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Cost of Cardiac Care in the Three Years After Coronary Catheterization in a Contained Care System: Critical Determinants and Implications

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Objectives. **We sought to determine the clinical, angiographic, treatment and outcome correlates of the intermediate-term cost of caring for patients with suspected coronary artery disease (CAD).**

Background. **To adequately predict medical costs and to compare different treatment and cost reduction strategies, the determinants of cost must be understood. However, little is known about the correlates of costs of treatment of CAD in heterogenous patient populations that typify clinical practice.**

Methods. **From a consecutive series of 781 patients undergoing cardiac catheterization in 1992 to 1994, we analyzed 44 variables as potential correlates of total (direct and indirect) in-hospital, 12- and 36-month cardiac costs.**

Results. **Mean (±SD) patient age was 65 ± 10 years; 71% were men, and 45% had multiple vessel disease. The initial treatment strategy was medical therapy alone in 47% of patients, percutaneous intervention (PI) in 30% and coronary artery bypass graft surgery (CABG) in 24%. The 36-month survival and event-free (death, infarction, CABG, PI) survival rates were 89.6 ± 0.2% and 68.4 ± 0.4%, respectively. Median hospital and 36-month costs were $8,301 and $28,054, respectively, but the interquartile ranges for both were wide and skewed. Models for $\log_e$ costs were superior to those for actual costs. The variances accounted for by the all-inclusive models of in-hospital, 12- and 36-month costs were 57%, 60% and 71%, respectively. Baseline cardiac variables accounted for 38% of the explained in-hospital costs, whereas in-hospital treatment and complication variables accounted for 53% of the actual costs. Noncardiac variables accounted for only 9% of the explained costs. Over time, complications (e.g., late hospital admission, PI, CABG) and drug use to prevent complications of heart transplantation became more important, but many baseline cardiac variables retained their importance.**

Conclusions. **1) Variables readily available from a comprehensive cardiovascular database explained 57% to 71% of cardiac costs from a hospital perspective over 3 years of care; 2) the initial revascularization strategy was a key determinant of in-hospital costs, but over 3 years, the initial treatment become somewhat less important, and late complications became more important determinants of costs.**

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To meet the challenge of reducing medical resource utilization without jeopardizing the quality of patient outcomes, knowledge of the determinants of long-term cost is imperative (1). Cardiovascular disease and its management are prime targets for cost reduction initiatives because of the high prevalence and cost of the disease ($128 billion in the United States alone in 1994 [2]). Judgments regarding cost and quality of outcome with different treatment strategies and from different providers are pivotal. Data from randomized, controlled trials minimize many forms of bias but are typically limited to selected patient groups (2,4). Evaluation from nonrandomized sources requires the capacity to appropriately "adjust" for differences in baseline variables. Data identifying key determinants of long-term costs in patients with coronary artery disease (CAD) are limited.

Although several carefully performed cost studies in this area have been reported (5,6), many have serious limitations (7). These limitations include use of charges rather than actual costs (8–10), estimated unit costs rather than actual costs (11,12), administrative datasets not including key variables (10), small number of patients (13), lack of long-term perspective (14,15), failure to capture many outpatient costs (12) and less than optimal statistical modeling (invalid assumption of normality of cost distribution, lack of validation testing or specification of degree of model fit) (9,13–15).

Therefore, we sought to carefully evaluate the major determinants of cardiac costs over a 2- to 3-year period in a well

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Abbreviations and Acronyms

CABG = coronary artery bypass graft surgery
CAD = coronary artery disease
CCS = Canadian Cardiovascular Society
PI = percutaneous intervention

characterized patient cohort in whom all cardiac costs from a provider perspective could be ascertained.

Methods

Patients. All patients undergoing cardiac catheterization with coronary angiography from January 1, 1992 through December 31, 1994 who responded to a query as to whether, since January 1992, they had received, and were continuing to receive, all cardiac care at our institution and who consented to participate in the study were eligible for study inclusion. If a patient was alive and had exited our care system, their data were censored at the time of exit. Treatment recommendations were made by the patient's clinic physician. Baseline, treatment and in-hospital clinical outcome and all cost data were recorded prospectively in several hospital databases that were merged for the purposes of the study. Patients treated with percutaneous or surgical revascularization had their long-term clinical outcome tracked prospectively by means of written questionnaire, telephone contact or direct contact with referring physicians or family members. Patients treated medically had their clinical outcome evaluated retrospectively using methodology nearly identical to that for the other groups. Cost and clinical data were available for all eligible patients.

