

Reducing Costs and Improving Outcomes of Percutaneous Coronary Interventions

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Objective: To describe cost reduction and quality improvement efforts in our percutaneous coronary intervention (PCI) program and how risk adjustment was used to assess the effects of these changes.

Study Design: Single center registry analysis.

Patients and Methods: Data were collected on 2158 PCIs performed between July 1, 1994, and June 30, 1997. Of these, 1126 PCIs reflected care provided after implementation of competitive bidding for catheterization lab supplies, and efforts to reduce the use of postprocedure heparin and to implement early arterial sheaths removal (postbidding period). Hospital costs were estimated using a microcost accounting method. In-hospital mortality rates during the 2 time periods were compared using standardized mortality ratio estimated with a previously validated risk adjustment model for in-hospital mortality.

Results: Compared with the prebidding period, the postbidding period was characterized by a significantly higher utilization of new technology (coronary stents and atherectomy devices 46% vs 25%; abciximab 19.1% vs 3.7, $P < .01$), and an overall increase in case complexity. Despite these changes, the average and median postbidding cost per case was \$1223 and \$1444 lower, respectively, than in the prebidding period. After adjustment for comorbidities, procedure variables, complications, and length of hospital stay, multivariate regression modeling identified the postbidding period as an independent predictor of lower hospital costs ($P < .001$) with an estimated adjusted cost savings of \$460. These cost savings were associated with trends toward a lower observed mortality rate, a higher predicted mortality rate, and a significantly lower standardized mortality ratio (SMR .71; 95% CI 0.48-0.9; $P < .05$).

Conclusion: Despite an increase in case complexity and utilization of new technology, cost reductions can be achieved through competitive bidding for supplies and modifications of periprocedure care. Risk adjustment appears to be a valid tool for assessing the effectiveness of these efforts independently from changes in case mix.

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Methods to reduce the cost of cardiovascular procedures include re-use of balloon catheters, percutaneous revascularization performed at the same time of diagnostic catheteri-

zation, reduced anticoagulation, the use of new devices or pharmacological interventions to reduce restenosis and complications, and the use of competitive bidding for cardiac catheterization (cath) lab supplies. However, it is difficult to know if the results of these efforts on outcomes and/or costs are due to the intervention itself or to changes in case mix over time. This report describes our efforts toward reducing costs of percutaneous coronary interventions (PCIs) through a competitive bidding process for cath lab supplies and modifications of periprocedure care, and the use of risk adjustment methodologies as an approach to assess the effects of cost-reducing efforts on hospital costs and outcomes of PCIs independently from changes in case mix.

METHODS

Study Patients

The study sample consisted of 2158 consecutive PCIs performed between July 1, 1994 and June 30, 1997 at the University of Michigan Medical Center. Clinical and laboratory data were prospectively obtained through a computerized database. Angiographic data were obtained through cinefilm review. Coronary artery stenoses were classified according to the modified American College of Cardiology/American Heart Association classification.¹ The database was divided into a baseline set (1032 procedures), and a follow-up set (1126 procedures) accrued after implementation of competitive

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bidding for cath lab supplies, and changes in the process of care including a reduction in the use of postprocedure heparin and by implementation of early arterial sheaths removal.

Competitive Bidding

A competitive bidding process for the supplies used in the cardiac cath laboratory was initiated in June 1995. The intent of the bid process was to reduce the number of vendors in the cath lab, to standardize products, and to reduce costs. A request for quotation with a generic listing of interventional products and diagnostic catheters was sent to 16 vendors. The vendors were asked to submit responses within 3 weeks and were asked to restrict communication with members of the purchasing group or physician group involved in interventional cardiology. No volume requests were made for items. Rather, the number of expected cases to be formed was used as the basis for annual expenses.

Four vendors bid the most complete line of products for interventional cardiology and were invited to present information on their programs to representatives from purchasing and the Heart Care physicians.

