The Heart Surgery Forum #2011-1087
15 (3), 2012 [Epub June 2012]
doi: 10.1532/HSF98.20111087

Online address: http://cardenjennings.metapress.com

Ten-Year Outcome Analysis of Off-Pump Sequential Grafting: Single Surgeon, Single Center Experience

Shahzad G. Raja,[1] Kareem Salhiyyah,[1] Manoraj Navaratnarajah,[1] Muhammad Umar Rafiq,[1] Jeremy Felderhof,[1] Christopher P. Walker,[2] Charles D. Ilsley,[3] Mohamed Amrani[1]

Departments of [1]Cardiac Surgery, [2]Anaesthesia & Intensive Care, and [3]Cardiology, Harefield Hospital, London, United Kingdom

ABSTRACT

Objectives: Despite increasing recognition that off-pump coronary artery bypass surgery and sequential grafting strategy individually are associated with improved outcomes, concerns persist regarding the safety and efficacy of combining these 2 techniques. We compared in-hospital and midterm outcomes for off-pump multivessel sequential and conventional coronary artery bypass grafting.

Methods: From September 1998 to September 2008, 689 consecutive patients received off-pump multivessel sequential coronary artery bypass grafting performed by a single surgeon. These patients were propensity matched to 689 patients who underwent off-pump coronary artery bypass grafting without sequential anastomoses. A retrospective analysis of prospectively collected perioperative data was performed. In addition, medical notes and charts of all the study patients were reviewed. The mean duration of follow-up was 5.1 ± 2.0 years.

Results: The major in-hospital clinical outcomes in the sequential and control groups were found to be similar. After adjusting for clinical covariates, sequential grafting was not an independent predictor of in-hospital adverse events (odds ratio [OR], 1.18; 95% confidence interval [CI], 0.86-1.50; P = .31), medium-term mortality (hazard ratio [HR], 1.26; 95% CI, 1.06-1.32; P = .92), and readmission to hospital (HR, 1.12; 95% CI, 0.96-1.20; P = .80). Sequential grafting was an independent predictor of receiving more than 3 distal anastomoses (OR, 7.46; 95% CI, 4.27-11.45; P < .0001). Risk-adjusted survival was 89% for sequential grafting patients and 88% for conventional grafting patients (P = .96) during the medium-term follow-up.

Conclusion: Our analysis confirms the short- and mid-term safety and efficacy of off-pump sequential coronary artery bypass grafting.

Presented at the 21st Congress of the World Society of Cardio-Thoracic Surgeons, 12–15 June 2011, Berlin, Germany

Received June 18, 2011; accepted August, 31, 2011.

Correspondence: Shahzad G. Raja BSc, MBBS, MRCS, FRCSEd(C-Th), Department of Cardiac Surgery, Harefield Hospital, Hill End Road, Harefield, UB9 6JH, London, United Kingdom; +441895828550; fax: +441895828992 (e-mail: drrajashahzad@hotmail.com)..

INTRODUCTION

Coronary artery bypass grafting (CABG) has been performed predominantly with the use of cardiopulmonary bypass (CPB) and cardioplegic arrest, which allows optimization of the surgical field and consistent placement of grafts. However, the use of CPB is also associated with numerous complications [Raja 2005]. A surgical technique avoiding CPB should, in theory, reduce the incidence of such complications and lead to improved patient outcomes. This assumption has rekindled interest in performing off-pump coronary artery bypass (OPCAB) surgery, which since its resurgence 2 decades ago has remained the focus of scientific scrutiny [Raja 2005]. Currently available evidence from a large number of randomized clinical trials, nonrandomized clinical trials, propensity-matched analyses, and experimental data suggests that outcomes are either comparable or superior after OPCAB than after CABG on CPB [Mack 2004; Al-Ruzzeh 2006; Al-Ruzzeh 2008; Raja 2010].

Similarly, the sequential grafting technique is reported to offer the hemodynamic advantage of increased total graft flow through improved distal runoff and, by extension, increased graft patency rates [Meurala 1982]. Additional benefits include greater conservation of conduit, reduced aortic manipulation, and last but not least more complete revascularization by allowing anastomoses to smaller coronary arteries, which theoretically should translate into improved clinical outcomes [Lattouf 2008].