Method of determining costs. Cost data were downloaded from the hospital and outpatient cost accounting system (Transition System, Inc.), a previously described commercially available system that calculates total (direct and indirect; hospital, outpatient and physician) cost on a per-patient basis (16). Not captured in the system were outpatient medication costs, which were obtained by 1) tracking all cardiac medications taken by patients on an every 2-month basis and calculating the costs on the basis of direct pharmacy costs at our center at the time that medications were taken; and 2) tracking costs from other institutions, which were obtained as necessary and estimated using institution-specific cost/charge ratios (Aspen Healthcare Metrics, Inc., 1994). All dollar costs were devalued to January 1992 dollars using the health care price index (17), and the future value of money was considered using the consumer price index.

Statistical analysis. Continuous time-independent data are described as mean value ± SD or median and interquartile range, depending on the normality of their distribution. Categoric data are presented as a percent. Standard errors of the estimate are provided for Kaplan-Meier survivor analyses.

Both cost and $\log_e$ cost at the time of hospital discharge and at 12 and 36 months after initial cardiac catheterization were tabulated. To determine predictive models for these six end points, univariable and multivariable modeling was performed using 36 candidate preprocedural covariates, allowing entry into the multivariable model only those variables that correlated with the dependent variable at $p < 0.05$. Explanatory models using 44 pretreatment and posttreatment candidate variables for the in-hospital and 12- and 36-month outcomes were also developed. Length of stay was not included as a potential covariate because it is, for the most part, not an independent variable; rather, length of stay is directly related to complications, and its inclusion would therefore eliminate variables that might provide more direct insight into the determinants of costs. These models were internally validated using a tenfold cross validation, using a randomly selected 80% sample for fitting and the remaining 20% of the sample for testing to assess the extent to which the predictive accuracy of the models was overly optimistic (18). The degree of model fit was assessed by evaluating the adjusted r^2 coefficient.

Potential covariates, definitions and conventions. Selected preprocedural candidate covariates are shown in Table 1. In addition, the following variables were considered: body mass index (weight/height^2), chronic obstructive pulmonary disease requiring medication, diagnosed CAD (see Other definitions), height, previous stroke or transient ischemic attack, sinus rhythm, stable angina, symptomatic peripheral vascular disease, valvular heart disease (moderate or severe stenosis or regurgitation) and weight.

For the explanatory models, the following post procedural variables were also considered: initial treatment and follow-up coronary artery bypass graft surgery (CABG), cardiac catheterization, death, hospital admission, myocardial infarction, outpatient medication use (see Other definitions), percutaneous intervention (PI) and use of cardiac rehabilitation.

Other definitions. *Arrhythmia as indication for cardiac catheterization* was defined as catheterization principally to exclude significant CAD as an underlying cause, or complicating feature, of supraventricular or ventricular arrhythmia. *Outpatient medications* included use of angiotensin-converting enzyme inhibitors, antiarrhythmic agents (Vaughn-Williams class Ia, Ic, amiodarone or sotolol), aspirin, beta-adrenergic blocking agents, calcium channel antagonists, digitalis, diuretic agents, statin-class lipid-lowering agents and warfarin at any time for ≥2 months during the first 12 months after catheterization and were coded separately. *Significant CAD* was defined as a history of myocardial infarction, previous PI or ≥50% diameter stenosis in a potentially bypassable artery (>1.5-mm diameter by visual estimate). *Urgent/emergency catheterization status* was defined as those procedures that, on the basis of clinical indication, should be performed on the same day as presentation (urgent) or immediately (emergency) as opposed to an elective procedure.

