Influence of graft anastomosis and graft morphology on long-term patency of the saphenous vein after aortocoronary bypass

Okaikor Okantey[1,3], Tomas Jonszta[2,3], Jiri Sieja[1,3], Miriam Kende[1,3], Radim Brat[1,3], Lubomir Pavliska[4]

Objective. Several factors are involved in the preservation of graft function after surgical myocardial revascularization. This follow-up study aimed to evaluate the effects of vein graft anastomosis and graft morphology on long-term graft patency a minimum of 10 years after aortocoronary bypass grafting.
Setting and Cohorts. This was a sub-analysis of a study that enrolled patients after isolated bypass surgery at the University Hospital Ostrava in order to evaluate the long-term graft patency of the saphenous vein after endoscopic harvest, a minimum of 10 years after aortocoronary bypass grafting.
Methods. Fifty angiograms, with a total of 90 grafts, after isolated myocardial revascularization were visualized using coronary computed tomography angiography, with 50% luminal stenosis or greater considered significant.
Results. The overall graft patency rate was 72.3%. The differences in occlusion rates between sequential and individual grafts were not statistically significant (*P*=0.156). All y-grafts were totally occluded. Graft and target artery diameters had a statistically significant influence on patency (*P*=1.000 and 0.381, respectively). Longer graft length and higher calcium scores were associated with statistically significant graft occlusion (*P*=0.033 and 0.005, respectively).
Conclusion. Sequential grafts can be constructed safely, especially when the goal is complete myocardial revascularization.

Key words: sequential graft, graft patency, calcium score, graft morphology, target quality, graft length

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[1]*Department of Cardiac Surgery, University Hospital Ostrava, Ostrava, Czech Republic*
[2]*Department of Radiology, University Hospital Ostrava, Ostrava, Czech Republic*
[3]*Faculty of Medicine, University of Ostrava, Ostrava, Czech Republic*
[4]*Department of Science and Research, University Hospital Ostrava, Ostrava, Czech Republic*
Corresponding author: Okaikor Okantey, e-mail: okaikor.okantey@fno.cz

INTRODUCTION

Saphenous vein grafts are frequently used conduits in surgical myocardial revascularization[1-5]. A large number of factors play a role in the genesis and progression of atherosclerosis in native coronary arteries and conduits. It is not far-fetched to assume that the configuration of any anastomosis and graft morphology has an influence on hemodynamics, flow distribution, and hence appropriate short- or long-term graft function. Traditionally, distal or peripheral anastomosis of a stenosed coronary artery is constructed using a harvested graft via an end-to-side technique below the lesion. Sequential grafting, introduced by Flemma in the early 70's[6-7], refers to one graft distally anastomosed to multiple afflicted coronary arteries, first by an end-to-side construction and subsequent side-to-side anastomoses of the remaining target arteries. One major setback of sequential grafting is compromised blood flow to multiple afflicted coronary arteries when grafts develop blockage or impeded flow more centrally above the distal anastomoses. Some studies report higher flow rates in sequentially constructed grafts in the short term; however, few studies have examined the influence of graft anastomosis and morphology on long-term vein graft patency.

METHOD AND MATERIALS

This is a follow-up to a single-center study conducted in the Department of Cardiac Surgery, University Hospital Ostrava, to evaluate the effect of endoscopic vein harvesting of the greater saphenous vein on long-term (a minimum of 10 years) graft patency. A total of 50 patients were examined after isolated CABG to assess graft patency a minimum of 10 years after isolated surgical myocardial revascularization. Table 1 shows the basic patient characteristics of the initial study.

