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Optimizing Revascularization of Complex, Proximal Left Anterior Descending Coronary Stenoses: The Clinical and Financial Impacts of Catheter-Based, Median Sternotomy, and Port-Access Approaches

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INTRODUCTION

As technology advances and the general population of the world ages, there is a pronounced increase in the call for more efficient and less invasive coronary artery bypass grafting (CABG) procedures. Considering the significant role that managed health care organizations play in the financial aspect of medicine, more emphasis is also placed on the cost effectiveness of coronary artery therapy. Within this realm of interventional medicine, type C stenoses of the left anterior descending (LAD) coronary artery present a particular dilemma with regard to therapeutic options. Whether catheter-based, median sternotomy, or port-access approaches are appropriate to restore the LAD to its previous level of functioning is continuously debated: treatment by one method may result in re-intervention by another. Depending on the balance of the patient's and the surgeon's perspectives, it is necessary to prioritize a myriad of factors not limited to short-term and long-term outcome, cost, pain, and quality of life. Comparing qualitative outcomes to quantitative outcomes becomes exceedingly important when one considers that the average age of patients undergoing cardiac surgery is steadily increasing. This retrospective study evaluates the clinical and financial consequences of the approaches available at a community hospital to complete revascularization of single LAD lesions, and focuses on where improvements can be made.

MATERIALS AND METHODS

We undertook a retrospective analysis of four separate cohorts of patients who underwent coronary revascularization of a significant LAD coronary artery lesion through one of four methods: PTCA/stent (interventional), off-pump coronary artery bypass (OPCAB) utilizing the Medtronic Octopus system (Dusseldorf, Germany), conventional CABG (CCAB) via sternotomy using CPB, and port-access CABG (PACAB) via a small (5 cm.) anterior thoracotomy utilizing the Heartport system (Redwood City, CA).

The primary exclusion criteria were threefold. First, patients converted from one category to another during the hospitalization were not included. Second, analysis was only conducted on the primary procedure, and subsequent therapies were excluded. Third, to eliminate confounding variables associated with reoperative surgery, reoperative patients were excluded. No patient was excluded for excessive length of stay or complications.

The hospital information system was utilized to collect in-hospital charges on each patient. All charges antecedent to the procedure day were eliminated and length of stay was defined as post-procedure days in the hospital. Professional costs were not included in the analysis. Hospital costs were calculated by the hospital accounting department's "unit-cost" method, which was tabulated for each patient. Nine cost centers were identified: nursing, ICU, anesthesia, perfusion, operating room, blood bank, respiratory therapy, pharmacy, and laboratory.

Categorical variables were analyzed using either X^2 analysis or Fisher's exact test. Continuous variables were analyzed by analysis of variance. Corrections were not made for multiple comparisons, and in all instances, statistical significance was assumed at $p = 0.05$.

RESULTS

The 490 patients underwent primary or re-interventional cardiac surgery for single LAD lesions at Riverside Methodist Hospitals from June 1997 to May 2001. The demographics of the patients are represented in Table 1 (◉). Patient characteristics were similar with respect to preoperative risks. No patients were converted to another form of surgery during any procedure. Specifically, 39 of these single LAD revascularizations were performed utilizing port-access: in total, 113 PACAB were performed by the two surgeons included in this study.

Median sternotomy with cardiopulmonary bypass is considered the gold standard of coronary artery bypass surgery. Of the four procedures herein investigated, CCAB and PACAB are the most similar in the aspect that strikes the largest difference amongst the four: both utilize CPB. With respect to this, intraoperative values were compared between CCAB and PACAB (Table 1, ◉). The time to incision was significantly

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Table 1. Patient demographics

	Interventional	CCAB/Sternotomy	OPCAB/Sternotomy	PACAB
#	351	50	50	39
NYHA Class	2.1	2.5	2.2	2.3
Male (%)	71	73	66	63
Female (%)	29	27	34	374
Current Smoker (%)	41	35	36	43
Age	55.3*	65.6	67.2	62.5
DM (%)	41	35	33	30
EF (%)	50	45	45	50
Previous MI (%)	3*	7	10	8
CPB Time (min)	N/A	28	N/A	41.5+
Cross-Clamp Time (min)	N/A	9.6	N/A	15.3+
Mortality (%)	0	0	0	0
Morbidity Requiring Reintervention (%)	2	0	0	21+

