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Cost-Effectiveness of Minimally Invasive Coronary Artery Bypass Surgery

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Abstract

Background: Coronary artery bypass grafting without cardiopulmonary bypass (CPB) is gaining popularity as an alternative to conventional on-pump technique for myocardial revascularization. This includes minimally invasive direct coronary artery bypass (MIDCAB) and full sternotomy off pump (OPCAB) methods. These two approaches should be evaluated for financial and clinical appropriateness.

Materials and Methods: Records of patients who had single or double bypass (IMA and/or saphenous vein) grafts between January 1997 and June 1998 were reviewed. These included 44 MIDCAB, 92 OPCAB and 243 conventional coronary artery bypass (CCAB) patients. The pre-operative, intra and post-operative variables and clinical outcomes among these 3 groups were analyzed. With univariate analysis, the MIDCAB and OPCAB patients were compared to the CCAB group. The cost to perform each of these procedures was obtained from the participating institutions.

Results: MIDCAB patients compared to CCAB patients had a higher predicted risk (5.4 ± 11 vs 2.3 ± 2.8 , $p=0.012$), an increased incidence of reoperative status and preoperative COPD. OPCAB patients had a higher predicted risk (5.3 ± 7.8), with greater incidence of co-morbidities of renal failure and prior CVA. MIDCAB and OPCAB procedures required less OR time and utilized less blood products. The observed operative mortality rates were MIDCAB 4.5%, OPCAB 1.6% and CCAB 2.8% (NS). Mean hospital costs for each procedure were \$21,000 CCAB, \$19,000 for OPCAB and \$17,000 for MIDCAB.

Conclusion: Both MIDCAB and OPCAB procedures can be performed in selected patient populations without any statistical increase in major morbidity or mortality rates. Off pump procedures are safe and currently reflect acute episode of care cost savings over CCAB. Longitudinal comparison of these off-pump to on-pump procedures should be a priority.

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New surgical approaches for the treatment of coronary artery disease must be evaluated for financial and clinical appropriateness. Conventional coronary artery bypass (CCAB) surgery utilizing a full sternotomy and cardiopulmonary bypass is considered to be the "gold standard" for myocardial revascularization. Minimally invasive direct coronary bypass surgery (MIDCAB) via a limited incision and without CPB evolved as a method that offers the advantages of surgical revascularization in combination with reduced morbidity. The MIDCAB procedure involves arterial grafting of the left internal mammary artery to the left anterior descending coronary artery and its branches via an anterior thoracotomy incision without arresting the heart, thereby avoiding both a sternotomy and cardiopulmonary bypass.¹ The OPCAB via a full sternotomy technique is particularly useful in high-risk patients such as those with renal failure, respiratory problems, advanced age, cerebral vascular accidents and is most susceptible to the affects of CPB. Although the method was described many years ago,² it was abandoned with the advent of cardiopulmonary bypass and cardioplegic arrest. Recently, there has been a resurgence of the OPCAB procedure utilizing the full sternotomy and commercially available stabilizers,³ This communication is to review our own experience with these three techniques (CCAB, MIDCAB, OPCAB) with particular attention to the safety, efficacy and cost of each procedure.

MATERIALS AND METHODS

A Retrospective consecutive review of patients whom had one or two coronary bypass grafts at our institution between January 1997 through June 1998 was carried out, and divided into three groups:

- MIDCAB - coronary artery bypass grafting performed without CPB with a limited incision.
- OPCAB - coronary artery bypass grafting performed without CPB with a full sternotomy incision.
- CCAB - coronary artery bypass grafting performed with CPB and a full sternotomy incision.

All demographics, pre, intra and post-operative variables were collected according to the Society of Thoracic Surgeons National Cardiac Surgery Database (STS.NCSD). With univariate analysis, the MIDCAB and OPCAB patients were compared to the CCAB group. Total hospital costs (direct, indirect,

fixed and variable costs) were obtained for comparison. Costs per patient were reported by day and by hospital department. This provided the opportunity to identify pre-op, intra-op, and post-operative costs associated with each group.