Technique of vein harvest

The greater saphenous vein grafts were harvested via two techniques; the traditional open approach and the newer, minimally invasive, endoscopic vein harvest. Patients were randomized into both groups of harvest at the time of admission before surgery. EVH was performed using the VirtuoSaph® Plus Endoscopic Harvest System coupled with a Terumo® endoscope (Terumo Cardiovascular Systems Corporation, MI, USA). OVH began with a classic surgical incision from the medial aspect of the ankle and harvested proximally up the shin to the required length of graft based on the number of target coronary arteries. EVH began with a 2–3 cm incision at the medial aspect of the knee (a point marked after vein mapping prior to surgery) and harvested proximally up the thigh; first, with an atraumatic, blunt dissector and subsequently an electrocautery device to sever the vein branches, in conjunction with carbon dioxide insufflation. The vein grafts were cannulated at the distal end. Branches of all harvested vein grafts were either ligated or clipped and the vein grafts were distended at pressures ranging from 50–120 mmHg. The vein grafts were then preserved in a mixture of heparin and Ringer's solution at room temperature before anastomosis to prevent the formation of microthrombi and fibrin deposits.

Construction of anastomoses

The point of every distal anastomosis is an appropriate segment of the target coronary artery distal to the site of significant stenosis. The reverse saphenous vein graft was used in all aortocoronary anastomoses. All the distal anastomoses of sequential, single/individual and "Y" vein grafts were constructed first with an end-to-side anastomosis to the respective target coronary arteries (one end of the vein graft connected to the side of target coronary artery via an arterotomy of an incision length approximately matching the diameter of the vein graft) with uninterrupted 7–0 monofilament polypropylene sutures. Subsequent multiple distal anastomoses of sequential grafts were constructed along the length of the same vein graft via a side-to side anastomosis (via an arterotomy of target coronary artery and an adjacent venotomy of the vein graft, both incisions not exceeding 3 mm) with uninterrupted 7–0 monofilament polypropylene sutures. Y-grafts are usually anastomotic constructs resulting from inadequately harvested vein graft for 2 diseased coronary arteries in close proximity. The "Y" configuration of the y-grafts was achieved via an end-to side anastomosis (the 2nd end of the shorter vein graft already distally anastomosed to the target coronary artery to a venotomy of the longer graft, also already distally anastomosed) using uninterrupted 7–0 or 6–0 monofilament polypropylene sutures. All proximal anastomoses, irrespective of type of distal anastomotic construction (in the case of y-grafts, the second end of the longer vein graft), were constructed via an end-to-side anastomosis (the 2nd end of the vein graft to the side of the aorta via an aortotomy) with uninterrupted 6–0 monofilament polypropylene sutures. The aortotomy was performed using an aortic partial occlusion clamp and a 4 mm single-use aortic punch. All the uninterrupted anastomotic sutures were constructed in a counterclockwise manner.

All vein grafts were harvested by experienced cardiac surgeons with over 7 years' experience with OVH and almost 3 years' experience with EVH. All aortocoronary anastomoses were constructed by experienced cardiac surgeons with over 7 years' experience with performing CABG.

A total of 90 vein grafts were visualized using CCTA as the preferred method for visualizing vein grafts. With the help of the surgical protocol, the precise target coronary arteries that were bypassed with the corresponding type of anastomosis were identified. Vein grafts with less than 50% luminal occlusion were considered patent.

Table 1. Pre- and perioperative patient characteristics and demographics.

Variable	Endoscopic vein harvest (n=25)	Open vein harvest (n=25)	*P*
Age in years (mean ± SD)	72.9 ± 7.33	72.8 ± 6.08	0.95
Gender			
Male, n (%)	19 (76)	21 (84)	0.981
Female, n (%)	6 (24)	4 (16)	0.817
BMI >30kg/m^2, n (%)	9 (36)	5 (20)	0.519
LV EF <55%, n (%)	9 (36)	7 (28)	0.882
COPD, n (%)	5 (20)	8 (32)	0.666
Previous MI, n (%)	10 (40)	9 (36)	1.0
Diabetes mellitus, n (%)	13 (52)	12 (48)	1.0
Hypertension, n (%)	24 (96)	24 (96)	1.0
Dyslipidemia, n (%)	21 (84)	21 (84)	1.0
Tobacco use			
non-smokers, n (%)	11 (44)	9 (36)	0.909
ex-smokers, n (%)	8 (32)	9 (36)	1.0
current smokers, n (%)	6 (24)	7 (28)	1.0
Use of ECC, n (%)	21 (84)	18 (72)	0.883
Urgency of surgery			
planned, n (%)	24 (96)	16 (64)	0.463
urgent, n (%)	1 (4)	5 (20)	0.265
emergent, n (%)	0 (0)	4 (16)	0.158

BMI, body mass index; LV EF, left ventricular ejection fraction; COPD, chronic obstructive pulmonary disease; MI, myocardial infarction; ECC, extracorporeal circulation.