Evaluation of these vendors and their products then followed over a 1-month period. Following completion of this evaluation, a decision was made to limit the number of vendors to 2. This decision was based on physician consensus that the products were of comparable high quality, and that by selecting 2 vendors there was an opportunity to provide a full product line at the most reasonable price possible. Negotiations with the 2 selected vendors followed.

Vendors were informed that each would be awarded approximately 50% of the cath lab supply business with the intent that pricing would be roughly equal between the 2 companies. Physicians would then have the opportunity to select the product of their choice.

Modification of the Care Process

In view of data showing a relationship between arterial sheath duration and the development of vascular complications,^{2,3} the postprocedure critical pathway used in the postintervention period was modified by implementing early (same day) arterial sheaths removal. Arterial sheaths were removed the same day of the procedure, and their removal was timed to a fall of the postprocedure activated clotting time (Hemotech) to <150 seconds. A further modification of the critical pathway included a reduction in the use of postprocedure heparin that was based

on data showing the safety of not resuming heparin postcoronary interventions.^{4,5}

Data Analysis

Continuous variables were analyzed using analysis of variance and categorical variables were analyzed using a chi-square test.

Cost Analysis

Hospital costs were computed using a microcost accounting method (Transition System Incorporated, Boston, Mass). Cost data were available for 2138 of 2158 procedures (99%), while clinical data were available for all consecutive cases. There were 15 outliers with total costs >\$100 000 who were not included in the analysis (respectively 8 and 7 per group). However, exclusion or inclusion of these outliers did not modify the results. Baseline and postprocedure variables were evaluated to identify univariate predictors of costs. Independent predictors of hospital costs were identified using stepwise log-linear regression analysis after log transformation of hospital costs of a model containing univariates with $P < .05$. The log transformation was undertaken given the skewed distribution of hospital costs. The multivariate regression model was developed using the entire data set and including the time period as explanatory variable.

To determine the relative explanatory power of baseline comorbidities, process of care, complications, and length of stay on hospital costs, 3 models were developed in sequence. The first model was developed using only baseline comorbidities and preprocedure variables; the second model was developed using baseline comorbidities and postprocedure variables including complications; and the third model was developed adding length of hospital stay.⁶ The effect on hospital costs of the intervention performed was evaluated by creating a new dichotomous variable ("postbidding time period") that categorized procedures performed before or after the bidding. This new variable was used as explanatory variable in the multivariate analysis of hospital costs. In addition, to have a further estimate of cost savings in the postbidding time period, a linear regression model was constructed without log transformation of hospital costs. This last model was inclusive of baseline comorbidities, procedure variables, postprocedure variables including complications, and length of hospital stay.

Outcomes Assessed and Risk Adjustment

Outcomes evaluated included death in the hospi-

tal, need for emergent coronary artery bypass graft (CABG), Q wave or non-Q wave myocardial infarction, vascular complications and length of stay. Risk adjusted hospital mortality rates were assessed using the Northern New England risk adjustment model for PCI mortality.^{7,8} Predicted probabilities of in-hospital death for individual patients were obtained from the Northern New England logistic regression model. The predicted mortality for each time period was then calculated. Observed and predicted mortality rates during the prebidding time period were compared with observed and predicted mortality rates during the postbidding time period. Standardized mortality ratios and 95% confidence intervals were then calculated.⁹

Definitions

Cardiogenic shock was defined as systemic hypotension (systolic blood pressure <90 mm Hg) associated with high-filling pressure not responding to intravenous fluids, or systemic hypotension with high right atrial pressure and decreased cardiac output in the setting of right ventricular infarction. Angiographic success was defined as less than 50% residual stenosis with TIMI 3 flow. Multivessel disease was defined as >1 major epicardial vessels with >70% luminal diameter stenosis. Renal insufficiency was defined as baseline creatinine > 2 mg/dL. Vascular complications were defined as any access complication requiring surgical repair or blood transfusion. PCI in the setting of acute myocardial infarction was defined as balloon dilatation of the infarct vessel within 24 hours from onset of symptoms. History of congestive heart failure was defined as any history of congestive heart failure within 6 weeks of index hospital admission. Peripheral vascular disease was defined as any history of claudication, amputation, vascular reconstruction, bypass surgery or angioplasty, aortic aneurysm, stroke, transient ischemic attack, carotid surgery, or carotid stenosis. New device angioplasty was defined as use of coronary stents and atherectomy devices as opposed to standard balloon angioplasty alone.

