Letter to the Editor

Comparison of the Haemodynamic Parameters of Venous and Arterial Coronary Artery Bypass Conduits

Dear Editor,

Coronary artery bypass grafting (CABG) is an established revascularisation treatment for patients with coronary artery disease (CAD). However, the graft patency rate varies significantly among different bypass graft conduits. Ten years after CABG, more than 90% of the left internal mammary artery (LIMA) grafts are patent[1] but the patency rate of saphenous vein grafts (SVGs) ranges from 40% to 50%.[2] Radial artery (RA) grafts have better long-term patency than SVGs.[3]

The pathogenetic mechanisms responsible for the early development of thrombosis, intimal hyperplasia (IH) and atherosclerosis in grafts remain elusive. Physicians generally believe that haemodynamic forces on blood vessels, especially wall shear stress (WSS), play an important role in initiating the process of atherosclerosis.[4,5] Signalling pathways have been proposed to mediate the mechanochemical transduction in endothelial cells in response to disturbed flow and WSS.[6]

Recent developments in transit time flowmetry (TTFM) not only provide intraoperative mean graft flow (MGF), pulsatility index (PI) and diastolic filling (DF) measurements, but also provide a foundation for estimating WSS from the MGF and graft diameter. We hypothesise that WSS may play a role in graft patency and the purpose of this study was to examine the relationship between graft conduit types and haemodynamic parameters, such as MGF, PI, DF and WSS.

Materials and Methods

The study was approved by the local ethics committee. We recruited 38 patients who had undergone CABG with TTFM of bypass grafts. All surgeries were performed following a standard protocol. Graft and coronary vessel diameters were measured using a surgical metal probe.

TTFM measurements were performed for all the patients with either MEDISTIM VeriQTM or VeriQTM C system, which provided MGF (time-averaged graft flow rate, mL/min), PI (the pulsatility of flow, calculated as PI = maximum flow - minimum flow/mean flow) and DF (the fraction of diastolic volume flow to total flow) as shown in Figure 1.

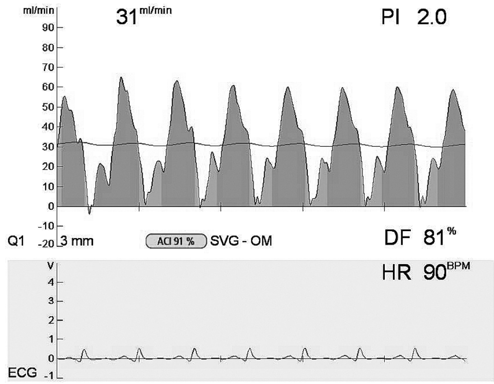

Fig. 1. A representative transit time flowmetry (TTFM) record for a coronary artery bypass grafting (CABG) patient. A typical curve has an M-shape. The blue and the red colours represent the flow during diastolic and systolic phases, respectively.

Using a modified Hagen-Paiseuille equation,[7] WSS was calculated as:

$$WSS = \frac{32\mu Q}{\pi D^3}$$

where μ was the blood viscosity, 0.0035 kg/m•s. Q and D represented the MGF and graft diameter respectively.

All data were grouped according to the bypass type: LIMA, SVG and RA. One-way analysis of variance (ANOVA) was used to compare the continuous data of these 3 groups. Non-linear regression was used to quantity the association between 2 continuous variables. All statistical analyses were performed using SPSS Version 21 software.

Results

A total of 38 patients were studied, with mean age at 60 ± 8 years and median heart rate of 75 ± 13/min. Thirty-one patients (81.6%) had hyperlipidaemia, 29 (76.3%) had hypertension, 13 had diabetes mellitus (34.2%) and 5 (13.2%) had prior myocardial infarction. TTFM measurements were performed on 89 grafts: 35 LIMA, 45 SVG and 9 RA. No significant differences in patient characteristics (age, sex, BMI, coronary risk factors, presurgery left ventricular ejection fraction (LVEF) or medical history) were observed among the 3 groups of patients (with LIMA, SV and RA grafts) separately.