Table 2. Patency rates of vein grafts with respect to anastomosis (sequential, single and "y" graft configuration).

	Sequential vein grafts (n=23)	Single vein grafts (n=65)	y-configured vein grafts (n=2)	*P*
≥50% – total graft thrombosis, n (%)	6 (26.1%)	18 (27.7%)	2 (100%)	0.156
0–49% graft stenosis (patent), n (%)	17 (73.9%)	47 (72.5%)	0 (0.00%)	

Table 3. Patency rates of vein grafts with respect to quality of target coronary arteries.

	Target coronary artery with diameter <1.5 mm (n=16)	Target coronary artery with diameter ≥1.5 mm (n=74)	*P*
≥50% – total graft thrombosis, n (%)	3 (18.8%)	23 (31.1%)	0.381
0–49% graft stenosis (patent), n (%)	13 (81.2%)	51 (68.9%)	

Table 4. Patency rates of vein grafts with respect to diameter of vein grafts.

	Vein graft diameter <3.5 mm (n=64)	Vein graft diameter ≥3.5mm (n=26)	*P*
≥50% – total graft thrombosis, n (%)	18 (28.1%)	8 (30.8%)	1.000
0–49% graft stenosis (patent), n (%)	46 (71.9%)	18 (69.2%)	

Table 5. Patency rates of vein grafts with respect to vein graft length.

	Vein graft with length <150mm (n=52)	Vein graft with length ≥150mm (n=38)	*P*
≥50% – total graft thrombosis, n (%)	10 (19.2%)	16 (42.1%)	0.033
0–49% graft stenosis (patent), n (%)	42 (80.8%)	22 (57.9%)	

Table 6. Patency rates of vein grafts with respect to calcium score of vein grafts.

	Calcium of vein grafts <100 (n=86)	Calcium of vein grafts ≥100 (n=4)	*P*
≥50% – total graft thrombosis, n (%)	21 (24.4%)	4 (100%)	0.005
0–49% graft stenosis (patent), n (%)	65 (75.6%)	0 (0.00%)	

CCTA analysis

All patients were examined using a Siemens Somatom Force double-source CT scanner with a 66 ms temporal resolution with EKG-gated scanning. Image reconstruction was performed using the software Syngovia (Siemens Healthcare GmbH), CT Cardiac dedicated software, and coronary vessel evaluation after semiautomatic vessel course identification. A virtual line along the long axis of the bypass graft center was created which enabled measurement of vessel length, diameter, plaque size, residual lumen diameter, and area. CT calcium scoring dedicated software (semiautomatic) was used for the detection and calculation of calcium deposition within the bypass grafts.

Statistical analysis

Results were processed using standard statistical methods for continuous variables (t-test, ANOVA, and Kruskal-Wallis) for categorical variables using the chi-square test. Continuous variables were expressed as means ± standard deviation, and categorical variables were expressed as percentages. Statistical significance was set at $P<0.05$.

RESULTS

Overall vein graft patency was 72.3%; none of the epsilon grafts were patent (Table 2). Patency of sequential grafts was estimated at 73.9% (17 of 23 grafts), while patency rates of single-vein grafts were 72.5% (47 of

65 grafts), with no statistically significant difference (P=0.156) (Table 2).