Minimally invasive direct coronary artery bypass surgery was performed through an anterior thoracotomy at the 4th or 5th intercostal space. The internal mammary artery harvest was difficult at times due to the limited exposure and access. Location of targeted vessels dictated access via a left or right thoracotomy approach. Bradycardia was achieved with pharmacological assistance of intravenous Beta blocking agents and anastomosis was completed during a slowed beating heart.

Off-pump coronary artery bypass surgery was carried out through a full sternotomy with takedown of the left internal mammary artery performed in the standard fashion. Deep pericardial traction stitches were placed near the left upper and lower pulmonary veins and to the left inferior cava thereby achieving elevation of the apex of the heart. To further assist in providing good presentation of targeted vessels on the lateral or inferior aspect of the heart; patients are placed in a gentle right decubitus Trendelenburg position.^{3,5} Stabilization of the heart was accomplished using one of several commercially available stabilizing systems.

Conventional coronary artery bypass surgery was performed through a full sternotomy incision with internal mammary artery takedown in the usual fashion. Institution of CPB was achieved by cannulating the ascending aorta and right atrium. Retrograde cardioplegia of either blood or crystalloid solution was delivered for myocardial protection of the arrested heart. All Cardiopulmonary bypasses were accomplished with a membrane oxygenator and centrifugal pump.

All patients followed standard care and processes from surgery until discharge. This includes admission to the Intensive Care Unit from the surgery suite with subsequent transfer to an intermediate care ward within 24 hours or as dictated by their clinical status according to standard practice guidelines. A hospital designed extubation protocol was followed; which targets extubation within 4 hours after surgery.

The pre, intra and post-operative variables used for univariate analysis between groups are listed in

Tables 1-3 with the CCAB patient population serving as a control group. The logistic regression risk model developed by the STS. NCSB was used to calculate the pre-operative predicted risk of each group.

Statistical Analysis

Preoperative, operative and post-operative variables were analyzed using Student t-test, χ^2 . Univariate analysis was used to compare MIDCAB and OPCAB to CCAB. A p-value of less than 0.05 is considered to be statistically significant. The logistic Regression Risk Model developed by the STS NCSB was used to obtain the pre-operative predicted risk in each group.

RESULTS

There were 44 MIDCAB, 92 OPCAB and 243 CCAB. The analysis confirmed statistical differences between the MIDCAB and OPCAB populations when compared to the CCAB population. The MIDCAB and OPCAB patients had a higher predicted risk than the CCAB group (5.4 ± 11 , 5.3 ± 7.8 vs 2.3 ± 2.8 , $p=0.012$) respectively. Mean age of these three groups showed MIDCAB 63 ± 15 , OPCAB 69 ± 13 and CCAB 64 ± 11 ($p=0.01$ for OPCAB vs CCAB) years. Additionally, pre-operative factors associated with increased operative

risk and morbidity were reported more frequently in the MIDCAB and OPCAB; there were more reoperative status in MIDCAB (30% vs CCAB 13%, $p=0.001$), more renal insufficiency in OPCAB (18% vs CCAB 4.5%, $p=0.001$), more Congestive Heart Failure in MIDCAB (14%) and OPCAB (23%) and only 3 per cent in CCAB for $p=0.007/<0.001$, more Chronic Obstructive Pulmonary Disease in MIDCAB (14%) and OPCAB (14%) when compared to only 5 per cent in CCAB ($p=0.005$) (Table 1).

Admission to surgery length of stay for the OPCAB vs CCAB was (3.6 ± 4.8 vs 2.3 ± 2.9 $p=0.006$) reflects a negative significance when viewed as a resource consumption variable. For our practice; initial application of the OPCAB approach targeted those patients that presented an increased risk of morbid events secondary to CPB. Possibly this 1-2 day difference may reflect time required for stabilization and system assessment of a more critically ill population prior to surgical intervention.

Surgery to discharge length of stay of the MIDCAB vs CCAB was (5.7 ± 3.5 days and 7 ± 6 days) with $p=0.06$. When comparing the OPCAB of 7 ± 3 days to the CCAB 7 ± 6 days these was no significance. Suggested efficiencies and effectiveness of Off-pump surgery either with a limited or full incisional approach could be

Table 1 Pre-operative demographics.

