Published in final edited form as:

Am J Crit Care. 2004 November ; 13(6): 499–508.

Short-Term Complications and Resource Utilization in Matched Subjects After On-Pump or Off-Pump Primary Isolated Coronary Artery Bypass

Marilyn Hravnak, RN, PhD, ACNP-BC, Leslie A. Hoffman, RN, PhD, Melissa I. Saul, MS, Thomas G. Zullo, PhD, Julie F. Cuneo, RN, MSN, and Ronald V. Pellegrini, MD

Department of Acute/Tertiary Care, School of Nursing (MH, LAH, TGZ, JFC), Center for Biomedical Informatics (MIS), and Department of Cardiothoracic Surgery, School of Medicine (RVP), University of Pittsburgh, Pittsburgh, Pa

Abstract

Background—Studies suggest that patients who undergo off-pump coronary artery bypass grafting (OPCABG) have fewer short-term complications and use fewer inpatient resources than do patients who undergo standard coronary artery bypass grafting (CABG) with extracorporeal circulation. However, dissimilarity between groups in risk factors for complications has hindered interpretation of results.

Objectives—To compare the prevalence of selected complications (atrial fibrillation, stroke, reoperation, and bleeding) and inpatient resource utilization (length of stay, discharge disposition, total charges) between subjects undergoing primary isolated CABG or OPCABG who were matched with respect to key risk factors.

Methods—Retrospective, causal-comparative survey conducted in 1 center for 18 months. Patients who underwent primary isolated CABG or OPCABG were matched for sex, age (within 2 years), left ventricular ejection fraction (within 0.05), and graft-patient ratio (exact match) and compared for prevalence of new-onset atrial fibrillation, stroke, reoperation within 24 hours, and bleeding. Statistical analysis included Wilcoxon and t tests for paired comparisons.

Results—The sample (107 matched pairs) was 63% male, with a mean age of 66 (SD 9.5) years, a mean left ventricular ejection fraction of 0.51 (SD 0.13), and a mean graft-patient ratio of 3.41 (SD 0.74). The 2 groups did not differ significantly in New York Heart Association class ($P=.43$), Acute Physiology and Chronic Health Evaluation III score ($P=.22$), postoperative β -blocker use ($P=.73$), or comorbid conditions. None of the complications examined differed significantly between pairs.

Conclusion—Patients with comparable risk profiles have similar prevalences of selected complications after CABG and OPCABG.

Early reports of coronary artery bypass grafting (CABG) performed on the beating heart date to the early 1960s.¹ Use of cardiopulmonary bypass and cardioplegia, however, provided a bloodless and motionless surgical field, and CABG with cardiopulmonary bypass quickly became the standard of care. Some complications of CABG, including atrial fibrillation, bleeding, and stroke, are thought to be associated with cardiopulmonary

bypass.²⁻⁴ Consequently, interest has been renewed in off-pump CABG (OPCABG) as a means to avoid cardiopulmonary bypass and, hence, complications attributed to its use.

Previous reports suggested that OPCABG is associated with a decreased prevalence of atrial fibrillation because of the elimination of inflammatory mediators that result from cardiopulmonary bypass, the mechanical irritation of cannulation,² and cardioplegic arrest.⁵ OPCABG has also been associated with a lower prevalence of stroke and neurocognitive dysfunction,^{6,7} presumably because of the elimination of aortic cross-clamping and atheromatous macroembolization and microembolization from the extracorporeal circuit. Furthermore, OPCABG has been associated with lower prevalence of bleeding⁸⁻¹⁰ and reoperation for bleeding,¹¹ ostensibly because of the preservation of red cells and platelets when cardiopulmonary bypass is not used. Finally, some investigators reported shorter length of stay (LOS) in the intensive care unit (ICU) and hospital ward^{11,12} and lower costs^{13,14} after OPCABG.

Use of cardiopulmonary bypass may increase postoperative atrial fibrillation, bleeding, and stroke.

However, in most studies, the researchers did not compare groups matched with respect to key risk factors. Notably, in previous studies, the investigators^{11,12} compared OPCABG cohorts that had 1 or 2 grafts per patient with CABG cohorts that had 3 or more grafts. Also, risk factors such as a history of atrial fibrillation, increased age, repeat CABG procedure, and combination procedures (eg, CABG plus valve surgery) have not always been equivalent.^{11,13} Consequently, differences in risk profile rather than the elimination of cardiopulmonary bypass alone may have contributed to the reported differences.