Interestingly, combination of OPCAB with sequential grafting to provide the maximum benefit is still regarded as a high-risk strategy because of concerns regarding the quality and completeness of revascularization during OPCAB [Grondin 1977] and the dependence of multiple grafts on a common inflow in sequential grafting with the possibility of catastrophic consequences in the event of a proximal occlusion. This perceived threat of the large myocardium at risk coupled with the disadvantages of increased conduit manipulation, suboptimal conduit lie, and the complexity of certain side-to-side anastomoses are predominant concerns preventing universal adoption of sequential grafting [Kieser 1986].

Existing evidence to validate the clinical safety and efficacy of sequential OPCAB grafting is scarce. The majority of studies report blood flow characteristics [Gwozdziewicz 2006] and angiographic patency [Gao 2010; Nakajima 2010] or are case series with no comparative cohorts [Quigley 2010]. The objective of the present study was to evaluate the clinical

safety and efficacy of sequential venous OPCAB grafting by comparing in-hospital and midterm outcomes with a control group of patients in whom left internal thoracic artery (ITA) and individual saphenous vein grafts (SVGs) were used.

MATERIALS AND METHODS

Study Sample

This study comprised a retrospective analysis of a prospectively collected cardiac surgery database (PATS; Dendrite Clinical Systems, Ltd, Oxford, UK) as well as a follow-up questionnaire approved by the institutional ethics committee; informed consent was waived for this study. The PATS database captures detailed information on a wide range of preoperative, intraoperative, and hospital postoperative variables (including complications and mortality) for all patients undergoing cardiac surgery in our institution. The database was collected and reported in accordance with the Society for Cardiothoracic Surgery in Great Britain & Ireland database criteria. In addition, the medical notes and charts of all the study patients were reviewed. For information on medium-term outcomes, a questionnaire was mailed to all surviving patients or to the general practitioners of those patients who had died during the follow-up period. From September 1998 to September 2008, 689 patients underwent sequential venous OPCAB grafting performed by the same surgeon (M.A.). During the same period, 1124 patients underwent OPCAB utilizing the left ITA in combination with individual SVGs. Patients in whom the number of distal anastomoses performed with a SVG exceeded the number of proximal anastomoses were determined to have received sequential grafts, whereas patients in whom the number of distal anastomoses performed with a SVG equaled the number of proximal anastomoses were determined to have received single grafts. Grafting strategy was influenced by surgeon's preference. Factors influencing surgeon's preference for sequential or non-sequential grafting may have included length of available conduit; desire to limit manipulation of the proximal aorta; and preconceptions regarding the safety and efficacy of sequential grafting.

Patient characteristics of both groups are shown in Table 1. Indications for CABG were determined at a weekly review involving cardiologists, cardiac surgeons, and cardiac radiologists. Patients were placed on a specific waiting list according to the urgency of their procedure. All patients with triple-vessel disease (defined as significant [>50%] stenosis in each of the 3 territories [left anterior descending, circumflex, and right coronary]) who underwent first-time, off-pump, isolated CABG were included in this study. Cases done on-pump or with total arterial grafting were excluded to minimize surgical variability.

Operative Technique

We have previously described our operative technique in detail [Al-Ruzzeh 2002]. All interventions were performed via a midline sternotomy, using a suction stabilizer. Left and right ITA were harvested with minimal trauma as pedicled grafts and treated with papaverine solution prior to use. Great saphenous vein was harvested using open technique or vein stripper.

Postoperative Management

All patients received intravenous nitroglycerin (0.1-8 μg/kg per minute) infusions for the first 24 hours unless hypotensive (systolic blood pressure < 90 mmHg). Choice of inotropic agents was dictated by the hemodynamic data. Other routine medications included daily aspirin and resumption of cholesterol-lowering agents and β-blockers.

