

A cost comparison of off-pump CABG versus on-pump CABG at one-year: The Canadian Off-Pump CABG Registry

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BACKGROUND: Evidence suggests that off-pump coronary artery bypass graft surgery (CABG) is as safe and effective as on-pump CABG, and the cost of initial hospitalization for off-pump CABG is less expensive than on-pump CABG. However, it is uncertain whether the cost savings are sustained over a longer period of time.

OBJECTIVE: To assess in-hospital and one-year direct medical costs of off-pump CABG versus on-pump CABG in the context of the Canadian health care system.

METHODS AND RESULTS: From March 2001 to December 2002, 1657 consecutive patients enrolled in the Canadian Off-Pump CABG Registry were compared with 1693 consecutive on-pump patients from Hamilton Health Sciences CABG database. At one year, patients of both groups were followed by telephone interview. An economic analysis was conducted from the perspective of the Ontario Ministry of Health and Long-Term Care, and the data analysis was based on propensity score-matched registry patients (1233 pairs) to ensure the comparability of the two study groups. Clinical event and resource use information was collected from all patients. Unit costs from the Hamilton Health Sciences case-costing system were used to estimate hospital costs; all costs were reported in 2003 Canadian dollars. Sensitivity analyses were performed to account for uncertainties. The cost of initial hospitalization for off-pump CABG was significantly less than on-pump CABG (\$11,744 versus \$13,720, $P < 0.001$). Although follow-up costs were similar between the groups, the one-year total cost per patient for off-pump CABG remained significantly less than on-pump CABG (\$12,063 versus \$14,141, $P < 0.001$).

CONCLUSION: Off-pump CABG offers significant savings during initial hospitalization that are also sustained after one year.

Key Words: *Cardiopulmonary bypass; Cost analysis; Follow-up studies; Health policy; New technology; Outcome research*

The Canadian Off-Pump Coronary Artery Bypass Grafting Registry ('the registry') is a nationwide, multicentre prospective study involving 13 adult cardiac centres and 42 surgeons across Canada. The objectives of the registry were to compare the in-hospital and one-year clinical outcomes of coronary artery bypass graft surgery (CABG) between off-pump and on-pump techniques in a regular practice setting, and to provide clinical evidence for developing patient selection

Comparaison des coûts du pontage coronarien à cœur battant avec ceux du pontage avec circulation extracorporelle au bout de un an : registre canadien sur le pontage à cœur battant

CONTEXTE : Selon des données, le pontage coronarien à cœur battant (PCB) serait aussi sûr et aussi efficace que le pontage réalisé avec circulation extracorporelle (PCE), et les coûts de la première hospitalisation sont moins élevés pour le PCB que pour le PCE. Cependant, on ne sait pas si les économies réalisées au départ se maintiennent sur une longue période.

BUT : L'étude visait à évaluer les coûts médicaux, directement liés au PCB et au PCE pendant l'hospitalisation et au bout de un an, dans le contexte du système de soins au Canada.

MÉTHODE ET RÉSULTATS : De mars 2001 à décembre 2002, 1 657 patients consécutifs, traités par PCB et inscrits dans le Canadian Off-Pump CABG Registry ont été comparés à 1693 patients consécutifs, traités par PCE et inscrits dans la base de données Hamilton Health Sciences CABG. Au bout de un an, des patients de chacun des deux groupes ont été interrogés sur leur état de santé, au téléphone. Une analyse économique a été réalisée du point de vue du ministère de la Santé et des Soins de longue durée de l'Ontario; celle-ci reposait sur l'appariement des indices de propension des patients inscrits (1 233 paires) et visait à s'assurer de la comparabilité des deux groupes à l'étude. Nous avons recueilli des données provenant de tous les patients sur les événements cliniques et sur l'utilisation des ressources. Les coûts unitaires calculés par le système de coûts par cas du centre hospitalier Hamilton Health Sciences ont servi de base à l'évaluation des coûts hospitaliers, tous exprimés en dollars canadiens de 2003. Des analyses de sensibilité ont été effectuées pour tenir compte des incertitudes. Le coût de la première hospitalisation pour le PCB était significativement plus bas que celui pour le PCE (11 744 \$ contre 13 720 \$; $P < 0,001$). Même si les coûts du suivi se sont révélés similaires dans les deux groupes, le coût total par patient au bout de un an pour le PCB est resté sensiblement inférieur à celui pour le PCE (12 063 \$ contre 14 141 \$; $P < 0,001$).