The purpose of this study was to observe and compare the prevalence of selected short-term postsurgical complications (atrial fibrillation, stroke, reoperation, and bleeding) and inpatient resource utilization (LOS, discharge disposition, total charges) between subjects undergoing primary isolated CABG or OPCABG at a single center. The cohorts were matched with respect to key risk factors (patient's sex, age, left ventricular ejection fraction [LVEF], graft-patient ratio) to balance distribution of confounding variables.

Materials and Methods

A retrospective, matched-pair cohort design was used. Data were retrospectively obtained from the Medical Archival System (MARS, Medical Archival System Inc, Pittsburgh, Pa), the local repository for the Society of Thoracic Surgeons database, and the Critical Care Information System (Eclipsis Corp, Delray Beach, Fla) for the University of Pittsburgh Medical Center. The MARS is a repository for information forwarded from the health system's electronic clinical, administrative, and financial databases. MARS data are indexed on every word and will recover all encounters with a given patient between specific dates.¹⁵ With the approval of the institutional review board (January 17, 2002), data were de-identified (De-ID Software, University of Pittsburgh) by an honest broker (a person independent of the research) and obtained with a waiver of informed consent.

All patients undergoing primary isolated CABG or OPCABG during an 18-month interval (January 1, 2000 through June 31, 2001) who were more than 18 years old were eligible for the study. Exclusion criteria were (1) history of atrial fibrillation (active or inactive), (2) prior CABG, (3) prior or current valve replacement or repair, (4) prior or current ventricular assist device or thoracic organ transplant, (5) prior or current minimally invasive direct vision coronary artery bypass, (6) any other surgical procedure during current admission, and (7) death in the operating room or within 12 hours of surgery (to limit confounding of study end points).

The sample was limited to patients undergoing first-time CABG or OPCABG with no combination procedures (ie, CABG plus valve, aortic, or carotid repair) to clarify the relationship between the operative procedure and the prevalence of complications. A history of atrial fibrillation was made an exclusion criterion to clarify the true prevalence of surgery-induced atrial fibrillation. All subjects participated in the routine prophylaxis strategy for atrial fibrillation that was in effect during the study period (magnesium supplementation in the operating room, at the time of admission to the ICU, and on the first postoperative day; β -blocker administration beginning the first postoperative day). Operations were performed by any of the 6 attending cardiac surgeons, and anesthesia was delivered by any of the cardiac anesthesiologists.

Patients were identified from discharge abstracts in medical records by using procedure codes 36.10 to 36.16 from the International Classification of Diseases, Ninth Revision, Clinical Modification (*ICD-9-CM*). Electronic operative reports were used to identify those patients who underwent primary isolated CABG or OPCABG and the number of vessels bypassed, corroborated by review of the Society for Thoracic Surgeons database. Discrepancies were resolved by review of the hard-copy chart (honest broker). Charts of patients who died were reviewed to determine the temporal relationship between surgery and death.

In order to ascertain history of atrial fibrillation, MARS was used to identify patients with an *ICD-9-CM* code for atrial fibrillation (427.31). Discharge summaries were reviewed to verify the occurrence of atrial fibrillation and to determine if this complication was of new onset or was a previous problem (if necessary, a full chart review was done by an honest broker). Second, all remaining patients (no code 427.31) were subjected to a MARS word search (for AFIB, atrial fib, atrial dysrhythmia, or word variations), and discharge summaries were reviewed to determine if atrial fibrillation was of new onset, preexisting, or not present. Finally, the pharmacy database was used to determine if procainamide or amiodarone (as a potential marker for atrial fibrillation treatment) had been administered to any remaining patients. Patients identified in this manner were further evaluated, as described previously (discharge summary and, if necessary, full chart review), to determine if the patient had been treated for atrial fibrillation, and if the atrial fibrillation was a new or existing problem. Patients with any history of atrial fibrillation in these screening steps were excluded, as were patients with a questionable atrial fibrillation status as indicated by review of the hard copy of the chart.

A total of 1013 patients were identified as having *ICD-9-CM* procedure codes 36.10 to 36.16. Of these, 234 patients were excluded: 1 died in the operating room or within 24 hours, 53 had a history of atrial fibrillation, 64 had minimally invasive direct coronary artery bypass procedures, 63 had a combination procedure, 46 had a prior CABG, and 7 had prior atrial fibrillation or ventricular arrhythmia revealed by the drug search. A total of 779 patients (613 CABG and 166 OPCABG) remained in the sample available for matching.