Variables and Data Collection

Preoperative variables of interest included age, sex, smoking history, chronic obstructive pulmonary disease, diabetes, hypercholesterolemia, renal insufficiency (preoperative serum creatinine ≥ 200 μmol/L), hypertension, peripheral vascular disease, cerebrovascular disease, left ventricular ejection fraction, urgency (operation performed < 24 hours versus > 24 hours from time of referral), prior percutaneous coronary interventions, and the number of diseased vessels. Intraoperative variables of interest included the number of distal anastomoses. Postoperative variables of interest included in-hospital mortality, intraoperative or postoperative intraaortic

Table 1. Patient Characteristics of Sequential Grafting Group versus Conventional Group in 1813 Unmatched Cases

Preoperative Demographics	Sequential Group, n = 689 (%)	Conventional Group, n = 1124 (%)	*P*
< 60 years	154 (22.4)	196 (17.4)	.09
60–74 years	271 (39.3)	486 (43.2)	.78
> 75 years	264 (38.3)	442 (39.3)	.90
Female	145 (21.0)	419 (37.3)	.0001
Diabetes	369 (53.6)	468 (41.7)	.001
Hypertension	258 (37.4)	598 (53.2)	.003
Hypercholesterolemia	409 (59.4)	547 (48.7)	.002
Peripheral vascular disease	89 (12.9)	114 (10.1)	.01
Previous stroke/transient ischemic attack	49 (7.1)	86 (7.7)	.92
Chronic obstructive pulmonary disease	87 (12.6)	145 (12.9)	.96
Serum creatinine ≥ 200 μmol/L^{-1}	46 (6.7)	51 (4.5)	.04
Left ventricle ejection fraction (LVEF) > 49%	421 (61.1)	706 (62.8)	.90
LVEF 30%–49%	195 (28.3)	312 (27.8)	.88
LVEF < 30%	73 (10.6)	106 (9.4)	.84
Elective	497 (72.1)	875 (77.8)	.87
Urgent	178 (25.8)	231 (20.6)	.64
Emergency	14 (2.1)	18 (1.6)	.62
3 grafts	295 (42.8)	897 (79.8)	.0001
4 grafts	324 (47.0)	198 (17.6)	.0001
> 4 grafts	70 (10.2)	29 (2.6)	.0001
Duke Jeopardy Score (interquartile range)	10 (8–10)	10 (7–12)	.94

balloon pump (IABP), postoperative myocardial infarction (MI), stroke or transient ischemic attack (TIA), prolonged ventilation > 24 hours, atrial fibrillation, deep sternal infection, blood products, inotropes leaving operating room (OR), chest infection, return to OR for graft occlusion, return to OR for bleeding, number of grafts/patient (mean ± standard deviation [SD]), conversion to CPB, and length of hospital stay. The medium-term outcomes of interest were all-cause mortality following discharge from hospital and readmission for any cardiac cause defined by the following codes from the 9th revision of the International Classification of Disease, Clinical Modification [Centers for Disease Control and Prevention 2009]: 410 (acute MI), 411 (unstable angina), 412 (old MI), 413 (angina pectoris), 414 (other forms of chronic ischemic heart disease), 426 (conduction disorders), 427 (cardiac dysrhythmias), 428 (heart failure), 429 (ill-defined descriptions and complications of heart disease), and coronary reintervention (percutaneous or CABG).

Statistical Analysis

Patients who underwent OPCAB with a sequential grafting strategy were compared to those who did not using t-tests and Kruskal–Wallis tests for continuous variables and $\chi 2$ tests for categorical variables. A propensity analysis was performed modeling the probability of receiving sequential grafting. A nonparsimonious multivariate logistic regression model using clinically relevant variables was generated to compute a propensity score for each patient (Appendix). All clinically relevant variables were included in the model. The propensity score (or probability of receiving sequential grafting) was then used to obtain a one-to-one match of all sequential grafting cases with non-sequential controls by a "greedy matching" technique [Parsons 2001]. In-hospital outcomes were compared between these matched groups.

Logistic regression was used to examine the association of sequential grafting with in-hospital adverse events after adjusting for differences between patients on the basis of each of the above-mentioned preoperative variables. The association between sequential grafting and the midterm outcomes of interest was analyzed using adjusted survival curves and Cox proportional hazards modeling techniques. All baseline characteristics were included in the fully adjusted multivariate Cox models. Differences in the severity of coronary disease were examined by comparing the Duke Jeopardy Score [Califf 1985] between the sequential and non-sequential groups. In the Duke Jeopardy Score, the coronary tree is divided into 6 segments, and all segments distal to ≥70% stenosis are considered to be at risk. The association between sequential grafting and the number of distals received at the time of CABG was examined using a logistic regression model that considered the coronary disease burden as measured by the Duke Jeopardy Score.