Poor run-off of target coronary arteries, characterized by diseased coronary arteries with luminal diameters of less than 1.5 mm, showed patency rates of 81.2% (13 of 16 grafts) compared to quality target arteries with patency rates of 68.9% (51 of 74 grafts) without significant statistical significance P=0.381, see Table 3. Vein grafts of higher luminal diameters (>3.5 mm) showed similar patency rates 71.9% (46 of 64 grafts) as vein grafts with diameters <3.5 mm 69.2% (18 of 26 grafts) without significant statistical difference, see Table 4. Longer graft lengths (exceeding 150 mm) were associated with statistically significantly lower patency rates of 57.9% (22 of 38 grafts) than shorter grafts of less than 150 mm, that is, 80.8% (42 of 52 grafts) P=0.033, see Table 5. All vein grafts with an estimated calcium score of >100 were totally occluded with patency rates of 0% (0 of 4 grafts) compared with grafts with an estimated calcium score of <100 75.6% (65 of 86 grafts), with a statistically significant difference (P=0.005).

DISCUSSION

The goal of surgical myocardial revascularization is to achieve good long term results like all other surgical modalities. Saphenous veins are the most common conduits for aortocoronary bypass[1-5]. Several factors influence graft patency in the short- or long-term[8]. However, some of these factors have not been extensively investigated. Arterialization of a vein graft causes adaptation, for example, neointimal hyperplasia, in which an abnormal excessive progression likely leads to abnormal vessel wall remodeling and subsequent vein graft failure and clinical complications, thus making it more susceptible to atherosclerosis and thrombosis than arterial grafts[8-9]. This is theorized because, unlike arteries, the wall structure and properties of veins do not possess optimal long-term adaptive mechanisms to withstand high intravascular pressures. The available literature on how graft morphology and surgical techniques, such as the impact of type of anastomosis, influence long-term graft patency, is scarce. In addition to analyzing the influence of vein graft anastomosis on long-term graft patency, we also assessed the calcium score of the grafts themselves, diameter of the vein grafts, and graft length in relation to graft patency. Typically, significant coronary artery stenosis is resolved by constructing distal anastomoses below the lesions using single or individual grafts via an end-to-side anastomosis and subsequent aortocoronary end-to side-anastomosis. Sequential grafts introduced by Flemma in the early 70's[6-7] are constructed by a side-to-side anastomosis using a single graft (vein or arterial graft) to more than one diseased coronary artery[10-11]. This implies that such lengthy grafts are not required to revascularize multiple target coronary arteries, thus possibly shortening harvest time and reducing the construction of multiple proximal anastomoses. This also facilitates the complete revascularization of all diseased coronary arteries with limited graft lengths. In terms of flow distribution and patency, it is believed that sequential grafts outdo individual or single grafts by 10–15% (ref.[12]), although the flow direction through the grafts depends on the differences in pressure present in the grafts and target vessels. From what has been established about hemodynamic risk factors causing thrombosis and atherosclerosis, increased intravascular pressure, in this case arterial hypertension[5], plays a role in graft failure directly related to flow distribution to the target vessels by decreasing total resistance to the graft flow and reducing impedance mismatch[6]. Similarly, relative stagnation of blood in the grafts caused by competitive flow between native coronary arteries and grafts, facilitates the progression of thrombosis of vein grafts[4,13].

One study reported that sequential vein grafts (side-to-side anastomoses) observed over a 13 year period, showed higher patency rates over single grafts (even end-to-side anastomoses of sequential grafts) at all of the timepoints of examination but with little statistical significance[14].

Another study assessed the outcome of sequential and single-vein grafts in patients with proximal critical circumflex lesions[6] with revascularization of the obtuse marginal branches by evaluating transit-time flowmetry and graft flow reserve. This study showed that sequential grafts showed better maximum and mean flow rates intraoperatively with a higher graft flow reserve than single grafts, which was expected to allow for lower treatment failure with respect to mid-term results[6].