The cohorts were then developed by matching subjects with respect to selected risk factors. Matching was by an iterative selection, prioritizing, in descending sequence, number of grafts, then the patient's sex, then age, then LVEF. For each OPCABG patient with a given graft-patient ratio and sex, the study database was examined to identify a CABG patient of the same age and sex with an LVEF within 0.05 of the OPCABG patient's LVEF. If more than 1 OPCABG and 1 CABG patient matched exactly on age and LVEF values within 0.05, the 2 with the closest LVEF values became the match. If a match could not be made for LVEF within 0.05 for OPCABG and CABG patients of the same age, the age search for the CABG patient was expanded to plus or minus 1 year and a LVEF search was done. Then, if necessary, the age search was expanded to plus or minus 2 years and an LVEF was done. If

more than 1 CABG patient matched the OPCABG patient on all 4 variables, the patient with the closest procedure date was chosen. The selectors were blinded to patients' outcomes. Matches were made for 214 subjects (107 for OPCABG and 107 for CABG). All unmatched OPCABG patients (n=59) and CABG patients (n=506) were eliminated. Most OPCABG cases for which matches could not be identified involved single and double vessels (n=38).

Demographic, clinical, fiscal, and disposition data were obtained from the MARS and from scores on the Acute Physiology and Chronic Health Evaluation III from the Critical Care Information System. In order to identify past medical problems, *ICD-9-CM* codes were clustered within similar disease categories and those with cumulative frequencies of 50 or more were selected for analysis. In order to identify new-onset stroke, (1) MARS was used to identify patients with ICD-9-CM code 997.02 (iatrogenic cerebrovascular infarct/hemorrhage), (2) MARS was used to identify all patients who had a computed tomography scan of the head, and (3) the Society for Thoracic Surgeons database was used to identify patients who had had a stroke. Hard copies of charts of patients thus identified were then reviewed to verify clinical findings of stroke with probable ischemic causation. Reoperation was identified first by using the *ICD-9-CM* procedure code, and the operative report was reviewed to determine the type of operation and the temporal relationship to the index surgery (within 24 hours). Bleeding was evaluated by determining the number of units of packed red blood cells transfused on the operative day (including during surgery) through the time of discharge. Resource utilization was evaluated with regard to postoperative LOS (operative day through discharge), postoperative ICU LOS, and 30-day nonelective readmission from the Admission/Discharge/Transfer database from MARS. Charges were extracted from MARS, which stores each charge transaction. Charges were used because they are considered less proprietary than costs yet still reflect the magnitude of between-group differences in a single institution. In order to account for inflationary increases, charges in months 13 to 18 of the study period were decreased by 3%.

Statistical Analysis

SPSS, version 11.0 (SPSS Inc, Chicago, Ill), was used to compare the unlinked pairs (ie, 2 groups frequency matched with respect to age, sex, LVEF, and graft-patient ratio) for differences in baseline characteristics, demographics, complications, and resource utilization. The χ^2 test was used for proportions and the Wilcoxon sign rank test and *t* tests for paired comparisons.

Results

Demographics

The sample was 63% male. Patients had a mean age of 66 years, a mean LVEF of 0.51, and a mean of 3.41 grafts (Table 1). Most patients had 3 bypasses (45.8%) or 4 or 5 bypasses (44.9%); only a small percentage (9.3%) had 1 or 2 bypasses. No significant differences were found between CABG and OPCABG patients in regard to score on the Acute Physiology and Chronic Health Evaluation III, prevalence of comorbid health conditions, or postoperative use of β -blockers.

A trial fibrillation, stroke, reoperation, and transfusion requirements did not differ between patients experiencing on-pump versus off-pump CABG.

Complications

The 2 groups did not differ significantly in overall prevalence of complications. New onset of atrial fibrillation was experienced by 33.6% of CABG and 35.5% of OPCABG subjects ($P=.89$). Only small percentages of subjects in either group had a stroke (CABG 2.8% vs

OPCABG 1.9%, $P > .99$). Similar percentages of subjects required reoperation within 24 hours (CABG 5.6% vs OPCABG 4.7%; $P = .76$). The requirement for transfusion of packed red blood cells did not differ significantly between groups (mean [SD], CABG 1.95 [2.36] vs OPCABG 1.59 [1.90] units, $P = .19$). Overall, 27.1% of CABG subjects required 3 units or more of packed red blood cells compared with 21.5% of OPCABG subjects ($P = .34$).

Resource Utilization

CABG and OPCABG subjects did not differ significantly with respect to mean postoperative LOS or ICU LOS (Table 2). CABG subjects showed a trend toward higher total postoperative charges (\$86221 vs \$81264), but the difference was not significant ($P = .13$). Nearly three fourths of subjects in both groups were discharged to home, and one fourth to a posthospital care facility ($P = .55$). The 30-day nonelective readmission rate was similar (CABG 14.9% vs OPCABG 12.1%, $P = .55$). Only 1 CABG and no OPCABG subjects died.