Statistical significance was indicated by a 2-tailed *P* value < .05. All analyses were performed with the Statistical Analysis Systems software package (Release 9.1.3; SAS Institute, Cary, NC, USA). The authors had full access to the data and take responsibility for its integrity. All authors have read and agree to the manuscript as written.

RESULTS

A total of 1813 patients formed the final study population. Compared to patients who had non-sequential grafting, those receiving sequential grafting were more likely to be male and more likely to have diabetes, hypercholesterolemia, renal insufficiency, and peripheral vascular disease (Table 1). Sequential grafting patients also received more bilateral ITAs than control group (30.6% versus 6.6%; *P* <.0001). Overall, there were more distal anastomoses performed in the sequential group compared to the control group (4.1 ± 0.9 grafts versus 3.2 ± 0.2 grafts; *P* < .0001). Unadjusted hospital mortality was 1.2% for the sequential group and 1.7% for control group (*P* = .78). The overall mortality for the entire cohort was 1.5%.

The propensity score model included 18 patient variables that are listed along with their confidence intervals in the Appendix. The c statistic for this model was 0.81 (Hosmer–Lemeshow goodness-of-fit *P* = .3057). All 689 sequential grafting cases could be matched to 689 control patients. The 2 groups were well matched for all the patient variables (Table 2).

The in-hospital mortality for the propensity-matched sequential group was similar to the control group (1.2% versus 1.5%; *P* = .84). The length of hospitalization was a median of 6 days in both groups with an interquartile range (IQR) of 5 to

Table 2. Patient Characteristics of Sequential Grafting Group versus Conventional Group in 1378 Matched Cases

Preoperative Demographics	Sequential Group, n = 689 (%)	Conventional Group, n = 689 (%)	*P*
< 60 years	154 (22.4)	134 (19.4)	.52
60–74 years	271 (39.3)	289 (41.9)	.84
> 75 years	264 (38.3)	294 (42.7)	.71
Female	145 (21.0)	171 (24.8)	.69
Diabetes	369 (53.6)	378 (54.9)	.91
Hypertension	258 (37.4)	278 (40.3)	.56
Hypercholesterolemia	409 (59.4)	418 (60.7)	.94
Perpheral vascular disease	89 (12.9)	88 (12.8)	.98
Previous stroke/transient ischemic attack	49 (7.1)	47 (6.8)	.94
Chronic obstructive pulmonary disease	87 (12.6)	92 (13.4)	.89
Serum creatinine ≥ 200 μmol/L^{-1}	46 (6.7)	39 (5.7)	.78
Left ventricle ejection fraction (LVEF) > 49%	421 (61.1)	438 (63.6)	.91
LVEF 30%–49%	195 (28.3)	201 (29.2)	.89
LVEF < 30%	73 (10.6)	79 (11.5)	.88
Elective	497 (72.1)	509 (73.9)	.86
Urgent	178 (25.8)	169 (24.5)	.83
Emergency	14 (2.1)	11 (1.6)	.62
Duke Jeopardy Score (interquartile range)	10 (8–10)	10 (8–10)	1.00

8 days (P = .98). Major morbidity was not statistically different between sequential and matched groups (Table 3); however, significantly more patients in the sequential group required hemofiltration (5.7% versus 3.0%; P < .001), received blood products (P < .0001), and were re-explored for bleeding (P < .0001) compared with matched control patients. After adjusting for clinical covariates, sequential grafting was not an independent predictor of in-hospital adverse events (odds ratio [OR], 1.18; 95% confidence interval [CI], 0.86-1.50; P = .31).