Variable	MIDCAB (n = 44)	OPCAB (n = 62)	CCAB (n = 243)	P value
Mean Age (yrs)	63 ± 15	$69 \pm 13^*$	$64 \pm 11^*$	0.01
Female (%)	50	58	54	NS
% Pred Risk	5.4 ± 11	$5.3 \pm 7.8^*$	$2.3 \pm 2.8^*$	0.012
Redo (%)	30*	7	13*	0.001
Elective (%)	86	92	84	NS
Renal Failure (%)	6.8	18*	4.5*	0.001
COPD (%)	13.6*	14*	4.9*	0.04/0.019
CHF (%)	14*	23*	3*	0.007/<0.001
Prior CVA (%)	4.5	11*	4*	0.005
Prior MI (%)	47	45	45	NS
Diabetic (%)	25	30	22	NS

COPD = chronic obstructive pulmonary disease, CHF = congestive heart failure, CVA = cerebrovascular accident, MI = myocardial infarction

*Significant p-value

attributed to elimination or minimization of side effects of CPB. Effects of cardiopulmonary bypass are reflected in intra and post-operative blood loss, blood product utilization and total surgical time analyses. MIDCAB and OPCAB vs CCAB operative blood loss was 292 ± 241 ml, 401 ± 270 ml vs 517 ± 295 ml, $p < 0.001/0.003$ respectively. Blood product utilization was significant with respect to platelet administration (Table 2).

Success of aggressive extubation protocols for all surgical patients is reflected in the non-significant variation among groups as indicated by the low mode times of 0 Hrs for MIDCAB, 3 Hrs for OPCAB and 5 Hrs for CCAB. Despite patient presentation and variation in predicted risk, targeted extubation within 4 hours of procedure demonstrates that multi-disciplinary collaborative approaches benefit the patient as well as being essential in the provision of quality care and results. Incidence of reoperation for post-operative bleeding was 6.8 per cent MIDCAB vs 1.6 per cent in OPCAB and 1.2 per cent in CCAB ($p < 0.01$). Other post-operative complications are listed in (Table 3). Of interest, the occurrence of new atrial fibrillation

was non-significant across groups.

Patient cost information was provided by the two institutions where the populations were derived. These two institutions operate under the same health system and utilize identical cost accounting software. The clinical and financial management system used is Health Management Systems (EI Segundo, CA). Individual patient costs were reported by day and by department. Within each department direct and indirect costs were combined. The variable figures include the labor and supplies necessary to care for the patient. Fixed direct costs account for administration and equipment costs associated with care and do not vary significantly over a large volume of patients. Indirect costs are associated with care and other services not directly related to patient care but act as an ancillary or support the services provided. It is the indirect costs that can vary significantly from institution to institution.

Costs obtained from the two institutions are shown in (Tables 4 A and B). Request was made for breakdown of individual patient's total hospitalization account by department or service and by day. Univariate analysis of the cost data indicates that savings are

Table 2 Peri-operative demographics.

Variable	MIDCAB (n = 44)	OPCAB (n = 62)	CCAB (n = 243)	P value
Skin - Skin (min)	141 \pm 49*	145 \pm 37*	215 \pm 68*	< 0.001
EBL (ml)	291 \pm 241*	401 \pm 270*	517 \pm 295*	< 0.001/0.003
Blood Products: first 24 hrs (units/pt)				
Cryo	0	0.32	0.06	
FFp	0	0.22	0.39	
Plt	0.18*	0.51*	1.58*	0.01/0.001
RBC	0.43	0.66	1.04	
CT loss (8 hrs)	307 \pm 289*	395 \pm 290*	458 \pm 367*	0.01
Ventilator (Hrs)				
Mean	11	9	14	NS
Mode	0	3	5	
ICU (Hrs)				
Mean	31	42*	39*	0.001
Mode	0	19	24	
Admit/Surg (days)	2.5 \pm 2.8	3.6 \pm 4.8*	2.3 \pm 2.9*	0.006
Surg - D/C (days)	5.7 \pm 3.5	7 \pm 3	7 \pm 6	0.06

*Significant p-value

Table 3 Post-operative demographics.

