The real-world outcomes of off-pump coronary artery bypass surgery in a public health care system

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BACKGROUND: The population-based results of off-pump coronary artery bypass surgery (OPCAB) in a public health care system have not been reported.

OBJECTIVE: The study objective was to compare the one-year outcomes of OPCAB with those of the standard on-pump coronary artery bypass surgery (ONCAB) in the province of Ontario.

METHODS: The present study was a retrospective, population-based study (n=15,172, with 1660 OPCAB patients) undertaken in fiscal years 2000 and 2001 using clinical and administrative data. Multivariate regression modelling for risk adjustment and propensity matching were used to compare OPCAB with ONCAB for one-year outcomes, including death, repeat revascularization and cardiac readmission.

RESULTS: The rate of OPCAB was 11%, with institutional rates ranging from 3% to 51%. OPCAB patients were more likely to be female and older than 79 years of age, with peripheral vascular disease and higher socioeconomic status. OPCAB patients were less likely to have surgically significant coronary disease, poor left ventricular function, an urgent status, congestive heart failure and diabetes. The risk-adjusted one-year composite outcome was higher for OPCAB (11.8%, 95% CI 10.40% to 13.29%) than ONCAB (10.8%, 95% CI 10.23% to 11.27%); however, this difference was eliminated with propensity matching. OPCAB patients had shorter hospital lengths of stay and lower blood product transfusion rates than ONCAB patients.

CONCLUSIONS: Despite the minimal use of OPCAB in Canada's public health care system, outcome rates are similar to those of ONCAB. The benefits of OPCAB observed in randomized trials, including shorter hospital lengths of stay and lower transfusion rates, remained true in the investigators' real-world experience. The results OPCAB were at least equivalent to those of ONCAB.

Key Words: Off-pump coronary artery bypass surgery; Outcomes; Public health care; Utilization

The use of off-pump coronary artery bypass surgery (OPCAB) for surgical candidates deemed to be at high risk has become increasingly popular as a result of evolving evidence showing outcome and cost benefits (1-8). High-risk patients, such as the elderly and women, appear to benefit, with lower rates of mortality and other adverse events with OPCAB, compared with

Les issues dans le monde réel du pontage aortocoronarien à cœur battant dans un système de santé publique

HISTORIQUE : On ne connaît pas les résultats en population générale du pontage aortocoronarien à cœur battant (PACCB) dans un système de santé publique.

OBJECTIF : L'étude visait à comparer les issues du PACCB au bout d'un an à celles du pontage aortocoronarien avec circulation extracorporelle (PACCE) standard dans la province de l'Ontario.

MÉTHODOLOGIE : La présente étude était une étude rétrospective en population générale (n=15 172, dont 1 660 patients avec PACCB) entreprise pendant l'exercice 2000-2001 au moyen de données cliniques et administratives. On a utilisé la modélisation à régression multivariée de correction du risque et d'appariement des tendances pour comparer les issues au bout d'un an du PACCB par rapport au PACCE, y compris le décès, la revascularisation répétée et la réhospitalisation pour des causes cardiaques.

RÉSULTATS : Le taux de PACCB était de 11 %, les taux en établissement variant entre 3 % et 51 %. Les patients ayant subi un PACCB étaient plus susceptibles d'être des femmes, d'avoir plus de 79 ans, de souffrir d'une maladie vasculaire périphérique et d'avoir un statut socioéconomique élevé. Les patients ayant subi un PACCB risquaient moins de souffrir d'une coronaropathie importante d'un point de vue chirurgical, d'une mauvaise fonction ventriculaire gauche, d'un problème devant être traité d'urgence, d'une insuffisance cardiaque congestive et de diabète. L'issue composite corrigée du risque au bout d'un an était plus positive pour les patients ayant subi un PACCB (11,8 %, 95 % IC 10,40 % à 13,29 %) qu'un PACCE (10,8 %, 95 % IC 10,23 % à 11,27 %), mais cette différence disparaissait avec l'appariement des tendances. Les patients ayant subi un PACCB étaient hospitalisés moins longtemps et présentaient un taux de transfusion de produits sanguins plus faible que les patients ayant subi un PACCE.