Table 3. Perioperative Outcomes for 1378 Propensity-Matched Cases

Perioperative Outcome	Sequential Group, n = 689 (%)	Conventional Group, n = 689 (%)	P
In-hospital mortality	8 (1.2)	10 (1.5)	.92
Perioperative myocardial infarction	10 (1.5)	12 (1.7)	.94
Stroke/transient ischemic attack	4 (0.6)	4 (0.6)	1.00
Ventilation > 24 hours	7 (1.0)	9 (1.3)	.89
Atrial fibrillation	46 (6.7)	49 (7.1)	.88
Chest infection	36 (5.2)	40 (5.8)	.86
Deep sternal infection	7 (1.0)	5 (0.7)	.89
Blood products	98 (14.2)	58 (8.4)	<.0001
Return to operating room for bleeding	32 (4.6)	10 (1.5)	<.0001
Inotropes	96 (13.9)	104 (15.1)	.78
Hemofiltration	39 (5.7)	21 (3.0)	<.001
Postoperative intraaortic balloon pump	9 (1.3)	11 (1.6)	.89
Conversion to cardiopulmonary bypass	3 (0.4)	4 (0.6)	.90
Number of grafts/patient, mean ± standard deviation	4.1 ± 0.9	3.1 ± 0.7	<.0001
Hospital stay, days (interquartile range)	6 (5–8)	6 (5–8)	.98

The mean duration of follow-up was 5.1 ± 2.0 years with 100% complete follow-up. Over the entire follow-up period, 16 (2.3%) patients died in the sequential group and 28 (2.5%) in the control group (P = .92). After adjusting for clinical covariates, sequential grafting did not emerge as a significant independent predictor of medium-term mortality: the hazard ratio (HR) was 1.26 (95% CI, 1.06-1.32; P = .92). Risk-adjusted survival was 89% after sequential grafting and 88% after non-sequential grafting (P = .89) during the medium-term follow-up (Figure 1). After discharge, 6.8% of sequential grafting patients and 7.2% of non-sequential grafting patients were readmitted to the hospital for cardiac reasons (P = .84). These included 13 (1.9%) sequential grafting and 24 (2.1%) non-sequential grafting patients who were readmitted for repeat revascularization (percutaneous or CABG; P = .87); repeat CABG was performed in 4 (0.6%) sequential grafting patients and 8 (0.7%) non-sequential grafting patients (P = .96). After adjusting for clinical covariates, sequential grafting did not emerge as a significant independent predictor of readmission to hospital (HR, 1.12; 95% CI, 0.96-1.20; P = .80). Risk-adjusted freedom from readmission for any cardiac reason is illustrated in Figure 2.

The extent of coronary disease, as measured by the Duke Jeopardy Score, was similar between the sequential and non-sequential groups (10 [IQR 8-12] versus 10 [IQR 7-12]; P = .94). After adjusting for baseline clinical variables and the Duke Jeopardy Score, sequential grafting was an independent predictor of receiving more than 3 distal anastomoses (OR, 7.46; 95% CI, 4.27-11.45; P < .0001).

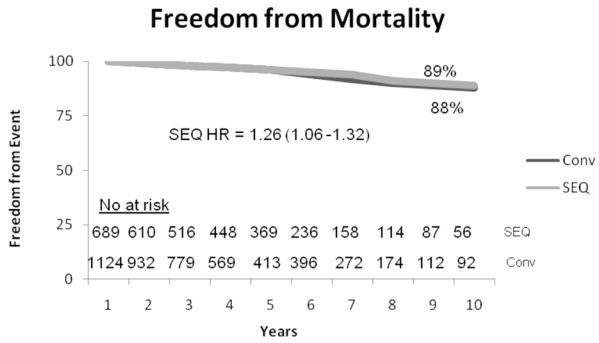

Figure 1. Comparison of risk-adjusted freedom from mortality between the sequential (SEQ) and conventional (Conv) grafting groups.

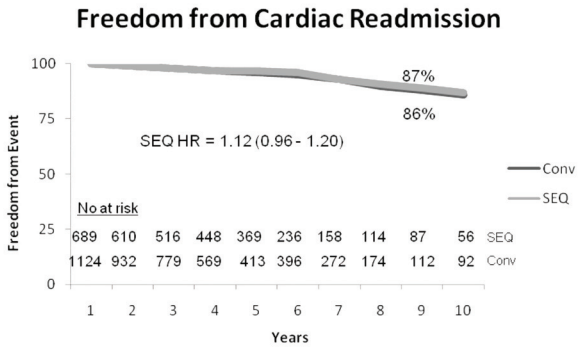

Figure 2. Comparison of risk-adjusted freedom from readmission to hospital for cardiac reason between the sequential (SEQ) and conventional (Conv) grafting groups.