Table 1. Haemodynamic Data

	LIMA	SV	RA	*P* Value
MGF (mL/min)	25 ± 13	39 ± 21	28 ± 18	0.004
PI	2.7 ± 1.1	3.0 ± 1.8	2.0 ± 0.6	0.178
DF (%)	76 ± 8	66 ± 11	70 ± 7	<0.001
Graft diameter (mm)	1.8 ± 0.4	3.7 ± 0.6	2.6 ± 0.5	<0.001
WSS (dyn/cm^2)	30.2 ± 22.9	4.6 ± 2.1	10.1 ± 6.4	<0.001

DF: Diastolic filling; MGF: Mean graft flow; LIMA: Left internal mammary artery; PI: Pulsatility index; RA: Radial artery; SV: Saphenous vein; WSS: Wall shear stress

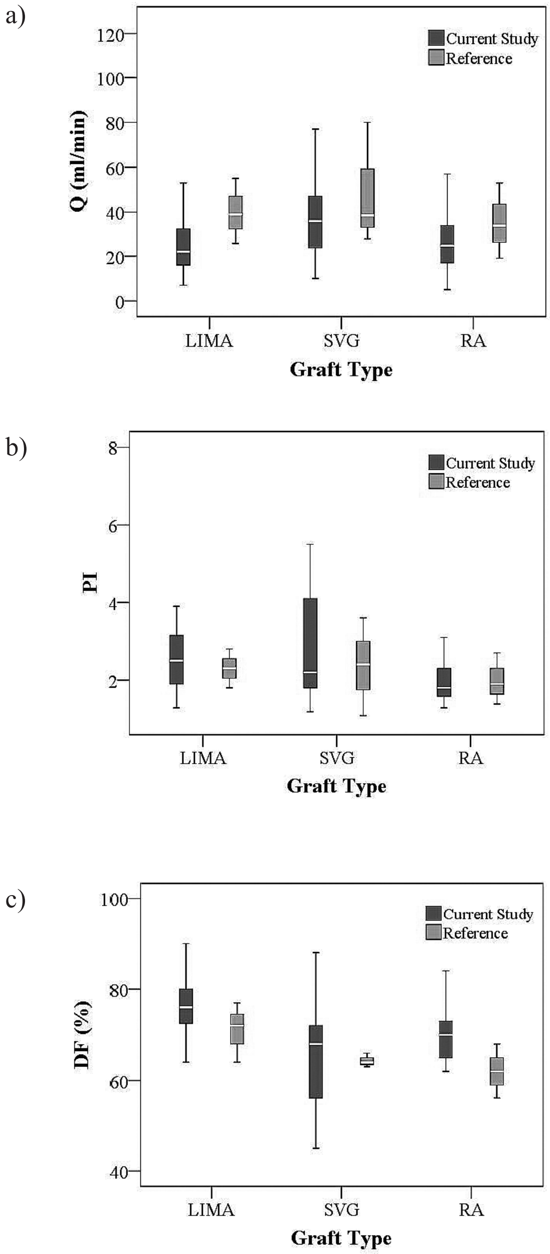

Fig. 2. Comparisons of a) MGF, mean graft flow; b) PI, pulsatility index; and c) DF, diastolic filling between current and reported[8] studies.

In general, median MGF, PI and DF values for all graft types (LIMA: MGF = 25 mL/min, PI = 2.7, DF = 76%; SV: MGF = 39 mL/min, PI = 3.0, DF = 66%; RA: MGF = 28 mL/min, PI = 2.0, DF = 70%) were all satisfactory (Table 1) according to TTFM guidelines[8] of MGF >15 mL/min, PI <5 and DF >25%. Graft types were observed to significantly affect MGF (Q) (P = 0.004) and DF (P <0.001), but no PI (P >0.05).

SVG had slightly higher MGF (39 ± 21 mL/min) than that of LIMA (25 ± 13 mL/min) or RA (28 ± 18 mL/min) grafts. Lower DF was found for SV (66 ± 11%) than that of LIMA (76 ± 8%) or RA (70 ± 7%) grafts. These observations were congruent with data reported by Kieser et al[8] who studied TTFM in 336 consecutive patients (Fig. 2). Because they only reported the data of grafts with PI ≤5 and had only a small sample size of SVG (n = 15), there was smaller variation ranges of their data in contrast to ours.