Discussion

Our findings suggest that (1) CABG and OPCABG patients matched with respect to risk factors experience a similar prevalence of selected complications and (2) when the OPCABG procedure is extended beyond 1 or 2 grafts, some benefits thought to be attributed to elimination of cardiopulmonary bypass^{16,17} are attenuated.

We found only 2 studies in which case-matched comparisons were done. In a retrospective review, Haase et al¹⁶ compared 90 CABG and OPCABG patients matched with respect to graft-patient ratio (2.1 vs 2.1), target vessels (80 of the 90 were left anterior descending artery), EuroSCORE (3.6 vs 3.3), age (65 vs 66 years), and sex (62% vs 73% male). They reported that a greater percentage of OPCABG patients (13.3%) than CABG patients (7.8%) required intraoperative administration of packed red blood cells, although the difference was not significant ($P = .33$); both groups had a similar need for intraoperative administration of platelets (3.3% vs 3.3%, $P > .99$) and fresh-frozen plasma (0% vs 2.2%, $P = .25$). Postoperatively, a higher percentage of CABG patients required transfusion of red blood cells (OPCABG 4% vs CABG 17.8%, $P = .002$), but the groups had similar postoperative requirements for transfusion of platelets ($P = .13$) and fresh-frozen plasma ($P = .33$). The prevalences of postoperative atrial fibrillation (OPCABG 32.2% vs CABG 34.4%, $P = .87$) and stroke (1.1% vs 3.3%, $P = .37$) were similar, but a trend toward greater prevalence of return to the operating room for CABG patients (6.7 vs 1%, $P = .66$) was noted. Finally, no differences occurred in the LOS in the ICU ($P = .20$) or in the hospital (mean [SD], CABG 12.3 [12.7] vs OPCABG 10.9 [5.6] days, $P = .78$).

Louagie et al¹⁷ also performed a retrospective case-matched study, with 45 pairs matched with respect to age, sex, body surface area, number of diseased vessels, and LVEF. Although not matched with respect to graft-patient ratio, which was significantly different between groups, graft numbers were clinically similar between groups (mean [SD], OPCABG 2.3 [0.1] vs CABG 2.8 [0.1] vessels, $P = .02$). Louagie et al found no difference in the prevalence of postoperative atrial fibrillation (OPCABG 37% vs CABG 24%, P not reported) or reoperation for bleeding (1 subject each group). Although OPCABG patients experienced a shorter ICU LOS than did CABG patients (mean [SD], 47.4 [4.6] vs 69.2 [3.3] hours, $P = .002$), hospital LOS was nearly equivalent (mean [SD], 11.6 [0.9] vs 12.2 [0.7] days, P not significant). Stroke prevalence and transfusion requirements were not reported.

Our results, similar to these other matched-case studies, indicate that postoperative atrial fibrillation remains a complication of CABG whether or not cardiopulmonary bypass is applied. The origin of this phenomenon continues to remain unclear. Variables thought to be

associated with postsurgical atrial fibrillation such as increased age, sex of the patient, concomitant surgery, reoperation, history of atrial fibrillation, and poor left ventricular function⁵ were controlled via exclusion criteria or matching. Some investigators have hypothesized that inflammatory mediators thought to cause atrial fibrillation would be eliminated if cardiopulmonary bypass were not required. However, Diegeler et al¹⁸ found that some inflammatory mediators are released during OPCABG. They examined the immune response patients who had CABG with cardiopulmonary bypass or 2 OPCABG techniques (mediastinal or lateral thoracotomy). Complement activation, although present in all 3 groups, was more pronounced in the group who had CABG with cardiopulmonary bypass, with an augmented inflammatory response paralleled by an increase in interleukin-10 in the CABG group. All groups also had an immune response to surgical trauma as evidenced by the same increase in level of interleukin-6. Diegeler et al concluded that although the release of immune mediators is enhanced by the use of cardiopulmonary bypass, an inflammatory, as well as an anti-inflammatory, response to surgical trauma occurs regardless of whether cardiopulmonary bypass is used.

Postoperative atrial fibrillation remains a complication of CABG whether or not cardiopulmonary bypass is used, although the cause is unclear.