Subset analyses. Prespecified subgroup analyses intended to provide insight into either the comparability of these data with cost data from randomized, controlled trials or into potential areas for cost reduction were risk-adjusted time-related costs of 1) PI and CABG for patients with multiple-

Table 1. Patient Characteristics (by treatment group)

	Study Cohort				All Pts Undergoing Cath 1992–1994 (n = 16,219)
	Medicine* (n = 347)	PI (n = 232)	CABG (n = 185)	Total† (n = 781)	
Age (yr)	65 ± 11	64 ± 10	66 ± 10	65 ± 10	62 ± 11
CCS angina class					
I or II	51%	48%	42%	48%	NA
III or IV	26%	40%	38%	33%	NA
Current smoker	16%	17%	21%	17%	22%
Diabetes mellitus	28%	26%	33%	29%	29%
Hypertension	67%	60%	71%	66%	62%
Male	67%	77%	72%	71%	70%
Major comorbidities					
COPD	5%	7%	7%	6%	6%
Creatinine ≥2 mg%	8%	4%	2%	6%	5%
CVA/TIA	12%	8%	14%	11%	10%
PVOD	18%	17%	19%	18%	19%
Prior CABG	31%	25%	20%	27%	25%
Prior MI	45%	40%	42%	43%	43%
Prior VT/VF	7%	4%	3%	5%	NA
LVEF <40%	13%	12%	11%	12%	15%
Multivessel disease	29%	37%	89%	45%	52%
Jeopardy score (0–6)	1.3 ± 1.5	2.3 ± 1.3	3.8 ± 1.4	2.2 ± 1	NA
Unstable angina	44%	49%	49%	47%	NA
Hospital transfer	9%	17%	17%	13%	19%
Urgent/emergency cath	33%	46%	55%	41%	NA

*Excludes data for transplant recipients. †Includes data for transplant recipients. Data presented are mean value ± SD or percent of patients. CABG = coronary artery bypass graft surgery; Cath = catheterization; CCS = Canadian Cardiovascular Society; COPD = chronic obstructive pulmonary disease; CVA = cerebrovascular accident (stroke); LVEF = left ventricular ejection fraction; MI = myocardial infarction; NA = not available; PI = percutaneous intervention; Pts = patients; PVOD = peripheral vascular obstructive disease; TIA = transient ischemic (neurologic) attack; VF = ventricular fibrillation; VT = ventricular tachycardia.

vessel disease; and 2) initial medical therapy or PI for patients with one- or two-vessel disease. Covariates were derived from analyses shown later in Tables 3 to 8, modified as necessary for the subgroups studied. Covariates used in the models are presented in the Appendix.

Results

Initial treatment and outcome. *Medical therapy.* After catheterization, 239 of 364 patients referred for medical therapy had significant coronary artery disease (Table 1). The survival rates at 30 days and 1, 2 and 3 years for these 239 patients were 98.8 ± 0.1%, 95.2 ± 0.1%, 89.9 ± 0.2% and 81.0 ± 0.4%, respectively, and the infarct- and bypass-free survival rates were 98.0 ± 0.1%, 89.8 ± 0.2%, 76.2 ± 0.4% and 63.5 ± 0.6%, respectively. At the latest follow-up visit, 79.2% of patients had no angina, 13.3% had Canadian Cardiovascular Society (CCS) class I or II angina, and 7.5% had CCS class III or IV angina. Their resource utilization is described in Table 2; their cumulative cost of cardiac care is shown in Figure 1; and the distribution of their costs is shown in Figure 2. In addition, 17 patients underwent heart transplantation, 5 had primary ventricular arrhythmias, 4 had primary valvular heart disease, 4 had coronary spasm, and 98 had suspected but no significant CAD.

Percutaneous coronary revascularization. Two hundred thirty-two patients had PI as their initial treatment after the index catheterization. Their baseline characteristics are de-

Table 2. Resource Utilization After Initial Hospital Stay*

	Medicine†	PI	CABG	Total
CABG	7.7%	15.5%	0.6%	8.4%
Cardiac cath	25.6%	48.9%	17.1%	31.1%
Cardiac rehabilitation	5.6%	15.1%	24.3%	16.7%
Hospital admission	36.5%	49.4%	27.8%	38.5%
PI	9.4%	26.8%	5.0%	13.8%
Pharmaceutical agent (selected)				
Aspirin	88%	97%	94%	93%
ACE inhibitors	15%	18%	26%	24%
Antiarrhythmic agents	7%	6%	9%	8%
Beta-blockers	20%	38%	24%	32%
Calcium channel blockers	38%	57%	28%	46%
Statin-class lipid-lowering agents‡	18%	23%	17%	24%
Nitrates	20%	29%	17%	33%
Warfarin	7%	4%	13%	8%

*At any time during follow-up (27 ± 12 months). †Excludes patients without coronary artery disease and transplant recipients. ‡3-hydroxy-3-methylglutargl-coenzyme A inhibitors (e.g., lovastatin). ACE = angiotensin-converting enzyme; other abbreviations as in Table 1.