CONCLUSIONS : Malgré l'utilisation minime du PACCB dans le système de santé publique canadien, les taux d'issues sont similaires à ceux des PACCE. Les bienfaits du PACCB observés dans le cadre d'essais aléatoires, y compris l'hospitalisation moins longue et le taux de transfusion moins élevé, se vérifiaient dans le monde réel. Ainsi, les résultats du PACCB étaient au moins équivalents à ceux du PACCE.

conventional on-pump coronary artery bypass surgery (ONCAB) (9-11). In fact, the female sex has disappeared as a risk factor from studies of OPCAB, which demonstrate reduced mortality, respiratory complications and lengths of hospital stay for women (11,12). It also appears that high-risk patients may have lower rates of adverse outcomes with the use of OPCAB.

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However, there appears to be no benefit with OPCAB in the average-risk patient, as shown by a meta-analysis of the composite outcome of death, stroke and myocardial infarction (OPCAB OR 0.48, 95% CI 0.21 to 1.09) (13). This meta-analysis allowed for the comparison of 558 control and 532 OPCAB patients, with an average graft number of at least two (13). More recent trials (14-16) have reported inconsistent results. One study (15) found that graft patency three months after surgery was higher for ONCAB, despite no difference in clinical end points with OPCAB. A larger trial (14) showed that OPCAB had similar graft patency, clinical outcomes and health-related quality of life one year after surgery, with a net benefit in cost savings of US\$1,266. Similar findings showing no difference in clinical outcomes but a cost savings with OPCAB were reported in another trial (16).

Large, observational cohort studies in the United States have reported conflicting results regarding the benefits of OPCAB. One retrospective study (17) conducted from 1998 to 1999 reported lower rates of short-term mortality (2.9% ONCAB versus 2.3% OPCAB) and morbidity (14% ONCAB versus 11% OPCAB) for OPCAB, using data from 126 experienced centres with 11,717 OPCAB patients that comprised 10% of total coronary artery bypass graft surgery (CABG) patients. A more recent study (18) conducted from 1999 to 2000 using the same database found a survival benefit with OPCAB (OR 0.83), especially in high-risk subgroups. In New York state, a cohort study (19) of OPCAB in 1997 to 2000 found no difference in hospital mortality compared with ONCAB. In addition, this study found that after three years of follow-up, OPCAB patients had a survival disadvantage (hazard ratio 1.086) (19). This analysis, when limited to a more recent subgroup (1999 to 2000), showed no difference in the two-year mortality rates of ONCAB and OPCAB (19). The conflicting results in this study suggests a learning curve with OPCAB in the earlier era of the study, but also make it difficult to draw conclusions regarding the superiority of one technique over the other.

It is evident that there is clinical equipoise regarding the superiority of OPCAB to ONCAB, and the evidence continues to evolve. The goal of the present study was to compare the one-year outcomes of OPCAB with those of the standard ONCAB in the province of Ontario. It is currently unknown whether the real-world results of OPCAB are comparable with those of ONCAB in our region, and whether benefits, such as shorter hospital lengths of stay and lower transfusion rates that have been observed in randomized trials, are present in our cohort. Because our region is publicly funded, there is less market pressure for surgeons to perform OPCAB compared with privately funded health care systems (17).

METHODS

Study population

One thousand six hundred sixty patients were identified retrospectively as having undergone OPCAB during fiscal years 2000 and 2001 in Ontario at one of the nine hospitals performing cardiac surgery. Ninety-seven per cent (n=1660) of these patients could be linked by unique identifiers to the Cardiac Care Network of Ontario database of isolated CABG. The patients were further linked to three administrative databases, including the Canadian Institute for Health Information database, the Registered Persons Database and the Ontario Health Insurance Plan (OHIP) database. The Canadian Institute for Health

Information database was used to determine outcome data, such as hospital lengths of stay, in-hospital mortality, repeat revascularization (angioplasty, CABG) and readmission to hospital (eg, for acute myocardial infarction, unstable angina, congestive heart failure or stroke). The Registered Persons Database was used to determine in- and out-of-hospital deaths of patients residing in Ontario. The OHIP database was used to determine claims submitted by cardiac surgeons for reimbursement for provided services (this excluded one hospital, which was funded by an alternate plan). The OHIP database was used to determine the number of grafts, the use of arterial grafts and whether the patient required postoperative repeat revascularization. Socioeconomic status was determined from linkage of the postal code of each patient (enumeration area) to the 1996 Canadian census database, through which each patient's income quintile was designated based on their primary residence.