Place et al⁵ compared prevalence of atrial fibrillation and time to onset in 199 subjects undergoing OPCABG or CABG (mean [SD], OPCABG 3.0 [0.84] vs CABG 3.3 [0.86] distal anastomoses, $P = .03$). Although the graft-patient ratio was significantly different between the groups (less in the OPCABG group), the 2 groups had similar prevalences of atrial fibrillation regardless of procedure (OPCABG 25% vs CABG 18%, $P = .23$). The time to onset peaked on postoperative day 2 for both groups. Thus, our findings corroborate that there may exist a common, albeit unknown, pathophysiology for postoperative atrial fibrillation that is independent of cardiopulmonary bypass and its consequences.

Researchers in 2 prior studies,^{8,9} conducted by using unmatched subjects, reported findings in subjects with higher graft-patient ratios. Magee et al⁸ reported a retrospective analysis of 6466 CABG (median 4 grafts) and 1983 OPCABG (median 3 grafts) nonrandomized subjects. The CABG patients were more likely than the OPCABG patients to receive packed red blood cells (39% vs 29%, respectively, $P < .001$) and to require reoperation for bleeding (3.63% vs 1.97%, respectively, $P < .001$), but the 2 groups had similar prevalences of stroke (1.35% vs 1.06%, respectively, $P = .32$). Magee et al did not report on the prevalence of atrial fibrillation. They did report a selection bias for fewer grafts per OPCABG subject.

In a different study, Puskas et al⁹ examined subject groups with closer similarity in the graft-patient ratios. They compared the outcomes of 98 unmatched subjects undergoing primary isolated OPCABG (mean 3.39 [SD 1.04] grafts) with 99 CABG patients (mean 3.40 [SD 1.08] grafts, $P = .83$). The groups were similar with respect to prevalence of atrial fibrillation (OPCABG 16% vs CABG 22%, $P = .37$) and stroke (1 OPCABG patient and 2 CABG patients). Cumulative transfusion of packed red blood cells from surgery to postoperative day 3 (mean [SD], OPCABG 0.40 [0.77] vs CABG 0.61 [1.79] units, $P = .01$) was significantly different but clinically similar (mean difference 0.2 units).

We also found equivalence between administration of packed red blood cells in the CABG (mean 1.95 units) and OPCABG (mean 1.95 units) groups. Our results and those of Puskas et al suggest that when the graft-patient ratio exceeds 2:1, transfusion requirements for OPCABG approach those for CABG. Our replacement requirement, although equivalent between groups, was higher than that reported by Puskas et al. Nevertheless, the mean number of units of packed red blood cells transfused for both groups in our study is still lower than the lesser requirements reported for OPCABG subjects in some studies that noted between-group differences.^{10,19} For example, Nader et al¹⁰ reported mean replacement of 2

units of packed red blood cells for OPCABG patients and 5 units for CABG patients ($P < .05$), a difference that was statistically significant between groups, but the overall transfusion requirements for both their groups were greater than in our series.

Some of these differences in blood product administration may be related to local practices and transfusion thresholds, and thus make it difficult to interpret significance from both a statistical and a clinical standpoint. Variation in local transfusion thresholds may be a particularly important factor in examining between-group differences in the setting of mild pump-related hemodilution. Additionally, the timing of administration of blood products must be defined. In our study, we accounted for all units of packed red blood cells administered, during surgery as well as postoperatively. Although Haase et al,¹⁶ in the previously mentioned matched comparison study, noted that the percentages of patients needing transfusions of packed red blood cells were lower postoperatively in the OPCABG subjects, more OPCABG patients required intraoperative transfusions, perhaps reflecting more intraprocedural bleeding for OPCABG patients. Thus, the greater transfusion requirement reported for CABG subjects in some studies is difficult to interpret when the timing of the transfusions is not reported. We recommend that investigators include both the intraoperative and postoperative time frame when defining transfusion requirements, because this definition more closely reflects true consumption of and exposure to blood products.

The prevalence of ischemic stroke was low in our study (3 CABG and 2 OPCABG patients). As in other matched-case studies,¹⁶ none of these strokes occurred in matched pairs. Of our 5 patients who had a stroke, 4 had quadruple grafts (2 OPCABG and 2 CABG subjects) and 1 had triple grafts (CABG). These results suggest that OPCABG patients with multiple conduits may have other causes of stroke that are independent of cardiopulmonary bypass.