DISCUSSION

The results of our study demonstrated that sequential OPCAB grafting is associated with similar in-hospital and midterm outcomes compared with non-sequential OPCAB grafting. A large volume of data has been accumulated to document the advantages of sequential grafting for myocardial revascularization. These advantages include conservation of conduit and reduction in the number of aortic anastomoses with reduced manipulation of the aorta [Grondin 1977; Kieser 1986]. In addition, by having more than 1 target, sequential

grafts may have better vascular runoff and thus improved flow and patency [Gwozdziewicz 2006; Gao 2010; Nakajima 2010]. Similarly, there is abundant evidence to validate the safety and efficacy of OPCAB [Mack 2004; Al-Ruzzeh 2006; Al-Ruzzeh 2008; Raja 2010]. Logically, a combination of these 2 strategies would offer their combined benefits. A recently published case series attests to the safety of this approach [Quigley 2010], but to date a comparative study reporting clinical outcomes has not been carried out. This study is unique because it the largest reported clinical experience to date of sequential OPCAB grafting and confirms that sequential grafting was not independently associated with either in-hospital or midterm adverse events following OPCAB surgery.

We have attempted to make meaningful comparisons between the sequential grafting group and a contemporaneous group of non-sequential grafting control patients. To do this we have used 2 statistical approaches based on propensity modeling, a technique that has been strongly advocated in several recent publications [Austin 2007], in an effort to better evaluate treatment comparisons from nonrandomized clinical experiences. The propensity score is the probability of a patient receiving a given intervention (in this case sequential grafting) based on a nonparsimonious model derived from preoperative patient variables. The propensity model thus reduces many variables to a single balancing score, facilitating meaningful intergroup comparisons. We used 2 approaches, namely the creation of matched pairs based on propensity score and logistic regression analysis of outcomes in which propensity score participated as a variable.

Using the propensity matching technique, the sequential and control groups were remarkably well matched in terms of known risk predictors of outcomes after CABG surgery. The overall mortality and major morbidity between groups were not statistically different; however, the incidence of re-exploration for bleeding and increased transfusion of blood products in the sequential group was significantly higher than the control group. The 4.6% incidence of re-exploration for bleeding in this study compares quite well with incidences of 2% to 6% mentioned in the literature [Karthik 2004]. Continuation of aspirin until the day of surgery, greater use of bilateral ITAs, and increased number of distal anastomoses with an increased number of potential bleeding sites are some of the reasons for these phenomena [Karthik 2004]. In addition, significantly more patients in the sequential grafting group were hemofiltered. This may simply be a reflection of the fact that more patients with preoperative serum creatinine ≥200 μmol/L were in the sequential group.

Perhaps one of the more significant advantages of sequential grafting validated by this study is the achievement of more complete revascularization. There is plenty of evidence to suggest that survival benefit was reduced if revascularization was incomplete (ie, when ≥1 of the major diseased vessels had not been bypassed) [Bell 1992; Lattouf 2008]. This issue is particularly important in the current era of OPCAB surgery in which the possibility of incomplete revascularization and early failure resulting from technical difficulties in constructing bypass grafts to the lateral and inferior wall must be considered. In this study, despite all patients having triple-vessel disease, patients undergoing OPCAB surgery with sequential grafting received a greater number of distal anastomoses compared with those receiving single grafts (4.1 ± 0.9 versus 3.2 ± 0.2; $P < .0001$). When the extent of coronary disease was considered for the entire cohort, sequential grafting was the only independent predictor of receiving more than 3 distal anastomoses at the time of surgical revascularization. Interestingly, failure of this additional graft to translate into clinical benefit despite more extensive revascularization may be due to a plateau effect seen with more than 3 bypass grafts [Bell 1992].

Another important finding of this study was the increased use of bilateral ITAs in patients receiving sequential grafts. There is evidence to support the concept that the greater the number of arterial conduits used, the better the long-term results [Raja 2009]. Two meta-analyses have proven the advantages of bilateral ITA grafting compared with single ITA grafting [Taggart 2001; Rizzoli 2002]. However, at present in this study it is not possible to demonstrate a survival benefit of increased bilateral ITA usage in patients with sequential grafting due to the relatively short follow-up for this cohort.

One of the major concerns regarding sequential grafting is the size of the myocardial region at risk in the event of a proximal occlusion. It has been suggested that a larger region is at risk than with the occlusion of a single graft, potentially leading to catastrophic consequences such as infarction or death. We, however, only witnessed recurrence of angina in the 13 patients who occluded their sequential grafts. This observation is similar to that of Christenson and Schmuziger [Christenson 1996].

