with anterior and septal wall circulation from LCA. In a research paper, Gregg et al. [19] stated that the pulsatile RCA blood flow pattern in a normotensive dog at rest differed in appearance from LCA flow patterns. In addition, Lowensohn et al. stated that RCA systolic flow was proportionately significantly greater than LCA systolic flow, and the differences between RCA and LCA systolic flow may be explained by the temporal relationships between coronary perfusion pressure and intramyocardial tension [20]. Therefore, it is thought that an antegrade flow occurs more easily during cardiac systole in a GEA graft to RCA than in an IMA graft to LCA. When the native RCA was occluded (RCA total), the spike shape of the antegrade flow (arrowheads) during cardiac systole, after opening the aortic valve (ejection period), appeared as shown in Fig. 1. When the native RCA was not occluded, and displayed only mild stenosis, the retrograde flow during cardiac systole (arrows), before opening the aortic valve (isovolumic contraction period), and the spike shape of the antegrade flow during the ejection period (arrowheads) appeared as shown in Fig. 2. Because it is a peripheral vessel, a

![Figure 3: TTFM figure. Occlusion including string graft. TTFM: transit-time flow measurement; GEA: gastroepiploic artery; RCA: right coronary artery; ACI: acoustic coupling index; ECG: electrocardiogram; HR: heart rate.](https://academic.oup.com/ejcts/article-abstract/47/3/459/522661)
GEA graft tends to show competitive flow. When Fig. 3 was intraoperatively obtained, the GEA graft may have been patent because the spike shape during the antegrade flow and fully diastolic flow were shown. However, the GEA graft was occluded 1 week after the surgery. TTFM could assess the graft flow only during the measurement time, i.e. intraoperatively. This does not reflect the graft flow or patency after surgery even with early postoperative assessment; this is a limitation of TTFM. Takami et al. [21] investigated the flow characteristics of grafts. We also paid attention to the shape, especially the fluctuation of the graft-flow curve obtained using TTFM. In Fig. 3, the parameters MGF, PI, and DF showed good values, but the flow curve was not smooth during the diastolic period.

Stein et al. [22] studied the relationship between turbulent flow and thrombus formation. They established two AV shunts using a dog’s femoral arteries and veins. One of them was constricted with tape to create a turbulent shunt, and the other one was left untouched and considered as a laminar shunt. In that study, the laminar shunt showed a smooth flow velocity, while the turbulent shunt did not. They concluded that turbulence appears to contribute to the formation of thrombi. In our study, the flow curve in Figs 1–3 shows flow volume (ml/min) and not flow velocity (cm/s). However, the flow of blood in a vessel is related to velocity in the equation: \( F = V \times A \), where \( F \) is the flow (ml/min), \( V \) is the mean velocity (cm/s) and \( A \) is the cross-sectional area of the vessel.

This relationship indicates that at a constant vessel radius, changes in flow are proportional to changes in velocity.

The smoothness of the flow–volume curve was affected by the quality of the graft and anastomosis, the run-off quality of the coronary bed and the blood viscosity. We believe that a flow–volume curve that is not smooth expresses a turbulent graft flow, which causes the graft to be postoperatively graded as an occlusion or string graft. Therefore, an analysis of the graft-flow curve may become a new indicator to predict the postoperative graft patency.

In conclusion, this study illustrates that it is difficult to adapt previously reported TTFM parameter cut-off values to GEA grafts performed during RCA bypass surgery. In a GEA graft for RCA, MGF is lower, the PI value is higher and the DF value is lower than the values typically seen in IMA or SV grafts for LCA. We consider the graft-flow curve obtained using TTFM as an important predictor of postoperative graft patency and use it to help judge whether the graft requires revision.

Conflicts of interest: none declared.

REFERENCES