We did not find any significant between-group differences in postoperative LOS. Lee et al¹³ found a significant difference in total hospital LOS for OPCABG and CABG patients but did not report if some of these days preceded surgery. Jarvinen et al¹² noted a significantly longer postoperative stay for CABG subjects, which was attributed to a lower prevalence of complications in OPCABG patients. However, the groups in the study of Jarvinen et al were dissimilar with respect to the number of grafts. Our findings indicate that equivalence of risk factors and complications may foster equivalence in LOS. Our findings may also reflect differences in discharge criteria and a parochial bias for earlier discharge. Nonetheless, our practice of early discharge appears appropriate because our findings on the 30-day nonelective readmission rate, and discharge destinations, are similar to those reported by others.^{20,21}

Despite similar LOSs and prevalences of complications in the OPCABG and CABG groups in our study, a trend toward lower postoperative charges (Table 2) was apparent in the OPCABG group (mean difference \$5000). In an attempt to explicate this difference, we examined charges associated with the operating room post hoc (see Figure). Total operating room charges were \$39 762 for CABG subjects and \$34 735 for OPCABG subjects, a difference primarily explained by perfusion service charges (\$8754 for CABG vs \$4578 for OPCABG). Thus, total operating room charges for CABG patients were greater by a mean difference of \$5027, with perfusion charges accounting for 83% of the difference. Perfusion charges appeared to account for the overall trend for postoperative charges to differ between the groups.

Limitations

This study had several limitations. Some benefits of the OPCABG or CABG procedures may not have been examined. In prior studies, researchers found that compared with CABG

patients, OPCABG patients required less administration of fluids and vasoactive drugs,^{16,22} had less release of myocardial enzymes,⁹ and had less cognitive impairment.^{23,24} We also did not examine graft patency, and some evidence from 1 randomized trial suggests that graft patency rates were lower at 3 months for multivessel OPCABG patients than for CABG patients.²⁵

Additionally, our study was conducted in a single academic teaching institution with multiple surgeons who had various levels of experience with the OPCABG procedure. Some evidence indicates that both short- and long-term outcomes can be correlated to the experience and skill of the individual surgeon^{8,9,26} and anesthesia team with the OPCABG procedure, especially when anastomosing posterior vessels or when managing the hemodynamic instability often encountered during cardiac manipulation. Our results reflect the composite experience of the surgical staff, and individual variation was not controlled for. Our findings therefore may not be comparable to findings of other studies of the outcomes achieved by a single surgeon or highly experienced team, or to other settings because of differences in the surgical team or the population of patients. Our sample does not reflect extremely high- and low-risk patients, because they tended to be selected out in the matching process. Our study was underpowered to fully assess complications with low prevalence such as stroke and death. Finally, we used a retrospective data set, a practice that has inherent limitations. Possibly, procedures used to identify and match subjects did not correctly identify all subjects or matching criteria.

Off-pump CABG patients had shorter ICU stays but similar hospital stays compared with on-pump CABG patients.

Conclusions and Recommendations

Prior studies suggested that matched pairs of patients who undergo OPCABG and CABG experience similar rates of complications when the surgery involves 1 or 2 grafts. We extended this observation by comparing complications in patients who underwent primary isolated CABG and OPCABG to receive more grafts. In our study, 90% of the matched cohorts had 3 or more grafts, and 45% had 4 or more grafts. A matched cohort comparison was used to neutralize age, sex, baseline LVEF, and graft-patient ratio as confounding variables. When risk factor profiles for the comparison groups were matched, the between-group prevalences of atrial fibrillation, bleeding, reoperation, and stroke were similar. Our results do suggest some cost benefit associated with OPCABG; the lower cost for OPCABG appeared to be due to lower consumption of perfusion services in the operating room. We recommend that future studies comparing the clinical and financial outcomes of patients undergoing primary isolated CABG and OPCABG include controls for the number of grafts as well as other key risk factors.

Acknowledgments

Financial support for this study was provided by a Central Research Development Fund Award from the University of Pittsburgh.

Thanks to Fred Tasota and Kathryn Cuneo for assistance with manuscript preparation and to Bob Jones, Diane Davis, and Judy Vaglia for assistance with data collection.

REFERENCES

1. Kirklin JK, Westaby S, Blackstone EH, Kirklin JW, Chenoweth DE, Pacifico AD. Complement and the damaging effects of cardiopulmonary bypass. *J Thorac Cardiovasc Surg.* 1983; 86:845–857. [PubMed: 6606084]