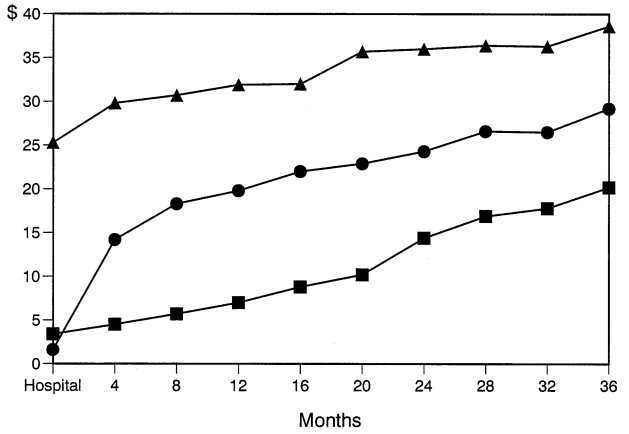

Figure 1. Median actual costs over time for patients treated with an initial strategy of medical therapy alone **(squares),** PI **(circles)** or CABG **(triangles).** Costs for transplant recipients are excluded.

scribed in Table 1. The primary PI was balloon angioplasty in 68.6%, stenting in 12.3%, directional atherectomy in 10.6%, rotational atherectomy in 6.8% and excimer laser in 1.7%.

Technical success without death, infarction or need for CABG was obtained in 94.5% of patients. Overall survival and infarct- and bypass-free survival rates at 30 days and 1, 2 and 3 years were 98.9 ± 0.1%, 98.2 ± 0.1%, 95.4 ± 0.2% and 94.1 ± 0.2%, and 92.9 ± 0.2%, 82.5 ± 0.3%, 77.8 ± 0.3% and 71.8 ± 0.4%, respectively. At latest follow-up, 84.9% had no angina, 12.3% had CCS class I or II angina, and 1.4% had CCS class III or IV angina. Their resource utilization, cumulative cost of cardiac care and cost distribution are shown in Table 2 and Figures 1 and 2, respectively.

Bypass surgery. One hundred eighty-five patients had CABG as their initial therapy after catheterization. Seventy-one percent received one or more arterial conduits, and 10% had concomitant valve surgery. Their survival and infarct- and bypass-free survival rates at 30 days and 1, 2 and 3 years were 97.5 ± 0.1%, 94.2 ± 0.2%, 93.0 ± 0.2% and 91.4 ± 0.3%, and 92.1 ± 0.2%, 86.4 ± 0.3%, 85.2 ± 0.3% and 81.4 ± 0.4%, respectively. At the time of latest follow-up, 87.7% had no angina, 10.4% had CCS class I or II angina, and 1.9% had CCS class III or IV angina. Their resource utilization, cumulative costs and distribution of costs are shown in Table 2 and Figures 1 and 2, respectively.

Patients without demonstrable heart disease. Ninety-eight patients had "insignificant" or no demonstrable CAD and were treated medically. Their survival and infarct- and bypass-free survival rates at 1, 2 and 3 years were 99.3 ± 0.1, 99.3 ± 0.1 and 99.3 ± 0.1, and 97.3 ± 0.2%, 94.7 ± 0.3% and 92.4 ± 0.4%, respectively. At latest follow-up, 83.6% had no angina, 16.4% had CCS class I or II angina, and none had CCS class III or IV angina. Over the 25 ± 11-months follow-up period, 10.3% required hospital admission for cardiac indications, and 6.0% required repeat catheterization. Their median cardiac costs at 1, 2 and 3 years after discharge were $960, $1,035 and $4,415, respectively. Thirty-eight patients had one or more abnormal functional tests before catheterization. The 3-year postdischarge costs for these patients was only $522 per patient.