CONCLUSION : Le pontage à cœur battant permet de réaliser des économies importantes au cours de la première hospitalisation, économies qui se maintiennent tout au long de la première année.

guidelines among these techniques. The registry also aimed to collect health resource use data and to provide information for decision-makers on the resource use pattern and cost of the alternative techniques in the context of the Canadian health care system. The registry's clinical results have demonstrated that off-pump CABG is at least as safe and effective as on-pump CABG during initial hospitalization and at one year after surgery (1).

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The present economic study is based on the clinical results of the registry. The study objectives are to address the health care resource use patterns of off- and on-pump CABG in Canada, and to estimate the cost of each of these techniques during initial hospitalization and up to one year after surgery.

PATIENTS AND METHODS

Patient population

A total of 3350 patients underwent isolated CABG surgery at various Canadian cardiac centres between March 2001 and December 2002. Of these, 1657 consecutive off-pump CABG patients were enrolled in the registry, and 1693 consecutive on-pump CABG patients from the Hamilton Health Science (HHS) cardiac surgery database formed a comparison group. One year after surgery, patients from both groups were interviewed by telephone (98% follow-up rate), and information on major cardiac-related events and patient memory status was obtained. Details on patient demographics and risk profiles, and a comparison of in-hospital and one-year clinical off- and on-pump CABG group results were described in a previous study (1).

Due to the nonrandomized nature of the registry, baseline demographics and risk profiles of registry patients were significantly different between the off- and on-pump CABG patients. The cost analysis in the present study is based on the propensity score-matched registry population to ensure the comparability between the two groups. The propensity score was used to pair-match patients (1:1 ratio) to the closest estimated propensity score (± 0.001). After controlling for the potential selection and treatment bias, 2466 patients, approximately three-quarters of the registry population, were successfully matched (1233 pairs). The baseline characteristics and risk profiles of all pairs were similar between the two groups (1).

Economic analysis method

In the present economic evaluation, the direct medical costs of off-pump CABG versus on-pump CABG for the initial hospitalization and at one-year after surgery were estimated and compared. Analysis was conducted from the perspective of the Ontario Ministry of Health and Long-Term Care. Clinical data and resource use for the alternative CABG techniques from both groups were prospectively collected at the patient level. Unit cost estimations were based on the HHS case-costing system, developed by the CADENCE Research Group in Hamilton, Ontario (2,3). All costs were reported in 2003 Canadian dollars, and the Ontario health sector Consumer Price Index was used when needed (4). Sensitivity analyses were performed to test the robustness of the study results.

Determination and measurement of resource use

Detailed resource use during initial hospitalization was recorded for each patient in four major categories: CABG procedure, surgical device, hospital length of stay (LOS) and number of blood transfusion products. The CABG procedure category included operating room (OR) staff and supplies and physician services measured by the type of CABG, the length of OR time and the number of grafts. Average perfusionist time in OR was included in both off-pump and on-pump procedures, based on the assumption that even during an off-pump procedure, there must still be a perfusionist on standby in case the need arises. Surgical devices were singled out from the CABG procedure and data were collected as a separate measure of resource use. For on-pump CABG, a surgical device was considered the disposable portion of the coronary pulmonary

bypass (CPB). For off-pump CABG, surgical devices included disposable and nondisposable stabilizers. Hospital LOS was measured as postoperative LOS only, defined as hospital days between the date of surgery and the date of discharge from the hospital. LOS included stay at the intensive care unit (ICU) and the cardiac ward ('ward'). Blood product use included perioperative and postoperative blood transfusions, measured as the sum of red blood cells, fresh frozen plasma and pooled platelets. Follow-up resource use was measured by follow-up events such as death, stroke, myocardial infarction (MI), angiography and coronary revascularization, including redo CABG and percutaneous cardiovascular intervention (PCI). These follow-up events were collected from patients based on the confirmation of their physician.

Determination of unit costs

Unit costs were derived from various sources; those associated with surgical procedures (CABG and PCI), hospital LOS and blood product use were obtained from the HHS case-costing system, where the case-cost was developed using the combination of a microcosting approach and the top-down method. The surgical device unit costs were based on national wholesale prices obtained from manufacturers (2003 average). To calculate the unit cost of nondisposable surgical devices (Coroneo, CoroNéo Inc, Canada), a three-year device amortization period and an annual 5% increase in off-pump CABG cases were assumed based on each centre's actual number of off-pump CABG surgeries. All technical and professional fees for performing surgeries and PCI procedures were obtained from the 2003 Ontario Schedule of Benefits (5).