The primary limitation of the study is its retrospective nature. Propensity score adjustment is no substitute for a properly designed, randomized, controlled trial. The retrospective nature of the study cannot account for the unknown variables affecting the outcome that are not correlated strongly with measured variables. However, retrospective comparisons with propensity score adjustment are more versatile and offer a useful way of interpreting large amounts of audit data and of seeking answers to questions that may present insuperable difficulties in the design of randomized, controlled trials. Despite the retrospective and observational nature of the study, we provided data on a large cohort of exclusively sequential grafting patients undergoing OPCAB for comparison with non-sequential OPCAB control group, which has not been reported before, and demonstrated the safety of OPCAB sequential grafting and its potential for providing complete revascularization as well as increased usage of bilateral ITAs, both of which translate into better long-term outcomes. Lastly, our analysis would have been enhanced substantially if midterm graft patency comparisons were available. However, due to costs, routine follow-up coronary angiography was not performed. The need for coronary angiography was dictated by the occurrence of angina, instability, or electrocardiogram changes in the perioperative or late follow-up period. It is, however, worth mentioning that initially when sequential grafting was combined with OPCAB in our institution, early postoperative angiography to check the quality of the grafts and anastomoses was undertaken [Al-Ruzzeh 2002].

CONCLUSION

In conclusion, our analysis confirms the short- and midterm safety and efficacy of sequential OPCAB grafting. Sequential grafting technique for venous conduits is a useful strategy that can be employed in combination with OPCAB to achieve complete revascularization with the potential to enhance usage of arterial conduits in patients with multivessel coronary artery disease affecting all 3 coronary artery territories.

ACKNOWLEDGMENTS

We would like to thank Ms. Emily Dwyer, senior clinical outcomes analyst, and Ms. Siobhan Daley, clinical outcomes officer, for assistance with data collection.

APPENDIX

Logistic Regression Model to Generate Propensity Scores for Sequential Grafting Group (n = 689) versus Control Group (n = 1124)

		95% Wald Confidence Limits		
Effect	Point Estimate	Lower	Upper	*P*
< 60 years	0.791	0.689	1.123	.23
60–74 years	0.774	0.675	1.035	.19
> 75 years	0.789	0.596	1.119	.21
Gender	0.745	0.598	1.054	.20
Diabetes	0.786	0.611	1.087	.17
Hypertension	1.114	0.976	1.657	.49
Hypercholesterolemia	1.546	1.231	2.105	.56
Perpheral vascular disease	0.799	0.658	1.114	.23
Previous stroke/transient ischemic attack	1.113	0.832	1.978	.64
Chronic obstructive pulmonary disease	0.986	0.732	1.347	.41
Creatinine ≥ 200 $\mu mol/L^{-1}$	0.943	0.755	1.121	.24
Left ventricle ejection fraction (LVEF) > 49%	1.746	1.431	2.321	.59
LVEF 30%–49%	0.884	0.601	1.287	.22
LVEF < 30%	1.446	1.331	1.921	.43
Elective	0.724	0.665	1.033	.21
Urgent	0.674	0.475	1.011	.22
Emergency	1.614	1.896	2.157	.47
Duke Jeopardy Score (interquartile range)	0.946	0.731	1.129	.28

REFERENCES

Al-Ruzzeh S, Epstein D, George S, et al. 2008. Economic evaluation of coronary artery bypass grafting surgery with and without cardiopulmonary bypass: cost-effectiveness and quality-adjusted life years in a randomized controlled trial. Artif Organs 32:891-7.

Al-Ruzzeh S, George S, Bustami M, et al. 2006. Effect of off-pump coronary artery bypass surgery on clinical, angiographic, neurocognitive, and quality of life outcomes: randomised controlled trial. BMJ 332:1365.

Al-Ruzzeh S, George S, Bustami M, et al. 2002. The early clinical and angiographic outcome of sequential coronary artery bypass grafting with the off-pump technique. J Thorac Cardiovasc Surg 123:525-30.

Austin PC. 2007. Propensity-score matching in the cardiovascular surgery literature from 2004 to 2006: a systematic review and suggestions for improvement. J Thorac Cardiovasc Surg 134:1128-35.