Transplant recipients. Seventeen patients underwent cardiac catheterization after heart transplantation or underwent transplantation within 12 months of catheterization. One, 2 and 3 years after index catheterization, 95.3%, 88.3% and 88.3% were alive, and their cardiac costs were $56,532 ± $68,317, $51,248 ± $50,100; and $83,261 ± $48,216, respectively. These costs were in large part due to the cost of the hospital stay for transplantation ($77,786 ± $45,464) and the cost of outpatient medications ($28,221 ± $18,701).

Long-term follow-up. The average time of clinical follow-up in survivors was 27 ± 12 months. Ten patients (1.3%) were lost to follow-up, and 69 (8.8%) left the clinic system for another medical care group at 23 ± 10 months. Patients leaving the clinic system less often had baseline creatinine levels ≥2.0 mg% (1.6% vs. 6.9%, p = 0.007) and congestive heart failure (4.3% vs. 10.6%, p = 0.02), but were otherwise similar to patients remaining in the system. Cost data through 12 months, when most patients who eventually left were still in the system, were nearly identical for those who eventually left and those who did not. The number of patients thus eligible for the in-hospital and 1- and 3-year follow-up analyses were 781, 684 and 296, respectively.

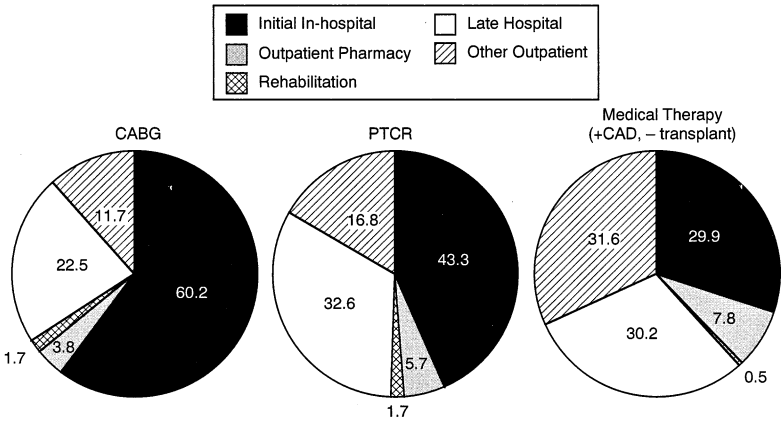

Figure 2. Distribution of cost sources for patients treated with initial treatment strategies of CABG, PI PTCR or medical therapy alone (transplant recipients excluded).

Table 3. Independent Pretreatment Correlates of In-Hospital Log_e Cost*

	Cost Effect (%)†	95% CI	$ Increment	Multiple p Value‡
Jeopardy score	11.1/U	9.3 to 12.9	1,541/U	< 0.001
MI <2 wk before catheterization	42.6	33.3 to 52.9	5,908	< 0.001
CHF	55.5	41.6 to 69.4	7,697	< 0.001
Arrhythmia indication	54.6	36.4 to 72.8	7,578	< 0.001
Prior CABG	−14.5	−18.5 to −10.5	−2,009	< 0.001
Valvular heart disease	35.3	23.1 to 47.5	4,893	0.001
Catheterization status	15.1	9.9 to 20.3	2,098	0.001
Unstable angina	19.8	12.8 to 26.8	2,743	0.001
CAD	24.7	14.9 to 34.5	3,426	0.004
Hospital transfer	22.5	13.4 to 31.6	3,123	0.005
Creatinine ≥2 mg%	29.4	15.8 to 43.0	4,079	0.010
CCS angina class III/IV	13.9	7.5 to 20.3	1,928	0.013
Positive stress test	−10.8	−15.6 to −6.0	−1,496	0.025

*Constant = 7.797; adjusted multiple r^2 = 0.391. †See Appendix for definition. ‡Univariate and multivariate p values for other selected variables: age, p = 0.02, p = 0.94; chronic obstructive pulmonary disease, p = 0.14, p = 0.11; diabetes, p = 0.01, p = 0.77; left ventricular ejection fraction, p < 0.001, p = 0.18; height, p = 0.007, p = 0.08; male gender, p = 0.32, p = 0.16; number of diseased vessels, p < 0.001, p = 0.86; previous myocardial infarction, p = 0.40, p = 0.09; symptomatic peripheral vascular obstructive disease, p = 0.28, p = 0.50; weight, p = 0.27, p = 0.23. CAD = coronary artery disease; CHF = congestive heart failure; CI = confidence interval; other abbreviations as in Table 1.