The costs of CABG procedures, surgical devices, hospital LOS and blood products were calculated by multiplying patient-specific resource use with the corresponding unit cost. The costs of in-hospital MI and stroke were not calculated separately. Instead, they were reflected in patients' total hospital LOS costs, assuming that those patients with cardiac events would be hospitalized longer than those without. The unit cost of major cardiac events was estimated at follow-up. Because follow-up event information was collected from patients' reports, the assumption was that all reported stroke, MI and coronary revascularization events would result in hospital readmission. Follow-up event costs for stroke and MI were based on those found in the literature (6,7), and average CABG procedure costs during initial hospitalization were used as estimates for follow-up redo CABGs. Because bare metal stents were still predominantly used during the study period (8), the cost of PCI procedures was derived from the HHS case-costing system assuming only bare metal stents were used at 1.4 stent per patient.

Statistical methods

Data analysis: All data were analyzed based on intention to treat (if off-pump patients were converted for CPB, they were included in the off-pump group, and vice versa). Continuous variables were compared by the Student's *t* test and categorical variables were compared by χ^2 analysis or Fisher's exact test. All tests were two-sided and $P < 0.05$ was considered statistically significant. Because the distribution of hospital LOS and cost data tends to be right-skewed, analyses were performed on both original data and log transformed data; however, cost data in the tables were reported based on untransformed data and were expressed as mean \pm SD. Data were analyzed using SPSS statistical software (version 11.5, SPSS Inc, USA).

Sensitivity analysis and subgroup analysis: Two types of sensitivity analyses were performed to examine the robustness of the analysis toward various cost estimates and difference scenarios. In

TABLE 1
In-hospital and one-year clinical outcomes based on propensity score-matched registry patient population (n=2466)

	Off-pump (n=1233)	On-pump (n=1233)	OR (95% CI)	P
In-hospital events, %				
Mortality	1.5	1.7	0.90 (0.48–1.69)	0.750
Stroke	0.8	1.6	0.49 (0.23–1.06)	0.072
Myocardial infarction	3.0	1.5	2.09 (1.18–3.69)	0.011
Follow-up events, %				
Mortality	2.0	2.2	0.90 (0.52–1.56)	0.702
Stroke	0.6	1.1	0.55 (0.22–1.38)	0.198
Myocardial infarction	0.8	1.5	0.51 (0.23–1.14)	0.095
Angiography	3.3	3.8	0.87 (0.57–1.32)	0.502
Coronary revascularization	1.9	1.9	1.02 (0.57–1.84)	0.94
One-year total events, %				
Mortality	3.5	3.9	0.90 (0.59–1.38)	0.643
Stroke	1.4	2.7	0.49 (0.27–0.90)	0.021
Myocardial infarction	3.9	3.0	1.32 (0.85–2.06)	0.215
Angiography	3.3	3.8	0.87 (0.57–1.32)	0.502
Coronary revascularization	1.9	1.9	1.02 (0.57–1.84)	0.94

the univariate sensitivity analysis, several key cost estimates were tested using different assumptions. In the scenario analysis, cost analysis was based on the unadjusted registry population (n=3350).

Subgroup analysis was carried out to explore whether patient demographic characteristics and major cardiac risk factors would have an impact on magnitude of the total cost of each procedure. Patients in each group were stratified according to their sex, age, previous MI, previous stroke, diabetes, renal failure, previous CABG, and LVEF (more than 50%, 35% to 49% and less than 35%). Analysis was performed using Review Manager (version 4.2.3, Wintertree Software Inc, England).

RESULTS

Clinical outcomes and resource use

Table 1 presents propensity score-matched in-hospital and one-year clinical outcomes. Mortality rates at hospitalization and at one year after surgery were similar in off-pump and on-pump CABG groups. The in-hospital MI rate was significantly higher in the off-pump group than in the on-pump group (OR=2.09; 95% CI 1.18 to 3.69), but the difference disappeared one year after surgery (OR=1.32; 95% CI 0.85 to 2.06). The in-hospital rate of stroke was lower in the off-pump group than in the on-pump group (OR=0.49; 95% CI 0.23 to 1.06), and this difference became significant one year after surgery (OR=0.49; 95% CI 0.27 to 0.90). The coronary revascularization rate one year after surgery was not significantly different between the two groups.