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RESULTS

Competitive Bidding

Before the bidding took place, 188 balloons in 19 different types were available on the shelf. All these balloons had been prepurchased. After the bidding, 251 balloons in 13 different types were available on the shelf on consignment. Given that these balloons were on consignment and were not prepurchased, the estimated savings in capital outlay were \$118 440.

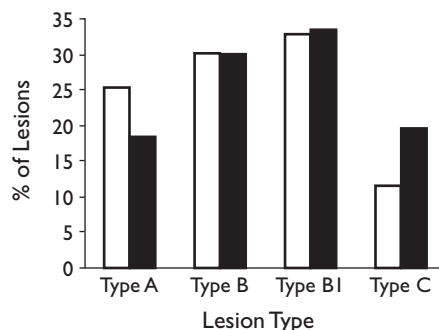
On average, the price of a PCI balloon before the bid process was \$630 each. Following the bidding process, the average balloon cost decreased to \$305. Similarly, guiding catheter costs were reduced from an average of \$85.60 to \$64 each. Annual expenditures on miscellaneous products such as Y adaptors and inflation devices were reduced from \$63 242.80 to \$47 522.40. Overall, the anticipated reduction in annual expenses on interventional products was \$406 825.86.

Table 1. Baseline Demographic Data and Resource Utilization

	Prebidding	Postbidding	P
Age	63.1 ± 11.5	62.4 ± 12.1	.2
Female (%)	37.3	30.6	<.01
Diabetes (%)	27.9	25.7	.15
History of congestive heart failure (%)	19.4	20.2	.5
Chronic obstructive pulmonary disease (%)	7.3	6.9	.6
Peripheral vascular disease (%)	22.9	17.8	<.01
Previous CABG (%)	20.2	18.6	.3
Multivessel disease (%)	51.7	58.2	<.01
Age >80 years (%)	7.2	10.1	.017
Acute myocardial infarction (%)	13.4	16.0	.087
Shock (%)	3.0	3.4	.6
Ejection fraction < 40% (%)	14.6	11.7	.045
Stent (%)	11.9	38.2	<.001
New device (%)	24.9	46.14	<.001
Abciximab (%)	3.77	19.1	<.001
Use of postprocedure heparin (%)	50	30	<.001

CABG indicates coronary artery bypass graft.

Figure 1. Lesion Complexity According to the Modified ACC/AHA Classification During the Preintervention and Postintervention Time Periods (* $P < .001$)



□ Preintervention; ■ postintervention.

ACC indicates American College of Cardiology; AHA, American Heart Association.

Baseline Clinical Variables

Table 1 shows baseline clinical characteristics of patients undergoing percutaneous revascularization before and after the intervention. There were higher percentages of women and patients with peripheral vascular disease in the preintervention period ($P < .02$), while there was no significant difference in average age. There were no significant differences in the need of emergency revascularization or in the number of patients presenting with cardiogenic shock. The postintervention period was

characterized by a higher percentage of patients who were >80 years old, a slightly higher percentage of patients presenting with a myocardial infarction within 24 hours, and by a higher percentage of patients with multivessel disease and with low ejection fraction ($EF < 40\%$). In addition, the postintervention period was also characterized by a significant increase in lesion complexity (Figure 1).

Clinical Outcomes and Risk-Adjusted

Mortality Rates

Angiographic success rate and procedure success rate were significantly higher in the postintervention period when compared to the preintervention period (Table 2). This difference was associated with a trend toward a lower incidence of death, and a lower incidence of a combined end point including death, acute myocardial infarction, and emergency CABG surgery (22% reduction—see Table 2).