Park et al. proved significantly higher patency rates of sequential vein grafts with two distal anastomoses than individual grafts with overall graft failure rates using angiography at 10 years estimated at 20.9% (ref.[15]). With respect to overall mortality, composite outcome of death, nonfatal myocardial infarction, and repeat revascularization, no statistical difference was found between sequential and individual vein grafts[15].

Vural et al. also concluded in a study comparing sequential and individual vein grafts at 5.8±3 years that sequential grafts significantly manifested higher patency, especially in target arteries of higher quality (diameter >1.5 mm) (ref.[7]). Grafts of minimal length were advantageous with respect to graft patency[7], which our study also showed. Longer grafts may be subject to kinking or bending, which could cause hemostasis, hypercoagulation, and subsequent graft occlusion.

Similarly, angiographic evidence of optimal blood flow and long-term patency rates in a study conducted by Ouzounian[10] at a mean follow-up of 78 months to evaluate clinical outcomes after sequential grafting concluded that sequential vein grafts did not present an independent predictor with respect to in-hospital adverse events or long-term mortality and/or readmission to hospital.

Although, sequential vein grafts have proven to exhibit optimal blood flow, the myocardial territories supplied by corresponding target arteries are at high risk of life-threatening acute or chronic ischemia or sudden death should a stenotic lesion develop more proximally to the anastomosis[2,6-7,11-10,14,16-17].

In contrast to the positive outcomes of sequential grafts, follow-up studies of the PREVENT IV trial[2] reported significantly poorer angiographic outcomes after 1 year, as well as significantly poorer clinical outcomes regarding composite deaths, redo CABG, and myocardial infarctions at 5 years. It is important to note that the PREVENT IV trial reported one of the worst overall vein graft patency rates at any given follow-up time point[2]; therefore, caution needs to be taken with respect to the outright dismissal of the efficiency of sequential grafts due to results based on a relatively large sample size. From these findings, it can be assumed that other technical surgical factors are at play when it comes to ensuring optimal longevity of any graft. Even poorly constructed grafts, in terms of angulation of anastomosis, whether sequential or individual, potentially influence flow dynamics and subsequently long-term patency.

Considering that graft patency, whether arterial or venous, depends on the accumulation of multifactorial entities[8], there is no doubt that graft choice to ensure reasonable longevity, ranging from individual intrinsic and extrinsic patient characteristics, quality of target arteries, choice and technique of graft harvest, type of construction of anastomosis, etc., need not be taken lightly. As it is impossible to tick all the right boxes regarding factors influencing graft patency, it is crucial to optimize post-surgical treatment to decelerate the atherosclerotic process.

CONCLUSION

Several factors, especially those related to hemodynamics, can be attributed to their important roles in the maintenance of graft integrity. Sequential vein grafts have been proven to yield good outcomes in terms of reducing intravascular resistance, thereby favoring long-term graft patency. Graft patency is also favorable, with minimal optimal graft length. Regardless of these findings, more studies need to be conducted to extensively analyze the cumulative factors affecting graft patency to influence the choice of grafts for revascularization and subsequently optimize treatment regimes postoperatively.

Study limitations

This was a single-center study; therefore, the sample size was small and not optimal. Follow-up of patients after 10 years of surgery was very tedious as most of the patients were lost to follow up. A number of patients refused follow up very likely due to old age.

ABBREVIATIONS

CABG, coronary artery bypass grafting; SVG, saphenous vein graft; CCTA, coronary computed tomography angiography; EVH, endoscopic vein harvest; OVH, open vein harvest.

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Conflict of interest statement: None declared.

Ethical Approval Statement: The initial study was approved by the Ethics Committee of the University Hospital of Ostrava on April 30, 2020; ethical approval number: 402/2020, project protocol number: 01/RVO-FNOs/2020. This follow-up analysis involved data extraction from the parameters already measured from the initial study. Patient confidentiality and appropriate ethical protocols we not breached.

Data availability: The processed data underlying this article are included in three tables. The raw unprocessed data are only accessible within the servers of the University Hospital Ostrava at vav.fno.cz via assigned login details. However, Excel files of raw unprocessed data can be made available on request.

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