Bell MR, Gersh BJ, Schaff HV, et al. 1992. Effect of completeness of revascularization on long-term outcome of patients with three-vessel disease undergoing coronary artery bypass surgery. A report from the Coronary Artery Surgery Study (CASS) Registry. Circulation 86:446-57.

Califf RM, Phillips HR 3rd, Hindman MC, et al. 1985. Prognostic value of a coronary artery jeopardy score. J Am Coll Cardiol 5:1055-63.

Centers for Disease Control and Prevention. International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM). Available at: www.cdc.gov/nchs/icd/icd9cm.htm. Accessed February 15, 2011.

Christenson JT, Schmuziger M. 1996. How serious is a proximal occlusion of a posterolateral sequential bypass? Tex Heart Inst J 23:201-6.

Gao C, Wang M, Wang G, et al. 2010. Patency of sequential and individual saphenous vein grafts after off-pump coronary artery bypass grafting. J Card Surg 25:633-7.

Grondin CM, Limet R. 1977. Sequential anastomoses in coronary artery grafting: technical aspects and early and late angiographic results. Ann Thorac Surg 23:1-8.

Gwozdziewicz M, Nemec P, Simek M, Hajek R, Troubil M. 2006. Sequential bypass grafting on the beating heart: blood flow characteristics. Ann Thorac Surg 82:620-3.

Karthik S, Grayson AD, McCarron EE, Pullan DM, Desmond MJ. 2004. Reexploration for bleeding after coronary artery bypass surgery: risk factors, outcomes, and the effect of time delay. Ann Thorac Surg 78:527-34.

Kieser TM, FitzGibbon GM, Keon WJ. 1986. Sequential coronary bypass grafts. Long-term follow-up. J Thorac Cardiovasc Surg 91:767-72.

Lattouf OM, Thourani VH, Kilgo PD, et al. 2008. Influence of on-pump versus off-pump techniques and completeness of revascularization on long-term survival after coronary artery bypass. Ann Thorac Surg 86:797-805.

Mack MJ, Pfister A, Bachand D, et al. 2004. Comparison of coronary bypass surgery with and without cardiopulmonary bypass in patients with multivessel disease. J Thorac Cardiovasc Surg 127:167-73.

Meurala H, Valle M, Hekali P, Somer K, Frick MH, Harjola PT. 1982. Patency of sequential versus single vein grafts in coronary bypass surgery. Thorac Cardiovasc Surg 30:147-51.

Nakajima H, Kobayashi J, Toda K, et al. 2010. Safety and efficacy of sequential and composite arterial grafting to more than five coronary branches in off-pump coronary revascularisation: assessment of intraoperative and angiographic bypass flow. Eur J Cardiothorac Surg 37:94-9.

Parsons LS. 2001. Reducing bias in a propensity score matched-pair

sample using greedy matching techniques. Proceedings of the 26th Annual SAS Users Group International Conference 2001. Cary, NC: SAS Institute, Inc.

Quigley RL. 2010. Sequential bypass on the beating heart can be achieved without compromising patient safety or regional myocardial blood flow. Int Surg 95:257-60.

Raja SG, Navaratnarajah M, Kitchlu CS, George S, Ilsley CD, Amrani M. 2010. 10-year follow-up of off-pump multivessel coronary artery bypass grafting. Asian Cardiovasc Thorac Ann 18:260-5.

Raja SG, Siddiqui H, Ilsley CD, Amrani M. 2009. In-hospital outcomes of off-pump multivessel total arterial and conventional coronary artery bypass grafting: single surgeon, single center experience. Ann Thorac Surg 88:47-52.

Raja SG. 2005. Pump or no pump for coronary artery bypass: current best available evidence. Tex Heart Inst J 32:489-501.

Rizzoli G, Schiavon L, Bellini P. 2002. Does the use of bilateral internal mammary artery (IMA) grafts provide incremental benefit relative to the use of a single IMA graft? A meta-analysis approach. Eur J Cardiothorac Surg 22:781-6.

Taggart DP, D'Amico R, Altman DG. 2001. Effect of arterial revascularization on survival: a systematic review of studies comparing bilateral and single internal mammary arteries. Lancet 358:870-5.