In addition, when compared with the prebidding period, the postbidding period was characterized by a trend toward a lower observed mortality rate. However, due to the increased case complexity, the predicted mortality rate during this time period was higher. These diverging trends (lower observed mortality with higher predicted mortality) resulted in a significantly lower standardized mortality ratio, consistent with an overall reduction of in-hospital mortality (Table 2).

Resource Utilization and Procedure Costs

As shown in Table 2, the postintervention period was characterized by a significant increase in the use of new device angioplasty (coronary stents and atherectomy devices) and the IIb/IIIa receptor blocker abciximab. However, despite this increase, the total cost of procedures performed in the postbidding period was on average \$1223 lower than the cost of procedures performed in the prebidding period (median \$1444 lower). After adjustment for baseline comorbidities, the postbidding period was a strong independent predictor of lower hospital costs (Table 3). This effect was present after adjustment for preprocedure and postprocedure variables including

Table 2. Clinical Outcomes

	Prebidding	Postbidding	<i>P</i>
Lesion success (%)	93.2	95.5	$<.05$
Procedure success (%)	90	93.2	$<.01$
Vascular complications (%)	4.7	2.9	$<.03$
Length of stay (d)	4.9	4.4	.08
Death, myocardial infarction, emergency CABG (%)	6.5	5.1	.1
Observed mortality (%)	3.5	3.0	.5
Predicted mortality (%)	3.8	4.2	NA
Standardized mortality ratio (95% CI)*	0.91 (0.7-1.14)	0.71 (0.48-0.9)	$<.05$

CABG indicates coronary artery bypass graft; NA, not applicable.

complications (adjusted $R^2 = .42$, data not shown), and after further adjustment for total length of stay (adjusted $R^2 = .70$, Table 4). The use of new device angioplasty was an important predictor of higher hospital costs, but its inclusion in the final model did not appear to further explain variation in costs (adjusted $R^2 = .71$). The adjusted cost saving during the postbidding period estimated using linear regression analysis was \$938.85 ($P < .05$) after adjustment for baseline comorbidities alone, and \$460.78 after further adjustment for procedure variables, complications and length of hospital stay ($P < .05$). Figure 2 shows the cumulative percentile distribution curve of total hospital costs during the 2 time periods. For each percentile, total hospital costs were lower in the postintervention period when compared to the preintervention period.

DISCUSSION

The overall costs of PCI are determined by cardiac catheterization laboratory costs, by professional fees, and by hospital costs including room charges, nursing care, medications, and postprocedure care.^{10,11} Methods that have been proposed to reduce these costs include implementation of critical pathways to decrease complications and postprocedure length of stay,^{12,13} re-use of balloon catheters,¹⁴ percutaneous revascularization performed at the time of diagnostic catheterization,^{15,16} and reduced anticoagulation and early sheath removal leading to shortened length of hospital stay.^{4,5} In addition, the use of new pharmacological interventions such as IIb/IIIa antagonists to reduce acute complications,¹⁷ or the use of new devices for coronary intervention such as coronary stents to reduce restenosis or to improve acute outcomes have been proposed as another approach to reducing costs.^{10,18}

In this report, we describe a multilevel effort for reducing costs in interventional cardiology that

included competitive bidding for cath lab supplies and modification of postprocedure care. The bidding process resulted in a 50% cost reduction for balloon catheters and in additional cost reduction for other supplies including guiding catheters and diagnostic catheters.

The second component of the effort was represented by a simple modification of postprocedure care through implementation of early arterial sheath removal and reduction in the use of postprocedure heparin. These modifications were made in an attempt to incorporate into standard care paths recent findings showing a direct relationship between arterial sheaths duration and an increase in the risk of vascular complications,^{2,3} and the lack of benefit in the use of postprocedure heparin after uncomplicated percutaneous interventions.⁴

As shown by our data, the observed costs in the postbidding time period were lower when compared to the observed costs in the prebidding period. However, it was difficult to determine from the observational data whether this reduction was due to changes in disease severity or just to sheer chance rather than to the intervention itself. Thus, in an attempt to correct for other covariates and confounders, we applied to the cost analysis the same risk