* p < 0.05 compared with sternotomy and Heartport approaches
+ p < 0.05 compared with sternotomy approaches

greater in the port-access procedure compared to sternotomy (56 min vs. 32 min, p<0.05). The time to direct vision harvest of the internal mammary artery was also significantly longer in the port access procedure compared to sternotomy (42 min vs. 14 min, p<0.05). It is possible here to equate the CCAB data of time to incision and time to direct vision harvest of the IMA with OPCAB results; both procedures carry similarities in these areas. Regarding time devoted to cross-clamping and grafting, PACAB again yielded a significantly longer part of the procedure compared to CCAB (15.3 min vs. 9.6 min, p<0.05). The overall duration of time the patient spent on CPB was 41.5 minutes during port-access procedures and 18 minutes during sternotomy, a significant difference (p<0.05).

Post-operatively, some significant differences were found, and in some aspects, trends certainly favored one method over others (Table 1, ◎). PACAB yielded shorter length of stay in the ICU, and subsequent faster return to work compared to the other procedures. The incidence of atrial fibrillation was compatible with that seen in OPCAB. However, with respect to post-operative hospital length of stay and incidence of cerebrovascular accidents, pleural cavity infection, and deep venous thrombosis, PACAB resulted in more negative outcomes. All port-access patients were free of angina and did not need to undergo reoperative for bleeding. There were no mortalities 30 days out for all four procedure categories.

Quantitatively, PACAB was considerably more expensive by charge/case ($38,392) and cost/case ($19,513) compared to interventional catheterization, on-pump sternotomy, and off-pump sternotomy (Tables 2 and 3, ◎). In breaking down the costs by cost center, PACAB consumed significantly greater resources in anesthetics and in the operating room than either CCAB or OPCAB. CCAB consumed the most nursing, blood bank, and respiratory therapy resources although these values were not significant. OPCAB used more ICU resources than any other procedure. Resource use by interventional catheterization was significantly more in the perfusion, pharmacy, and laboratory cost centers. When comparing by diagnosis related groups, CCAB turned in $6114 worth of profit, while reimbursements were not enough to cover the costs of PACAB.

Table 2. Inpatient costs and resource utilization

	Interventional	CCAB/Sternotomy	OPCAB/Sternotomy	PACAB
Nursing	1006*	2790	2503	1990
ICU	519*	1805	1807	1169
Anesthesia	N/A	1350	1203	1796+
Perfusion	6202+	1535	2509	6834+
Operating Room	3206+	4213	4018	5812+
Blood Bank	75	760	305	120+
Respiratory Therapy	103	703	651	397
Pharmacy	3800*	963	903	652+
Laboratory	900*	560	602	410

* p < 0.05 compared with sternotomy and Heartport approaches
+ p < 0.05 compared with sternotomy approaches

Table 3. Results

	LOS Post-procedure	Charge	Total Cost
PTCA/Stent	3.5	35238+	16915+
OPCAB/Sternotomy	6.6	28578	14371
CCAB/Sternotomy	6.0	30784	15817
PACAB	6.5	38392+	19513+

* $p < 0.05$ compared with sternotomy and Heartport approaches
+ $p < 0.05$ compared with sternotomy approaches
4 $p < 0.05$ compared with CPB sternotomy approach

DISCUSSION

In the pursuit of correlating optimal surgical techniques with optimal patient outcome, there are several goals in mind. For the patient, anticipated benefits include decreased hospital length of stay, reduced post-operative pain, accelerated recovery, reduced debility, and reduced atrial fibrillation. Financially, the objectives include fewer peri-operative and post-operative complications, decreased hospital length of stay, accelerated rehabilitation, and therefore a faster return to work. Many patients who are candidates for cardiac surgery also potentially qualify for a minimally invasive approach, and based on the wide potential benefits, it is an understandable assumption that should the techniques themselves be possible, that they should be the best option. However, as this study and others like it have found, minimally invasive techniques have not yet been practiced for long enough or widely enough for true long-term results to be accurately determined [Doty 1997, King 1997, Del Rizzo 1998, Galloway 1999, Groh 1999, Grossi 1999].