Variable	MIDCAB (n = 44)	OPCAB (n = 62)	CCAB (n = 243)	P value
Reop Bleed (%)	6.8*	1.6	1.2*	0.01
Perm Stroke (%)	0	3.2	2.4	NS
Perioperative MI (%)	0	0	1.6	NS
New Atrial Fibrillation (%)	18	13	16	NS
Operative Mortality (%)	4.5	1.6	2.8	NS

*Significant p-value

Table 4 Cost in US dollars.

Variable	MIDCAB (n = 44)	OPCAB (n = 62)	CCAB (n = 243)	P value
A <i>Cost in US dollars - Actual</i>				
Cost:**				
Pre-op	8055 ± 9418	6305 ± 6240	4505 ± 4633	
Surgery	6273 ± 3527*	5597 ± 2154*	9509 ± 2299*	< 0.001
Day of Surgery	3987 ± 2454	2928 ± 879	3212 ± 1549	NS
POD 1 to D/C	7177 ± 9464	6988 ± 5777	6829 ± 6058	NS
Surgery to D/C	17438 ± 12285	15514 ± 6600*	19551 ± 7421*	0.005
B <i>Cost in US dollars - Rounded</i>				
Cost: **				
Pre-op	8000 ± 9K	6300 ± 6K	4500 ± 5K	
Surgery	6200 ± 4K	5500 ± 2K*	9500 ± 2K*	<0.001
Day of Surgery	3900 ± 2K	2900 ± 8K	3200 ± 2K	NS
POD 1 to D/C	7100 ± 9K	6900 ± 6K	6800 ± 6K	NS
Surgery to D/C	17000 ± 12K	15000 ± 7K*	19000 ± 7K*	0.005

*Significant p-value

**Cost includes indirect and direct

primarily achieved in the operating room phase of the acute care episode. Comparing even total costs from one region to another or one software to another can lead to confusion because of the categorization or definitions assigned to each of the cost centers.

DISCUSSION

Advantages and disadvantages of the three approaches have been concisely summarized and are presented in Table 5. Comparison of the clinical

outcomes of the two off-pump procedures to the long accepted on-pump procedure are gradually becoming available. In the hands of skilled surgeons, it has been demonstrated that both off-pump procedures can be performed without increased intra or post-operative complications. Evaluation of the presented data can lead one to support the benefits of MIDCAB or OPCAB particularly in the high-risk patient population. Minimally invasive surgery, however defined, must withstand the rigors of clinical and financial evaluation.

Table 5 Options for coronary artery bypass grafting.

Approach	Advantage	Disadvantage
CCABG	<ul style="list-style-type: none"> - Excellent proven results - Technical able to be mastered - Applicable for multivessel disease 	<ul style="list-style-type: none"> - Morbidity of a sternotomy - Morbidity of CPB - Morbidity of aortic manipulation
OPCAB	<ul style="list-style-type: none"> - Full sternotomy - Unlimited access - Some multivessel disease possible - No CPB 	<ul style="list-style-type: none"> - Morbidity of sternotomy - Difficult to revascularize posterior lateral aspect of the heart - Difficult anastomotic technique on a beating heart
MIDCAB	<ul style="list-style-type: none"> - No sternotomy - No CPB - Short operating time - Short length of stay - Lower costs 	<ul style="list-style-type: none"> - Limited access - Limited exposure - Less accurate anastomotic technique with beating heart - No long-term follow-up - IMA steal concerns

Modification from Michael Maek, M.D. CSANT, Specialty Associates of North Texas, P.A.

Technological advancement have laid the foundation for performing, evaluating and improving the technical aspects of minimally invasive surgery.

Since this study was a retrospective non-randomized review of a dynamic technology, controls for patient selection, evolving techniques and improved instrumentation were not applied. Physician and institutional practice patterns remained fairly constant over the course of this evaluation period. Therefore, study biases can be focused on patient selection. The application of MIDCAB and OPCAB intervention is specifically determined by the attending physicians or patient depending upon clinical appropriateness. Early experience was gained in the higher risk patient population when the greatest potential clinical benefit could be achieved. As surgical skill and technological expertise is gained and scientific evaluations of early clinical results are reported, application of the off-pump procedure moves into the lower risk groups.