2. Mathew JP, Parks R, Savino JS, et al. Atrial fibrillation following coronary artery bypass graft surgery: predictors, outcomes, and resource utilization. MultiCenter Study of Perioperative Ischemia Research Group. *JAMA*. 1996; 276:300–306. [PubMed: 8656542]
3. Edmunds LH Jr. The evolution of cardiopulmonary bypass: lessons to be learned. *Perfusion*. 2002; 17:243–251. [PubMed: 12139382]
4. Almassi GH, Sommers T, Moritz TE, et al. Stroke in cardiac surgical patients: determinants and outcome. *Ann Thorac Surg*. 1999; 68:391–397. [PubMed: 10475402]
5. Place DG, Peragallo RA, Carroll J, Cusimano RJ, Cheng DC. Postoperative atrial fibrillation: a comparison of off-pump coronary artery bypass surgery and conventional coronary artery bypass graft surgery. *J Cardiothorac Vasc Anesth*. 2002; 16:144–148. [PubMed: 11957161]
6. Scarborough JE, White W, Derilus FE, Mathew JP, Newman MF, Landolfo KP. Neurologic outcomes after coronary artery bypass grafting with and without cardiopulmonary bypass. *Semin Thorac Cardiovasc Surg*. 2003; 15:52–62. [PubMed: 12813690]
7. Newman MF, Kirchner JL, Phillips-Bute B, et al. Longitudinal assessment of neurocognitive function after coronary artery bypass surgery. *N Engl J Med*. 2001; 334:395–402. [PubMed: 11172175]
8. Magee MJ, Jablonski KA, Stamou SC, et al. Elimination of cardiopulmonary bypass improved early survival for multivessel coronary artery bypass patients. *Ann Thorac Surg*. 2002; 73:1196–1203. [PubMed: 11996263]
9. Puskas JD, Williams WH, Duke PG, et al. Off-pump coronary artery bypass grafting provides complete revascularization with reduced myocardial injury, transfusion requirements, and length of stay: a prospective randomized comparison of two hundred unselected patients undergoing off-pump versus conventional coronary artery bypass grafting. *J Thorac Cardiovasc Surg*. 2003; 125:797–807. [PubMed: 12698142]
10. Nader ND, Khadra WZ, Reich NT, Bacon DR, Salerno TA, Panos AL. Blood product use in cardiac revascularization: comparison of on- and off-pump techniques. *Ann Thorac Surg*. 1999; 68:1640–1643. [PubMed: 10585034]
11. Cleveland JC, Shroyer ALW, Chen AY, Peterson E, Grover FL. Off-pump coronary artery bypass grafting decreases risk-adjusted mortality and morbidity. *Ann Thorac Surg*. 2001; 72:1282–1289. [PubMed: 11603449]
12. Jarvinen O, Laurikka J, Tarkka MR. Off-pump versus on-pump coronary bypass: comparison of patient characteristics and early outcomes. *J Cardiovasc Surg*. 2003; 44:167–172. [PubMed: 12813378]
13. Lee JH, Abdelhady K, Capdeville M. Clinical outcomes and resource usage in 100 consecutive patients after off-pump coronary bypass procedures. *Surgery*. 2000; 128:548–555. [PubMed: 11015087]
14. Nathoe HM, van Dijk D, Jansen EWL, et al. A comparison of on-pump and off-pump coronary bypass surgery in low-risk patients. *N Engl J Med*. 2003; 348:394–402. [PubMed: 12556542]
15. Yount RJ, Vries JK, Councill CD. The Medical Archival Retrieval system: an information retrieval system based on distributed parallel processing. *Info Process Manage*. 1991; 27:1–11.
16. Haase M, Sharma A, Fielitz A, et al. On-pump coronary artery surgery versus off-pump exclusive arterial coronary grafting: a matched cohort comparison. *Ann Thorac Surg*. 2003; 75:62–67. [PubMed: 12537194]
17. Louagie Y, Jamart J, Broka S, Collard E, Scavee V, Gonzalez M. Off-pump coronary artery bypass grafting: a matched-case comparison of hemodynamic outcome. *Eur J Cardiothorac Surg*. 2002; 22:552–558. [PubMed: 12297171]
18. Diegeler A, Doll N, Rauch T, et al. Humoral immune response during coronary artery bypass grafting: a comparison of limited approach, “off-pump” technique, and conventional cardiopulmonary bypass. *Circulation*. 2000; 102(19 suppl 3):III95–III100. [PubMed: 11082370]
19. Kirk KC, Aldridge RA, Sistino JJ, et al. Coronary bypass artery grafting with and without cardiopulmonary bypass: a comparison analysis. *J Extra Corpor Technol*. 2001; 33:86–90. [PubMed: 11467442]
20. Hannan EL, Racz MJ, Walford G, et al. Predictors of readmission for complications of coronary artery bypass graft surgery. *JAMA*. 2003; 290:773–780. [PubMed: 12915430]