The gold standard for coronary artery revascularization is median sternotomy with cardiopulmonary bypass. While this procedure is quite durable and yields satisfactory patient results, eliminating CPB is becoming a more common practice. Revascularization through off-pump methods is desirable for high–risk patients because there is no particular increase in the incidence of morbidity or mortality, and there is a decrease in ICU and hospital length of stay [Del Rizzo 1998, Gundry 1998, Weintraub 1998, Arom 1999, Boyd 1999, Diegeler 1999, Park 1999, Reichenspurner 1999, Diegeler 2000]. The advantages of OPCAB are also more likely to be seen when avoiding CPB in patients with significant neurologic dysfunction, coronary artery disease, chronic pulmonary disease, peripheral artery disease, renal dysfunction, calcified ascending aorta, and octogenarians [Diegeler 1999]. The paradox here is that while OPCAB may be preferred for high-risk patients, the procedure itself inherently causes more stress than when the same grafts are made on an arrested heart. Therefore, careful patient selection is very important. It has been determined by some that off-pump procedures yield the best results when excluding patients with small (<1.5mm) vessels, diffuse disease, calcifications, intramyocardial running LAD, and obese females; inclusion of similar features have been found to increase costs in CCAB procedures [Weintraub 1998, Diegeler 1999]. This subsequently introduces a question: if certain patients are not pathologically preferred for OPCAB and not financially preferred for CCAB, where should the balance lie?

Other differences between OPCAB and CCAB are that the hospital costs tend to be more for CCAB due to increased resource use. In this study, CCAB was on the average a more expensive procedure; others also concur [Doty 1997, Arom 1999, Reichenspurner 1999]. Compared to CCAB, OPCAB has decreased OR time, no CPB and therefore decreased OR staff use, decreased need of anesthesia, decreased perioperative blood loss, decreased intraoperative costs, and decreased ICU and hospital time. Although this study found no significant differences in the use of in-patient resources between OPCAB and CCAB, overall trends lean towards OPCAB as being more cost effective.

Studies have found results for PACAB techniques similar to results of the OPCAB methods, coupled with the added benefits of forming anastomoses on an arrested heart [Grossi 1999]. This present study has shown that performing CAB through a port-access system results in significantly less resource use by the hospital's blood bank and pharmacy despite an increased post-operative length of stay. This may be attributed to the fact that smaller incisions made in the course of PACAB are enough to carry out the goals of the surgery, and that patients experience less wound pain and less postoperative complications. Significantly increased OR time, anesthetic use, and perfusion use were mostly due to higher device usage and time to manipulate than often needed in standard sternotomy cases. As in this study, others have determined PACAB to be more expensive than CCAB or OPCAB with sternotomy; however, the conclusion has also been drawn that the initial costs will be off-set by a decreased need for rehabilitation and a faster return to work and normal activity [Reichenspurner 1999].

Perioperative advantages for PACAB regarding decreased incidence of reoperation compared to sternotomy, low incidence of new-onset atrial fibrillation because of decreased atrial manipulation, and decreased infections, pulmonary complications, and perioperative myocardial infarction have been reported on several occasions [Galloway 1999, Groh 1999, Reichenspurner 1999]. Gundry et al [Gundry 1998] exhibited extended year data reflecting significant increases in incidence of reintervention following off-pump procedures with limited revascularization, compared to on-pump procedures with complete revascularization. This may lend credit to the fact that while eliminating CPB will make a procedure less costly for the patient, there are also quality of anastomosis issues on a beating heart. Quality of anastomosis tends to be better on an arrested heart than on a beating heart, although patency rates are equivalent, so patients selection must be done with care [Diegeler 2000]. Disadvantages of PACAB may include higher incidences of stroke, higher risk of aortic dissection, and increased difficulty in removing air adequately from the newly-formed anastomoses [Galloway 1999, Groh 1999]. The fact that benefits and drawbacks to PACAB are not consistent from study to study, including this one which found higher incidences of wound infection and no change in incidence of atrial fibrillation, further reinforces the fact that this is a technique which requires longer-term follow-up to determine more congruous expectations.

The fact that PACAB involves the highest charge and total cost reflects the wider variety and more elaborate use of devices, hospital resources, and staff to carry out the procedure successfully. Such is similar, although to a lesser degree, for sternotomy procedures. In the current study, revascularization by PTCA or stenting resulted in significantly higher charges and total costs when compared to either sternotomy procedure. While the total hospital length of stay for catheter-based procedures may be quite short and patient selection skewed towards people considered low risk, the initial high costs are soon made even higher by subsequent procedures to remedy restenoses. It has been reported that during the first year after PTCA, 20-25% of patients will need either surgery or another PTCA, while only about 5% CAB patients will need a second procedure [Park 1999]. In another work, 20% of PTCA patients had to undergo a repeat angioplasty within three months of the initial procedure [King 1997]. A 94.4% mid-term success rate involving no need for a second intervention after OPCAB was calculated by Diegeler et al, an improvement over their findings for PTCA and stents alike [Diegeler 2000].