Statistical analysis

Two sample *t* tests for continuous variables and χ^2 tests were used for categorical values. The primary outcomes of interest were the one-year rates of mortality, cardiac readmission and repeat revascularization. Outcome risk adjustment was completed to make valid comparisons between OPCAB and ONCAB using logistic regression for binomial outcomes and Poisson regression for count variables. The variables included in risk adjustment models and the propensity score included age, sex, coronary anatomy, Canadian Cardiovascular Society angina class, left ventricular function, Charlson comorbidity score, triage status, previous CABG, congestive heart failure, peripheral vascular disease, diabetes, chronic obstructive pulmonary disease, preoperative creatinine level, dialysis, institution and socioeconomic status. The Charlson comorbidity score is an index predictive of a patient's mortality, and is calculated by identifying and applying weighted scores according to coexisting illnesses noted in hospital discharge data from medical records (20). Lack-of-fit statistics were optimized for all logistic models constructed, including the C statistic (area under the receiver-operator curve) and Hosmer-Lemeshow statistic, for adequate discrimination and calibration of the models.

A greedy propensity matching strategy was also used to compare outcomes of OPCAB patients with ONCAB patients matched for clinical characteristics. Of 1660 OPCAB patients, 1585 were matched by propensity score to ONCAB patients (95% efficiency). McNemar's test was used to ensure that propensity score variables were no different between matched OPCAB and ONCAB patients. Dialysis was the only variable that did not match equally (1.7% OPCAB versus 0.8% ONCAB, *P*=0.02). Cox proportional hazards models were used to compare death, readmission and repeat revascularization between propensity-matched groups. For hazards analysis, follow-up was available for up to 1.5 years for all patients after surgery. The statistical analyses were completed using SAS software (version 8.2, SAS Institute Inc, USA).

RESULTS

A total of 15,172 patients underwent isolated CABG in Ontario during fiscal years 2000 and 2001. Eleven per cent of patients (n=1660) underwent OPCAB, and 89% (n=13,512) underwent ONCAB.

Patients who underwent OPCAB were more likely to have the following clinical characteristics: female sex, age of 80 years or older, creatinine levels higher than 180 $\mu\text{mol/L}$,

TABLE 1
Demographic characteristics of off-pump coronary artery bypass surgery (OPCAB) versus on-pump coronary artery bypass surgery (ONCAB) patients in Ontario in fiscal years 2000 and 2001

Characteristic	OPCAB, % (n=1660)	ONCAB, % (n=13,512)	P
Female sex	27	21	<0.0001
Age			0.02
<60 years	32	33	
60–69 years	34	35	
70–79 years	29	29	
≥80 years	5	3	
Comorbidity score			NS
Charlson score 1	40	39	
Charlson score ≥2	23	24	
Creatinine level			0.01
121 µmol/L – 180 µmol/L	9	9	
>180 µmol/L	3	2	
Previous coronary artery bypass graft	2	3	0.001
Diabetes	29	33	0.004
Dialysis	1	1	NS
Congestive heart failure	10	12	NS
Peripheral vascular disease	15	13	0.003
Cerebrovascular disease	12	10	0.008
Chronic obstructive pulmonary disease	11	11	NS
Left main coronary artery disease	15	24	<0.0001
1- or 2-vessel CAD + PLAD, 3-vessel CAD	46	52	0.006
CCS class			0.001
CCS angina class I-II	20	21	
CCS angina class III	34	34	
CCS angina class IV	46	45	
LV grade			<0.0001
Grade 1 LV	53	48	
Grade 2 LV	32	34	
Grade 3 LV	13	15	
Grade 4 LV	2	3	
Triage status			<0.0001
Elective	47	36	
Urgent	47	55	
Emergent	6	9	
Income quintile*			0.03
1	15	18	
2	19	19	
3	21	20	
4	22	20	
5	23	23	