The resource use pattern for off- and on-pump CABG during initial hospitalization is shown in Table 2. Hospital LOS days and the number of blood transfusion products were significantly fewer in the off-pump group than in the on-pump CABG group. Approximately three-quarters of off-pump CABG surgeries were performed using disposable stabilizers. The resource use pattern at follow-up was similar between the two groups (Table 1).

Total cost comparisons

The average cost for initial hospitalization was significantly lower in the off-pump group than in the on-pump group

(\$11,744 versus \$13,720, $P<0.001$). Table 3 outlines the average costs of major cost components for the two groups. There was no difference in the average cost of CABG procedures between the two groups (\$5,013 versus \$5,147, $P<0.9$); however, a significant cost difference was observed in postoperative LOS (in total LOS and in the ICU and the ward). The average LOS cost was \$6,669 for the off-pump group, versus \$8,031 for the on-pump group ($P<0.001$). There was also a significant difference in average cost in blood transfusion products between the two groups (\$28 versus \$79, $P<0.001$). Because nearly 70% off-pump CABGs were performed by surgeons using nondisposable stabilizers, the average cost of surgical devices was significantly lower in the off-pump group than in the on-pump group (\$266 versus \$790, $P<0.001$).

At follow-up, the average cost was similar between off- and on-pump groups (\$319 versus \$421, $P=0.22$). At one year, the total cost per patient was significantly less in the off-pump group than in the on-pump group (\$12,063 versus \$14,141, $P<0.001$). Therefore, the off-pump CABG cost savings obtained at initial hospitalization were sustained one year after surgery, with a net cost reduction of \$2,078 per patient.

Sensitivity analysis and subgroup analysis

The unit costs of off-pump devices and health expenditure index were selected for univariate sensitivity analysis because variations associated with these variables were potentially more significant than with other variables. In addition, these variations (surgeon preference, centre and regional variations) could not be considered in propensity score matching. When total costs were recalculated based on the weighted average cost of the disposable stabilizer (\$747), the total average cost remained significantly smaller in the off-pump group than in the on-pump group (assuming all off-pump surgeries were performed using disposable devices). To address the regional variations and uncertainty in cost estimation, total costs were recalculated using an index, in which patient costs were adjusted based on their provincial health expenditures indexed to Ontario health expenditures. Univariate analyses of selected variables did not alter the study results, suggesting that the

TABLE 2
Resource use during initial hospitalization based on propensity score-matched registry patient population (n=2466)

	Off-pump (n=1233)	On-pump (n=1233)	P
Type of surgical device, %			
Coronary pulmonary bypass	2.3	100	NA
Disposable stabilizer	69.6	0	NA
Nondisposable stabilizer	30.4	0	NA
Total postoperative LOS, days (mean ± SD)	7.24±8.1	8.73±10.8	<0.001
Intensive care unit LOS	2.13±4.1	2.56±5.3	0.02
Cardiac ward LOS	5.1±5.8	6.2±8.8	<0.001
Total blood products (mean ± SD)	1.18±2.9	3.49±6.4	<0.001
Red blood cells	0.77±1.7	1.99±3.3	<0.001
Fresh frozen plasma	0.24±1.2	1.17±2.9	<0.001
Pooled platelets	0.17±1.2	0.33±1.0	0.001

LOS Length of stay; NA Not applicable

TABLE 3
Cost comparison based on propensity score-matched registry patient population (n=2466)*

	Off-pump (n=1233)	On-pump (n=1233)	P
Initial hospitalization costs, \$	11,744±8,316	13,720±10,553	<0.001
CABG procedure	5,013	5,147	NS
Surgical devices	264±310	790±0	0.001
Intensive care unit	3,422±6,580	4,106±8,564	0.026
Cardiac ward	3,045±3,427	3,677±5,270	<0.001
Total blood products	28±138	79±138	<0.001
Follow-up costs, \$	319±1,885	421±2,268	0.226
One-year total costs, \$	12,063±8,540	14,141±10,762	<0.001

*All costs are average and are expressed in mean ± SD based on nontransformed dataset. CABG Coronary artery bypass grafting; NS Not significant

results are robust. In scenario sensitivity analysis, the total cost comparison was based on the 'real world' practice: unadjusted registry total patient population (n=3350; 1657 for off-pump versus 1693 for on-pump). The study results were not modified (Table 4): the same resource use pattern was observed, and the average in-hospital cost remained significantly less for the off-pump group than for the on-pump group (\$11,948 versus \$13,968, P<0.001). Cost savings were maintained one year after surgery in the off-pump group, with a net savings of \$2,112 per patient.