Correlates of cost and log_e cost. Correlates of log_e cost are provided in Tables 3 to 8. The corrections to the linear regression models resulting from cross validation were generally small (that for pretreatment correlates of in-hospital cost reduced r^2 from 0.402 to 0.391 [Table 1]). For each analysis, either the proportion of explained variance (r^2) was less, or the Studentized residuals' variance (19) was greater, or both, for models of cost compared with log_e cost, indicating the latter's superiority (data not shown).

Table 4. Overall Independent Correlates of In-Hospital Log_e Cost*

	Cost Effect (%)†	95% CI	$ Increment	Multiple p Value
Medical Rx	−34.8	−37.1 to −32.5	−4,833	< 0.001
CABG	42.8	37.3 to 48.3	5,939	< 0.001
Arrhythmia indication	78.9	69.5 to 88.3	10,958	< 0.001
Recent MI	34.7	28.5 to 40.9	4,814	< 0.001
Creatinine ≥2 mg%	49.0	39.9 to 58.1	6,803	< 0.001
CHF	30.5	22.6 to 38.4	4,240	< 0.001
Cath status	11.4	7.8 to 15.0	1,579	0.001
Valvular heart disease	26.6	18.7 to 34.5	3,691	0.001
In-hospital MI	47.8	33.4 to 62.2	6,635	0.001
Positive stress test	−11.1	−14.8 to −7.4	−1,537	0.002
CCS/angina III/IV	11.5	7.1 to 15.9	1,599	0.006
Unstable angina	12.1	7.4 to 16.8	1,680	0.008
Hospital transfer	12.5	6.5 to 18.5	1,741	0.031

*Constant = 8.691; adjusted multiple r^2 = 0.570. †See Appendix for definition. Rx = treatment; other abbreviations as in Tables 1 and 3.

Table 5. Pretreatment Correlates of 12-Month Log_e Cost*

	Cost Effect (%)†	95% CI	$ Increment	Multiple p Value‡
CHF	49.7	35.4 to 64.0	12,138	< 0.001
CAD	36.8	24.1 to 49.5	8,999	0.001
Valvular heart disease	36.2	22.8 to 49.6	8,850	0.001
Creatinine ≥2 mg%	33.8	18.5 to 49.1	8,265	0.007
Recent MI	20.8	11.7 to 29.9	5,075	0.008
Cath status	13.6	8.1 to 19.1	3,313	0.008
Positive stress test	−12.6	−17.3 to −7.9	−3,089	0.012
Unstable angina	15.1	8.1 to 22.1	3,700	0.013
Jeopardy score	7.3/U	4.4 to 10.2	1,788/U	0.014
Prior CABG	−11.9	−16.6 to −7.2	−2,909	0.017
No. of diseased vessels	11.2/U	5.2 to 16.2	2,747/U	0.036
Arrhythmia indication	27.5	10.9 to 44.1	6,726	0.046

*Constant = 8.328; adjusted multiple r^2 = 0.330. †See Appendix for definition. ‡Univariate and multivariate p values for pretreatment variables correlated with log_e cost during hospital stay not entering this model: angina grade III/IV at baseline, p < 0.001, p = 0.33; hospital transfer, p < 0.001, p = 0.26. Abbreviations as in Tables 1 and 3.

Overall predictive capacity, measured by the explained variance (r^2), was 35% to 55% for models with pretreatment variables only and 57% to 71% for all-inclusive models. Variables representing baseline cardiac status and the initial treatment strategy dominated the models explaining in-hospital cost. Over time, complications, reflected by variables such as need for later hospital admission, PI or CABG, became powerful correlates of overall cardiac cost.