*Income quintile 1 is the lowest quintile of income, as determined by enumeration area. CAD Coronary artery disease; CCS Canadian Cardiovascular Society; LV Left ventricle; NS Not significant; PLAD Proximal left anterior descending coronary artery

peripheral vascular disease, cerebrovascular disease and higher socioeconomic status (Table 1). Patients who underwent OPCAB were less likely to have previous CABG, diabetes, congestive heart failure, surgically significant coronary disease (including left main, triple-vessel and double-vessel coronary artery disease, including the proximal left anterior descending artery), poor ventricular function and urgent or emergent triage status (Table 1).

Figure 1 The proportion of off-pump coronary artery bypass surgery (OPCAB) compared with conventional on-pump coronary artery bypass surgery (ONCAB) completed by institution in Ontario during fiscal years 2000 and 2001

TABLE 2
Operative characteristics of off-pump coronary artery bypass surgery (OPCAB) and on-pump coronary artery bypass surgery (ONCAB) patients in Ontario for fiscal years 2000 and 2001*

Outcome	OPCAB, %	ONCAB, %	P
No arterial bypass used	50	20	
1 arterial bypass	34	42	
2 arterial bypasses	14	30	
>3 arterial bypasses	2	8	<0.0001
Extra bypass†	48	78	<0.0001

*Excludes those patients from one hospital funded under an alternate funding plan, for which no billing information was available; †Represents a billing code that records when a patient receives more than two bypasses

The institutional rates of OPCAB ranged from 3% to 51% of cases and did not correlate with the total case volumes completed at an institution during fiscal years 2000 and 2001 (Figure 1). OPCAB patients were less likely to receive arterial grafts and extra grafts at the time of surgery (Table 2). In fact, 50% of OPCAB patients did not even receive one arterial graft, compared with 20% of ONCAB patients ($P<0.0001$, Table 2).

The risk-adjusted hospital length of stay was approximately two days shorter for OPCAB patients than ONCAB patients (Table 3). The one-year risk-adjusted mortality rate was lower for OPCAB patients than ONCAB patients, although the 95% CI between the groups overlapped (Table 3). In contrast, the risk-adjusted one-year repeat revascularization rate was slightly higher for OPCAB patients, again with the 95% CI overlapping between groups. The risk-adjusted cardiac readmission rate was significantly higher for OPCAB, at 11.2%, and the 95% CI overlapped, with the readmission rate of 10.3% for ONCAB (Table 3). This translated into an overall higher composite outcome rate for OPCAB, at 11.8% compared with 10.8% for ONCAB (Table 3). The rates of allogeneic blood transfusion remained lower for OPCAB patients, at 39%, compared with 55% for ONCAB patients with propensity matching (Table 3).

TABLE 3

Risk-adjusted outcome rates for off-pump coronary artery bypass surgery (OPCAB) and on-pump coronary artery bypass surgery (ONCAB) patients in Ontario for fiscal years 2000 and 2001

Statistical method	Outcome	OPCAB	ONCAB	ROC
Risk adjustment				
	Hospital length of stay, days (95% CI)	6.2 (6.11–6.30)	7.9 (7.84–7.91)	Poisson
	365-day death, % (95% CI)	3.4 (2.46–4.32)	3.8 (3.53–4.15)	0.79
	365-day revascularization, % (95% CI)*	3.4 (2.58–4.23)	3.1 (2.78–3.38)	0.67
	365-day cardiac readmission, % (95% CI)†	11.2 (9.75–12.57)	10.3 (9.76–10.77)	0.68
	365-day composite outcome, % (95% CI)	11.8 (10.40–13.29)	10.8 (10.23–11.27)	0.67
Propensity analysis				P
	Hospital length of stay, days	6.6	7.2	0.0010
	365-day death, %	3.0	3.6	0.33
	365-day revascularization, %*	4.4	3.7	0.29
	365-day cardiac readmission, %†	10.4	9.7	0.58
	365-day composite outcome, %	11.0	9.8	0.29
	Any blood products, %	39.0	55.0	<0.0001
	Plasma, %	14.0	18.0	0.0004
	Platelets, %	6.0	10.0	<0.0001
	Packed red blood cells, %	31.0	45.0	<0.0001