Figure 1 illustrates the effect of stratified patient groups on total average cost of each CABG procedure. The result of subgroup analysis showed that regardless of patient sex, age and presence of major cardiac risk factors at baseline, the off-pump procedure had a lower cost per patient at one year than the on-pump procedure in all subgroups.

DISCUSSION

The present economic study is based on the Canadian Off-Pump CABG Registry, the largest multicentre comparison of outcomes between the off- and on-pump CABG groups in Canada. The study examined the health care resource use pattern and cost estimates of routine surgical practices within the context of the Canadian health care system. However, the study has certain limitations. First, the cost analysis was based on registry results (a prospective, nonrandomized study); thus, outcome measures and resource use may have been affected by various biases (centre variations, surgeon preference, differential bias, recall

bias, ascertainment bias and reporting bias) despite our efforts in performing extensive sensitivity analyses and conducting cost analysis based on the propensity score-matched registry population. This further underlines the need and importance of a large-scale randomized clinical study (9). Second, the unit cost estimation was based on one cardiac centre's case-costing data. It could be argued whether this approach would be applicable to centres outside of Ontario; however, we believe that the Canadian health care system is relatively homogenous, and this has been confirmed by the univariate sensitivity analysis of the present study. Third, some cost variables, such as postoperative atrial fibrillation and postoperative use of medication, were not included in the total cost calculation. We believe that adding these event costs would not alter our findings, but would further increase the gap in total costs between off- and on-pump CABG procedures.

Our study identified and compared health resource use patterns for two alternative CABG techniques in a real world setting. Although the cost analysis was based on an observational study, our findings were comparable with reports from randomized trials on the economics of off-pump and on-pump CABG from other developed countries. For patients in the United States (US) enrolled in the Surgical Management of Arterial Revascularization Therapies (SMART) Trial, Puskas et al (10) reported that the combined hospital and physician cost was US\$2,277 less for the initial off-pump procedure than for the on-pump procedure. One year after surgery, the total average cost of off-pump CABG was US\$1,955 less than that of on-pump

TABLE 4
Sensitivity analysis: Cost comparisons based on unadjusted registry total patient population (n=3350)*

	Off-pump CABG (n=1657)	On-pump CABG (n=1693)	P
Initial hospitalization costs, \$	11,948±8,397	13,968±10,740	<0.001
CABG procedure	5,013	5,147	NS
Surgical devices	266±310	790	<0.001
Total length of stay	6,669±8,416	8,031±10,740	<0.001
Total blood products	44±536	81±135	0.006
Total follow-up costs, \$	331±1,914	443±2,332	0.216
One-year total costs, \$	12,279±8,608	14,391±10,994	<0.001

*All costs are averages and are expressed in mean ± SD based on nontransformed dataset. CABG Coronary artery bypass grafting; NS Not significant

CABG. Among the European CABG patient population, in the Beating Heart Against Cardioplegic Arrest Studies (BHACAS 1 and 2), Angelini et al (11) and Ascione et al (12,13) reported that off-pump CABG surgery was significantly less costly than on-pump CABG surgery with respect to procedure cost, hospital LOS and blood transfusion products. In a recent randomized trial composed of 281 European CABG patients, Nathoe et al (14) showed that off-pump CABG surgeries were associated with less direct medical cost per patient (US\$1,839) than that of the on-pump CABG surgeries. In another recent meta-analysis comparing randomized trials, Cheng et al (15) reported that only five of 37 trials had reported economic outcomes and all five studies had demonstrated off-pump CABG to be less costly than on-pump CABG. The cost savings by off-pump CABG surgeries were between 15% and 35%. Our study reported a similar relative cost difference (\$2,078) between off- and on-pump CABG techniques. Our study also demonstrated that cost savings were driven by similar resource use reductions suggested by most economic studies: shorter LOS and less blood transfusion product use in the off-pump group than in the on-pump group. However, we recognized that LOS is a discretionary outcome, particularly as surgeons were not blinded to treatment allocation in the registry study. Because propensity score matching cannot address this issue, the LOS outcome needs to be interpreted with caution.