21. Bohmer RM, Newell J, Torchiana DF. The effect of decreasing length of stay on discharge destination and readmission after coronary bypass operation. *Surgery*. 2002; 132:10–15. [PubMed: 12110788]
22. Ascione R, Reeves BC, Rees K, Angelini GD. Effectiveness of coronary artery bypass grafting with or without cardiopulmonary bypass in over-weight patients. *Circulation*. 2002; 106:1764–1770. [PubMed: 12356627]
23. Van Dijk D, Jansen EWL, Hijman R, et al. Cognitive outcome after off-pump and on-pump coronary artery bypass graft surgery: a randomized trial. *JAMA*. 2002; 287:1405–1412. [PubMed: 11903027]
24. Diegeler A, Hirsch R, Schneider F, et al. Neuromonitoring and neurocognitive outcome in off-pump versus conventional coronary bypass operation. *Ann Thorac Surg*. 2000; 69:1162–1166. [PubMed: 10800812]
25. Khan NE, DeSouza A, Mister R, et al. A randomized comparison of off-pump and on-pump multivessel coronary artery bypass surgery. *N Engl J Med*. 2004; 350:21–28. [PubMed: 14702424]
26. Mack MJ, Pfister A, Bachand D, et al. Comparison of coronary artery bypass surgery with and without cardiopulmonary bypass in patients with multivessel disease. *J Thorac Cardiovasc Surg*. 2004; 127:167–173. [PubMed: 14752427]

Figure 1.

Table 1

Demographic characteristics of the matched sample groups*

Characteristic	Coronary artery bypass graft		P
	On pump (n = 107)	Off pump (n = 107)	
Matched variables			
Age, mean (SD), years	66.40 (9.50)	66.32 (9.49)	.41
Sex, No (%)			>.99
Male	67 (63)	67 (63)	
Female	40 (37)	40 (37)	
Left ventricular ejection fraction, mean (SD)	0.51 (0.13)	0.51 (0.13)	.34
No. of vessels bypassed, mean (SD)	3.41 (0.74)	3.41 (0.74)	>.99
No. of vessels bypassed, No (%)			>.99
1	0 (0)	0 (0)	
2	10 (9.3)	10 (9.3)	
3	49 (45.8)	49 (45.8)	
4	42 (39.3)	42 (39.3)	
5	6 (5.6)	6 (5.6)	
Nonmatched variables			
Race, No (%)			.67
White	102 (93.5)	103 (96.3)	
Black	3 (2.8)	2 (1.9)	
Other	2 (1.9)	2 (1.9)	
New York Heart Association class, No (%)			.43
I	9 (8.4)	18 (16.8)	
II	33 (30.8)	36 (33.6)	
III	38 (35.5)	25 (23.4)	
IV	27 (25.2)	28 (26.2)	
Acute Physiology and Chronic Health Evaluation III score, mean (SD)	46.88 (11.48)	48.70 (13.48)	.22
Past medical condition, [†] No (%)			
Diabetes	37 (34.6)	44 (41.1)	.40
Hypothyroid	6 (5.6)	5 (4.7)	>.99
Hypertension	66 (61.7)	74 (69.2)	.31
Acute myocardial infarction	28 (26.2)	22 (20.6)	.42
Old myocardial infarction	22 (20.6)	20 (18.7)	.86
Heart failure	23 (21.5)	22 (20.6)	>.99
Chronic pulmonary disease	13 (12.1)	20 (18.7)	.26
Chronic renal disease	6 (5.6)	6 (5.6)	>.99
Total No. of conditions, No (%)			
0	12 (11.2)	8 (7.5)	
1	33 (30.8)	29 (27.1)	
2	32 (29.9)	39 (36.4)	
3	16 (15.0)	21 (19.6)	

Characteristic	Coronary artery bypass graft		<i>P</i>
	On pump (n = 107)	Off pump (n = 107)	
4	14 (13.1)	10 (9.3)	
Postoperative administration of β -blocker, No (%)	101 (94.4)	103 (96.3)	.73

* Because of rounding, percentages may not all total 100.

[†] Conditions are based on codes in the *International Classification of Diseases, Ninth Revision, Clinical Modification*. Each subject may be coded for more than 1 condition.

Table 2Resource utilization in the matched sample groups^{*}

Resource utilization	Coronary artery bypass graft		<i>P</i>
	On pump (n = 107)	Off pump (n = 107)	
Total postoperative length of stay, days	5.05 (1.38)	5.37 (2.21)	.19
Postoperative length of stay in the intensive care unit, days	1.66 (1.43)	1.78 (1.38)	.57
Postoperative charges, US\$	86221 (23467)	81264 (26678)	.13
Disposition at discharge, No. (%) of patients			.55
Home	77 (72.0)	80 (74.8)	
Posthospital care facility	29 (27.1)	27 (25.2)	
Death	1 (0.9)	0 (0)	

^{*} Data are given as mean (SD) except where noted.