*Excludes those patients from one hospital funded under an alternate funding plan, from which no billing information was available. †Includes patients discharged alive to be readmitted for primary diagnosis codes of unstable angina, congestive heart failure and myocardial infarction. ROC Receiver-operating characteristic of the multivariate logistic regression model used to risk-adjust outcome

TABLE 4

Hazards analysis of propensity-matched off-pump coronary artery bypass surgery patients in Ontario in fiscal years 2000 and 2001

Outcome	Hazard ratio	95% CI	P
Death	0.9	0.62–1.16	NS
Readmission for myocardial infarction	1.0	0.74–1.32	NS
Revascularization (angioplasty)*	1.1	0.81–1.48	NS
Revascularization (surgical)*	0.8	0.61–1.12	NS
Readmission for unstable angina	1.1	0.91–1.39	NS
Readmission for congestive heart failure	0.9	0.65–1.12	NS

*Excludes those patients from one hospital funded under an alternate funding plan, from which billing information was available. NS Not significant

After matching patients by propensity scores, there were no differences in outcomes, including death, cardiac readmission and repeat revascularization, between groups (Table 4). The 95% CI of OPCAB hazard ratios for all outcomes crossed one (Table 4).

DISCUSSION

Our cohort of OPCAB patients had similar rates of one-year mortality, revascularization and readmission to those of ONCAB patients. The present study presents real-world results of OPCAB from patient selection to perioperative results. The benefits of OPCAB observed in our population included lower rates of allogeneic blood transfusion and shorter lengths of hospital stay. These clinical benefits may improve the cost-effectiveness of bypass surgery, especially in a public health care system, in which efficiency is the key to safe rationing of care. Studies have repeatedly shown economic benefits associated with OPCAB (19,21,22).

The surgeons in our region were under no market pressure to perform OPCAB. In Ontario, limited capacity for cardiac surgical services blunts market forces. Only 11% of patients received OPCAB in our region. In the same time period, 27% of bypass surgery in New York state was completed as OPCAB (19). Patients who underwent OPCAB in Ontario were similar to OPCAB patients selected in New York state and the Society for Thoracic Surgery (STS) database, and were more likely to include those of female sex, aged 80 years or older, or with preoperative cerebrovascular disease and/or preoperative renal insufficiency (17-19). This suggests that there is a realization that high-risk patients, such as the elderly, appear to benefit with OPCAB compared with conventional ONCAB (9) having lower rates of mortality, neurological adverse events and renal adverse events. A population-based study in the United States found that there was a survival benefit with OPCAB (OR 0.83), especially in high-risk subgroups, including women, those with previous CABG, diabetes, and left ventricular dysfunction (30% to 50%), as well as those aged 66 to 75 years (18). Thus, high-risk patients may have lower rates of adverse outcomes with OPCAB.

Propensity hazards analysis of mortality showed no difference in mortality between OPCAB and ONCAB in our cohort. However, the risk-adjusted mortality rate at one year was lower for OPCAB than for ONCAB. In contrast to our findings, the majority of studies have reported no difference in early in-hospital mortality for OPCAB (19,21,22). The largest cohort study involving the STS database found that operative mortality rates were lower for OPCAB than ONCAB (17). In New York state, it was observed that the three-year mortality rates were higher for OPCAB patients (19). This difference was no longer present when a more current subgroup of patients was analyzed (19). These previous studies are consistent with our findings, in that at one year, the risk-adjusted mortality rates for OPCAB in our region were slightly lower, but similar to, ONCAB.