While nursing and ICU costs for interventional means are significantly less than any operative procedure, they also require significantly higher resource utilization of the pharmacy and hospital laboratories. As adverse perioperative outcomes are decreased for CCAB and OPCAB, resource use can be expected to fall accordingly so that sicker patients may have improved morbidity and mortality while still undergoing a demanding operation [Weintraub 1998]. In evaluating the initial financial impact of MIDCAB without CPB and catheter intervention, one group determined that MIDCAB had a decreased overall cost compared to stenting due to lower supply charge and procedural charge, despite increased operative charges [Doty 1997]. The same study also concluded that hospital length of stay has a direct impact on cost, and the fact that MIDCAB LOS was approximately 2.28 days less after stenting helped bring down the MIDCAB cost. While this conclusion is true based on the results on Doty et al, they do not entirely agree with results of this study in which the PACAB had increased length of stay and cost which may be considered counter-intuitive for a minimally invasive procedure. Total hospital costs for CAB were found to be $13000 more than stenting and $15500 more than angioplasty in another case [Cohen 1993]. The results in Table 3, ◎ correlate with these cost associations.

Survival rates for medical treatment, percutaneous intervention, and CAB have been compared at intervals of 30 days, and 1, 2, and 3 years [Ellis 1998]. By 3 years, patients who had percutaneous intervention had the highest survival rate at 94.1% and no death, infarction, or need for CAB in 94.5%; however, among patients who were infarct – and bypass-free, the survival rates were better for those who had undergone CAB, at 81.4%. Likewise, the CAB patients had the highest percentage free from angina, at 87.7%.

As the general population ages, the cost-effectiveness of CAD intervention becomes a more relevant topic. The three year survival of octogenarians who underwent CAB has been found to be 80% and 64% for those who were medically treated [Sollano 1998]. Patients who refused an offer of CAB and who instead were treated medically had a 10-month survival of 50%. In the same study, surveyed surgery patients reported better quality of life and perception of health than all patients who were medically treated. While there was about a 3-fold increase in average cost of surgery, the cost per quality-adjusted life years illustrated that CABG is nevertheless cost-effective in the elderly compared to those who did not receive surgical treatment.

In comparing the outcome of the elderly undergoing OPCAB and CCAB, OPCAB patients experienced significantly decreased incidence of atrial fibrillation and low-output syndrome, decreased need for perioperative blood products, and significantly less ventilation time, and ICU and hospital stay [Boyd 1999]. OPCAB patients also experienced a 30% decrease in adverse economic outcome. Possibly the only point of contention is that OPCAB patients received significantly fewer grafts than the CCAB patients, therefore implying that careful patient selection may yield better OPCAB results instead of it being a universally beneficial procedure for the elderly.

In this current study, catheter intervention patients were on average 10 years younger than the surgery patients. This may be explained by the fact that the catheter patients are probably at lower risk than the surgery patients and therefore opt for intervention first, and "wait and see" for the possibility of surgery in case of restenosis. Two percent of these patients required reintervention, 0% of the sternotomy patients required reintervention, and 21% of the port-access patients required reintervention. PACAB patients were not the oldest category of patients; OPCAB patients were the oldest. Age may then not be the best factor by which to select patients. If PACAB is to be hailed as superior combination of MIDCAB and OPCAB procedures, then patients' advantageous outcomes should increase with age and frailty, especially in the case of surgeons experienced in performing PACAB.

CONCLUSIONS

Median sternotomy revascularization of the LAD represented the most effective interventional method, utilized the least amount of resources, and had the highest intervention-free survival. Our four-year study showed that OPCAB was less expensive of the two sternotomy procedure types, PTCA and stents had intermediate costs, and PACAB had the most overall cost. Technically possible in all patients, port-access revascularization exhibited encouraging early results. However, achieving direct vision of the IMA during harvesting resulted in a high rate of wound complication. Additionally, costs and late complications of this approach limit its application and advisability. The patient population that can benefit the most from minimally invasive procedures like port-access also has the highest risk of medical comorbidity. The standard CCAB/OPCAB with sternotomy continues to yield the most consistent and favorable patient outcome; PACAB should continue to be weighed against them when pursuing avenues for successful coronary artery revascularization.

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