Graft diameters significantly differed among the 3 graft types (P <0.001) (Table 1). SVG had larger diameter (3.7 ± 0.6 mm) than either LIMA (1.8 ± 0.4 mm) or RA (2.6 ± 0.5 mm). The observed diameters of grafts were close to the values reported by Shimizu et al.[7] Significant differences were found in WSS for the 3 graft types (P <0.001) (Table 1). Lower WSS was found in SVG (4.6 ± 2.1 dyn/cm^2) than either LIMA (30.2 ± 22.9 dyn/cm^2) or RA (10.1 ± 6.4 dyn/cm^2), which was in agreement with an intravascular Doppler-tipped angioplasty study.[9] Similar WSS values of SVG (5 ± 2 dyn/cm^2) was reported by a postoperative coronary angiography study.[7] There was significant non-linear relationship found between WSS and graft diameter for LIMA and SVG (P <0.05). This inverse relationship between WSS and graft diameter could be explained by the Hagen-Paiseuille[7] equation, which states that WSS is inversely proportional to the third power of the internal radius.

Discussion

It has been speculated that WSS may be one of the major factors affecting graft patency. Local low WSS (<4 dyn/cm^2) was observed to lead to increase of platelet activation, vasoconstriction, oxidative state and cellular turnover, which may result in the switching of arterial endothelial phenotypes from atheroprotective to atherogenic.[10] In vitro experiments that subjected human saphenous vein to laminar flow reported that neointima formation was completely inhibited[11] when WSS = 9 dyn/cm^2 and only partly suppressed when WSS = 1 dyn/cm^2. In this study, WSS of SVGs was found to be significantly smaller than either LIMA or RA, and it varied between 2.5 and 6.7 (dyn/cm^2); 42% of SVGs had

WSS <4 dyn/cm^2. Therefore lower WSS of the SVG may be associated with initiation of intimal hyperplasia and/or atherosclerotic signalling and processes that induce graft failure and lead to lower graft patency rate of SVG[12] than LIMA and RA grafts.

As graft diameter was found to have an inverse relationship with WSS, smaller diameter of SVG was believed to lead to higher (and desirable) WSS and may finally result in the improvement of graft patency rate. This observation is consistent with some studies, which demonstrated that large vein calibre was associated with poor patency.[13]

Discordance was observed when researchers attempted to link their TTFM measured data (MGF, PI and DF) with graft patency rates.[8,13] The results of our study lend support to the usefulness of assessing WSS from intraoperative TTFM for better prediction of graft patency. The recent emergence of new TTFM technology not only allows the measurement of intraoperative flow parameters, but also enables the capture of intraoperative epicardial images, which can help in determining graft diameter and calculate WSS of grafts in real time during the surgery.

Strengths of this study include the linking WSS of grafts with the different types of graft conduits. The main limitation of this study is that WSS was estimated from Hagen-Paiseuille equation and it might not be as accurate as values derived from numerical simulations on 3D patient-specific models reconstructed from computed tomography (CT) and/or magnetic resonance imaging (MRI) images.[14] Nevertheless this method has been used in previous studies.[7,15] We believe that the WSS calculated in this study provides a good benchmark for comparison among the 3 types of bypass conduits.

Conclusion

In this study, lower WSS was found for SVGs than for either LIMA or RA grafts. WSS of SVG varied between 2.5 and 6.7 (dyn/cm^2) and 42% of SVGs had WSS <4 dyn/cm^2. Low WSS associated with SVG was conjectured to result in the generation of atherosclerosis and graft stenosis. Appropriate selection of SV segment with suitable calibre is thus necessary to accommodate physiological WSS, which may help improve SVG patency rate.

Acknowledgement

This research is supported by the SingHealth Foundation, Singapore under its Translational Research Grant and administered by SingHealth (SHF/FG503P/2012), the National Heart Centre Singapore under its NHCS Centre Grant Seed Funding (NHCS-CGSF/2014/003), and by Biomedical Research Council Research Grant (14/1/32/24/002). The financial support of NMRC/EDG/1037/2011 by the National Research Foundation, Singapore under its Cooperative Basic Research Grant, and Duke-NUS-GCR/2013/0009 by the Goh Cardiovascular Research Grant are gratefully acknowledged. The authors acknowledge the support of all staff at National Heart Centre Singapore, especially Qin Fang, Janice Heng Lee Phin, Ho Pei Yi and the staff in cardiothoracic surgery division.

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