There have been little data regarding the cardiac readmission rates following OPCAB. A small randomized trial (14) of 200 patients reported slightly higher one-year cardiac readmission rates with OPCAB, at 12%, compared with 10% with ONCAB. Our study also showed a significant trend toward a higher cardiac readmission rate for congestive heart failure, unstable angina and myocardial infarction one year after OPCAB. This may, in part, be related to the fact that our OPCAB patients were less likely to have received more than two bypasses and/or at least one arterial bypass. It may be no coincidence that in the STS report (17), OPCAB patients received a higher proportion of arterial grafts, which may have influenced the lower rates of early OPCAB mortality that were observed. The high rates of cardiac readmission may also have been a result of higher rates of incomplete revascularization with OPCAB, which we were not able to measure due to limited clinical data. Past observational research has suggested that there is a higher rate of incomplete revascularization with OPCAB (21).

In the present study, we observed slightly higher rates of risk-adjusted repeat revascularization for OPCAB compared with ONCAB. After propensity analysis, this difference was not significant. In New York state, it was also found that OPCAB patients had higher three-year rates of revascularization than ONCAB patients (19). Further to this, there have been conflicting randomized trial results regarding graft patency. One small study (15) that included inexperienced OPCAB surgeons showed that graft patency at three months was significantly worse for OPCAB patients than ONCAB patients (15). In contrast, two trials (16,14) have not found any significant difference between OPCAB graft patency one year after surgery. One may argue that this result of no difference in OPCAB graft patency is not reproducible in a general population of surgeons with varying skill. The higher rate of repeat revascularization observed in our study with OPCAB may also represent the previously mentioned issue of completeness of revascularization, which we could not measure. We also observed that OPCAB patients were less likely to receive the accepted best practice of at least one arterial graft compared with ONCAB patients. We know that there is generally an underuse of at least one arterial graft in Ontario for all CABG procedures, and this may have partially influenced the observed repeat revascularization rates (23).

In summary, the ultimate objective of bypass surgery is to provide patients with the best technical calibre of coronary anastomosis, which, in turn, should lead to optimal short- and long-term results. Cardiopulmonary bypass has allowed us to achieve this goal for many years in exchange for the recognized side effects of the bypass circuit, which incrementally negatively impact high-risk patients, such as those with existing preoperative comorbidities (eg, cerebrovascular disease, renal disease). The trade-off with OPCAB is that the anastomotic quality may be sacrificed because it varies more with surgical skill, and this may lead to higher mid- and long-term adverse outcome rates. Our study attempted to understand whether the anastomotic quality of OPCAB in our region, as measured by one-year cardiac outcomes, was different than ONCAB. However, the one major limitation of this study was the fact that selection biases in the patients chosen for OPCAB made it very difficult to accurately compare outcomes with those undergoing the standard ONCAB procedure. Although very powerful statistical methods were used to

minimize bias, such techniques can only control for measured confounders and cannot adjust for unmeasured variables.

It is apparent that despite the benefits observed with OPCAB, there has not been widespread use of this procedure. Only one-quarter to, at most, one-third of bypass procedures are completed off-pump in the United States, and in our region, this is an even lower proportion (19). The current scientific statement from the working group of the American Heart Association on this topic acknowledges that consistent findings favouring patient outcomes with OPCAB include reduced bleeding, less renal dysfunction, decreased short-term neurocognitive dysfunction and shorter length of hospital stay (24).

CONCLUSION

The current evidence is equivocal regarding the benefits of OPCAB in the average-risk patient (13). We observed that OPCAB had a slightly lower associated one-year risk-adjusted mortality rate than ONCAB (95% CI overlapped between groups). Despite this, slightly higher rates of risk-adjusted cardiac events were observed with OPCAB, including repeat revascularization, cardiac readmission and a composite of all outcomes (95% CI overlapped between groups). Propensity analysis confirmed that there was no difference in adverse outcome rates between OPCAB and ONCAB groups when matched rigorously for other patient characteristics. In our real-world experience, the only benefits observed with OPCAB were shorter hospital lengths of stay and lower blood product transfusion rates, which is surprisingly consistent with ideal data available from randomized trials average-risk patients.

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