Table 3. Multivariate Model of Hospital Costs. Effect of Baseline Variables, Preprocedure Care and Intervention

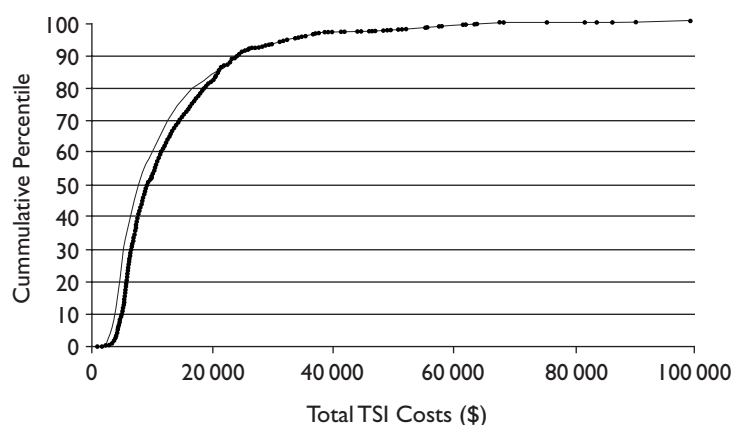
Variable	Coefficient	P	95 % CI
Age	0.004	.001	0.002-0.006
Male	0.080	.008	0.021-0.140
Peripheral vascular disease	0.158	<.001	0.087-0.229
Creatinine >2 mg/dL	0.197	.002	0.074-0.319
Congestive heart failure	0.178	<.001	0.102-0.255
Prior myocardial infarction	0.164	<.001	0.104-0.223
Ejection fraction <40%	0.202	<.001	0.131-0.311
Ejection fraction 40-49%	0.2023	<.001	0.104-0.299
Multivessel disease	0.108	<.001	0.050-0.165
Cardiac arrest	0.452	<.001	0.291-0.614
Acute myocardial infarction	0.469	<.001	0.384-0.555
Type C lesion	0.129	.001	0.054-0.203
Preprocedure heparin	0.307	<.001	0.248-0.366
Postintervention period	-0.181	<.001	-0.23 to -0.125
Intercept	8.44	—	8.28-8.59

Adjusted $R^2 = 0.29$; $f = 63.4$; $P < .0001$.

Table 4. Multivariate Model of Hospital Costs. Effect of Baseline Variables, Process of Care, and Length of Stay

Variable	Coefficient	P	95% CI
Baseline variables			
Peripheral vascular disease	0.049	.030	0.004-0.093
Congestive heart failure	0.072	.002	0.027-0.118
Multivessel disease	0.051	.005	0.016-0.087
Prior myocardial infarction	0.115	<.001	0.078-0.151
Acute myocardial infarction	0.171	<.001	0.114-0.228
Cardiac arrest	0.22	<.001	0.118-0.323
Process of care			
Preprocedure heparin	0.156	<.001	0.118-0.194
Postprocedure heparin	0.139	<.001	0.099-0.179
Intraaortic balloon pump	0.225	<.001	0.145-0.305
Outcomes			
Transfusion	0.183	<.001	0.115-0.251
Length of stay (per day)			
	0.084	<.001	0.080-0.087
Postintervention period			
	-0.12	<.001	-0.085 to -0.158
Intercept			
	8.53	—	8.9-8.87

Adjusted $R^2 = 0.70$; $f = 421.7$; $P < .0001$.

Figure 2. Cumulative Percentile Distribution Curves of Total TSI Costs*

*The x-axis represents total hospital costs and the y-axis represents percent of patients. For each value of hospital costs, the corresponding percentage of patients above or below this cost can be identified on the y-axis.

----- Preintervention; — Postintervention.

TSI indicates Transition System Incorporated.

adjustment methodology that has been applied to outcome analysis.