Evaluation of the safety of such techniques can be assessed through retrospective data review. Obviously, longitudinal follow-up to document procedural efficacy and equivalent patency rates, compared to the conventional on-pump full sternotomy population, is mandatory.

Few publications are available that have reported true procedural cost of minimally invasive coronary artery bypass procedures. Magovern et al,⁶ in 1998 reported the cost and six-month outcomes of MIDCAB surgery compared to the conventional CABG. This study was carried out between January 1995 and December 1996, it did not include the indirect costs. The results were, for CCAB total cost \$15,600 ± \$4,200 and for MIDCAB costs were \$11,200 ± \$3,100. When high-risk patients were analyzed, total costs revealed CCAB to be \$26,800 ± \$10,100 vs MIDCAB costs of \$16,120 ± \$7,200. Earlier, Zenati et al,⁷ reported the comparison between MIDCAB and CCAB performed at the University of Pittsburgh Medical Center. There were 17 patients in the MIDCAB group and 33 in the CCAB group. The cost again for the MIDCAB group was less (\$12,885 ± \$1,511 vs \$21,260 ± \$5,479). In a more recent study by Del Rizzo et al,⁸ safety and cost-effectiveness of high risk MIDCAB surgery was done. Using their Canadian cost model and risk stratification to predict cost for coronary artery bypass surgery in this particular subset, they estimated the cost for MIDCAB was about 6,000 (CD) to 12,000 (CD) for CCAB.

In this study, mean intra-operative costs were \$6,273 ± \$3,527 for MIDCAB, \$5,597 ± \$2,154 for

OPCAB and $\$9,509 \pm \$2,299$ for CCAB. Intra-operative cost savings can obviously be related to decreased expenditure for resources; such as perfusion circuit equipment and skin to skin times (MIDCAB = 144 ± 49 min, OPCAB 145 ± 37 min, CCAB 215 ± 68 min; p -value ≤ 0.001). Admission to surgery LOS costs are presented but not incorporated into the total hospital costs. Cost associated with this time period are influenced primarily by cardiology. Therefore, comparison of hospital costs are from procedure through discharge to control for variation. As indicated in Table 4 A, these costs are significantly lower for both off-pump surgical groups. Even though the predicted risk for operative mortality is significantly higher with more of the off-pump having a predicted risk of >5 per cent, costs are less.

Certain pre-operative risk factors have been documented to increase hospital costs⁹ such as congestive heart failure, renal failure and reoperative status. These risk factors were shown to be significant. Post-operative complications affiliated with these particular comorbidities did not occur in the post-operative recovery of the MIDCAB and OPCAB populations. Therefore, one may conclude that the elimination of CPB risks were avoided or significantly reduced in this high-risk population.

Critique of this study might be that it is a non-randomized retrospective review and thus is biased in its selected population. Effort was made to develop a homogenous patient population for comparison. Patients who received single or double vessel bypass were reviewed because initial application of the MIDCAB and OPCAB techniques were focused on these patients. Cost analysis components of this study may also be misleading due to the unsophisticated information systems and non-standardized definition of category components. Patient cost information was not accessible on the total population, which again may create biases of the presented data. Long-term follow-up is necessary to interpret off-pump results in terms of graft patency and the occurrence of reintervention. Gundry et al,¹⁰ reported a seven year follow-up comparison between off-pump with limited revascularization and on-pump with full revascularization. Their results show that the off-pump group had a threefold increase in reinterventions. Initial cost and clinical results are certainly promising especially with a high-risk patient.

CONCLUSION

Caution must be made in evaluating and recommending new technology or techniques purely on this basis of consumer and payer demands for cost-effective treatments. Our study showed that myocardial revascularization without cardiopulmonary bypass is safe and did not increase the occurrence in mortality or morbid events. Early clinical outcomes would imply that the high-risk patient clinically benefits from either of the two off-pump approaches. Total hospital costs also reflect effectiveness of these two approaches. However, continued evaluations of the techniques, particularly longitudinal outcome analysis is mandatory. Strategies must be focused on the efficacy of this application in the broad based lower risk population.

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