Comparing to other similar cost analyses, it is worth mentioning that our analysis included certain elements that were unique to the Canadian health care system. First, in Canada, blood is free to hospitals: collection, testing and delivery fees are paid by the Canadian Blood Services budget, jointly funded by all the provincial health ministries. It is estimated that the average cost of one unit of a blood product is about \$449 (16,17); however, to be consistent with our study perspective, we did not use this cost. Instead, our unit cost included the salary of the hospital blood bank technologist and the supply costs for in-patient blood testing and preparation. Based on the cost of one blood transfusion product, estimated by the Canadian Blood Services, the total one-year average cost in our analysis would be \$12,592 versus \$15,708 for off-pump and on-pump CABG, respectively ($P < 0.001$). This would further widen the cost gap between the two procedures, from \$2,078 to \$3,118 per patient one year after surgery.

The other notable costing difference is the cost of surgical devices. Many randomized studies comparing off- and on-pump CABG reported using disposable devices during off-pump surgery. Among the registry population, nondisposable stabilizers were used in nearly 70% of all off-pump CABG procedures. Given that the average off-pump device cost (disposable and

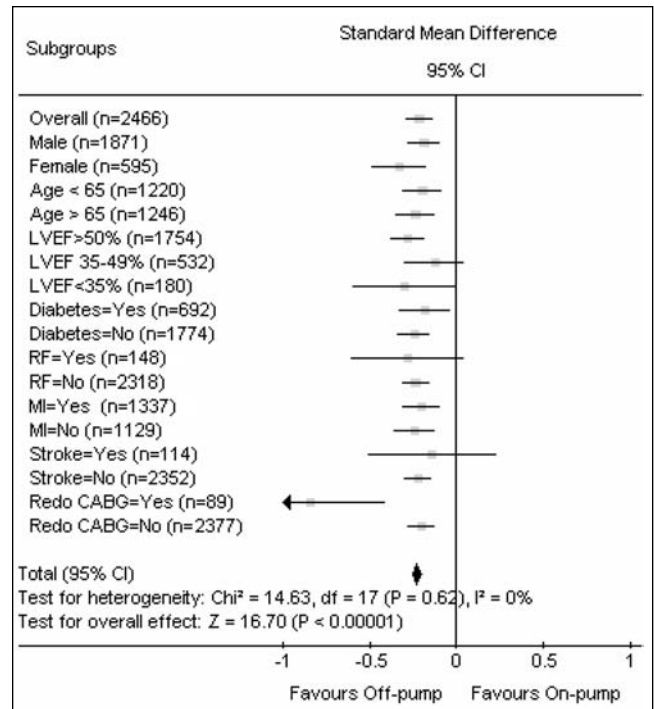


Figure 1 Subgroup cost comparison based on propensity score-matched registry patient population (n=2466). CABG Coronary artery bypass grafting; LVEF Left ventricular ejection fraction; MI Previous myocardial infarction; RF Renal failure

nondisposable) was only \$266 per patient, and the average on-pump device cost was \$790 per patient, the lower device cost was an important driving force in the lower off-pump costs in our study. Although many factors influence stabilizer selection (marketing, surgeon training and preference), the pattern of high percentage use of nondisposable stabilizers in Canadian hospitals reflects the reality of the global funding structure of the Canadian health care system.

We believe that off-pump CABG is cost-saving, and given the total number of isolated CABG surgeries performed in Canada each year, savings to the health care system could be substantial. However, the use of off-pump CABG in Canada was only reported as 16% of total isolated CABG cases in 2002, much lower than in other developed countries (18). In Canada's cost-confined environment, a cost-saving procedure that is not widely adopted by hospitals and physicians warrants further analysis.

CONCLUSIONS

Based on propensity score-matched patients, off-pump CABG procedures can be carried out at a significantly lower cost than on-pump CABG at initial hospitalization. The cost saved is sustained at one year after surgery, at \$2,078 per patient. Cost savings are primarily due to shorter postoperative hospital LOS, less use of blood transfusion products and nondisposable stabilizers during off-pump CABG surgery.

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