Correlates of Hospital Costs

Prior studies have tried to identify correlates of costs of PCI. Mark et al, in a cost-effectiveness analysis of the EPIC trial, identified bleeding complications, urgent and non-urgent CABG, and urgent and non-urgent PCI as important correlates of incremental costs.¹⁹ In the CAVEAT trial comparing balloon angioplasty with directional coronary atherectomy, a significant increment in cost was observed in the atherectomy arm when compared with the balloon angioplasty arm due to an increase in early complications.²⁰ More recently, in an analysis of direct cardiac cath lab cost from a large multicenter database, procedural factors including number and type of interventions and in-lab complications were identified as major determinants of cardiac cath lab costs, which, however, represents only a fraction of the total hospital costs evaluated in our study.²¹

Our analysis and results are similar to a detailed analysis of hospital cost of 1237 percutaneous interventions performed between November 1992 and June 1993 reported by Ellis, et al.⁶ In that study, the same microcost accounting method was used to determine total hospital costs, and similar correlates of hospital costs were identified. However, no intervention aimed toward cost reduction was performed.

The main finding of our study is that mathematical modeling of hospital costs and of outcomes can be used not only to identify correlates of hospital costs, but also to identify potentially correctable variables, and to assess the results of quality improvement and cost reduction efforts independently over time from changes in case mix. The identifi-

cation of variables such as use of postprocedure heparin, intraaortic balloon pump placement, and ischemic and nonischemic complications presents potential targets for quality improvement and cost reduction efforts. In addition, it is worth noticing that administration of blood transfusions emerged as an important predictor of higher hospital cost, confirming findings of Ellis, et al.⁶ The incremental costs associated with blood transfusion might be related to the costs of the transfusion itself, and to the association between blood transfusion and other bleeding complications. Importantly, in a recent analysis from our institution, we showed a direct correlation between intraprocedural blood losses and blood transfusions, but we also showed that many transfusions might be unnecessary when the American College of Physician Guidelines for blood transfusion are applied.²² Thus, meticulous care in the prevention of blood loss, and application of available guidelines for blood transfusion appear to be potential strategies that could be used to decrease the occurrence of this costly complication.

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**IMPROVED OUTCOMES OF
 PCIs AND COSTS**

Recent studies have shown a progressive improvement in outcomes of PCI believed to result from the introduction of new technology, and in particular of coronary stents.²³ To our knowledge, no studies have tried to assess the results of internal quality improvement and cost reduction efforts in interventional cardiology. We think that the lower standardized mortality ratio observed in the postbidding time period was a direct result of multiple changes including increased utilization of coronary stents and abciximab rather than the result of the intervention performed. However, we also believe that implementation of early arterial sheath removal and reduction in the use of postprocedure heparin was likely the cause of the decrease in bleeding complications and of the shorter length of hospital stay. Yet, after further adjustment for these covariates, the postbidding period was still an important correlate of lower hospital costs, thus suggesting an additive effect independent from a reduction in complications rates and length of stay. Thus, our data suggest that simple interventions such as competitive bidding for supplies, modification of postprocedure care, and introduction of new technology cannot only decrease overall hospital costs but can also improve absolute and risk-adjusted outcomes.

The power of the methodology used and of risk adjustment relies in the ability to correct for potentially confounding variables, and to further clarify the true effect of these efforts over time.

Limitations

Our study has several limitations. First, due to the nonrandomized nature, we cannot rule out completely the possibility that the observed differences between the two time periods might have been related to other factors rather than to the intervention itself. However, correction for other confounding variables through the methodology used supports the fact that the observed difference was at least in part the result of the interventions described. Second, the utilization of stents and of abciximab may be perceived as low. Yet, it was significantly higher than what has been reported from other registries and clinical trials with data collected during the same time period.^{7,24} Third, the analysis was focused on in-hospital outcomes, and, given the higher utilization of coronary stents during the second time period, it is likely that even higher savings might have accrued over time through a reduction of repeat procedures for restenosis. In addition, we did not break down the procedure costs in all the different components. However, our intent was not to perform a detailed costs analysis, but rather to assess through the use of risk adjustment changes over time of costs and outcomes independently from changes in case mix. Finally, the cost analysis was performed on data from a single tertiary care academic institution using a cost accounting methodology. Thus, these results should not be generalized.

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