Of the commonly predictive variables, most would be available in a cardiovascular database. One, the jeopardy score (20), is less commonly used. The number of diseased vessels, closely related to the jeopardy score, could be substituted with

Table 6. Overall Correlates of 12-Month Log_e Cost*

	Cost Effect (%)†	95% CI	$ Increment	Multiple p Value‡
Initial medical Rx	−32.3	−34.9 to −29.7	−7,892	< 0.001
Transplant patient	140.1	127.4 to 152.8	34,256	< 0.001
Late hospital admission	34.3	29.3 to 39.3	8,385	< 0.001
Initial CABG	40.2	34.0 to 46.8	9,813	< 0.001
Unstable angina at baseline	16.5	12.2 to 20.8	4,030	< 0.001
MI <2 wk before cath	20.6	15.3 to 25.9	5,024	< 0.001
Arrhythmia indication	41.6	30.2 to 53.0	10,162	< 0.001
Antiarrhythmic Rx	24.2	16.2 to 32.2	5,902	0.002
Baseline CHF	25.7	17.1 to 34.3	6,289	0.002
Late CABG	22.3	14.0 to 31.6	5,449	0.008
Baseline LV Function	2.3/U	1.4 to 3.2	567/U	0.014
Baseline creatinine ≥2 mg%	20.7	11.0 to 30.4	5,061	0.022
Use of cardiac rehabilitation	12.2	6.6 to 17.8	2,977	0.023
Diuretic Rx	9.3	4.7 to 13.9	2,263	0.034

*Constant = 9.149; adjusted multiple r^2 = 0.626. †See Appendix for definition. ‡Univariate and multivariate p values for variables correlated with log_e cost during initial hospital stay not entering this model: angina class III/IV, p < 0.001, p = 0.26; baseline catheterization status, p < 0.001, p = 0.20; hospital transfer, p < 0.001, p = 0.77; positive stress test at baseline, p < 0.001, p = 0.13; valvular heart disease, p < 0.001, p = 0.17. LV = left ventricular; other abbreviations as in Tables 1, 3 and 4.

Table 7. Preprocedural Correlates of Three-Year Log_e Cost*

	Cost Effect (%)†	95% CI	$ Increment	Multiple p Value‡
Jeopardy score	10.9/U	8.1–13.7	4,117/U	< 0.001
CAD	73.0	50.6–95.4	27,648	< 0.001
Baseline catheterization status	24.1/U	17.3–30.9	9,116/U	0.001
Baseline CHF	45.6	26.1–65.1	17,277	0.003
Baseline creatine ≥2 mg%	45.5	23.0–68.0	17,234	0.010
Valvular heart disease	29.6	11.2–48.0	11,196	0.047

*Constant = 8.555; adjusted multiple r^2 = 0.371. †See Appendix for definition. ‡Univariate and multivariate p values for pretreatment variables correlated with cost at an earlier follow-up time not entering this model: arrhythmia indication, p = 0.09, p = 0.57; baseline angina class III/IV, p = 0.009, p = 0.79; baseline positive stress test, p = 0.001, p = 0.17; baseline unstable angina, p < 0.001, p = 0.33; hospital transfer, p = 0.10, p = 0.50; myocardial infarction <2 weeks before initial catheterization, p = 0.01, p = 0.88; number of diseased vessels at baseline, p < 0.001, p = 0.27, prior bypass surgery at baseline, p = 0.16, p = 0.82. Abbreviations as in Table 3.

little loss of predictive capacity (e.g., adjusted r^2 with number of diseased vessels in the predictive model of log_e in-hospital cost reduced the adjusted r^2 from 0.391 to 0.383).

For patients with multiple-vessel disease not treated medically (n = 274), CABG compared with PI led to an incremental cost, after consideration of the possible effect of baseline variables noted in the Appendix, during the index hospitalization and at 12 and 36 months of \$4,796 ± \$850 (p < 0.001), \$3,329 ± \$2,087 (p = 0.07) and \$2,421 ± \$3,152 (p = 0.40), respectively. There was no difference in the level of angina at follow-up for the two groups.

For patients with one- or two-vessel disease not treated with CABG (n = 433), PI compared with initial medical therapy led to incremental costs during the index hospital stay and at 12 and 36 months of \$11,162 ± \$1,371 (p < 0.001), \$5,702 ± \$979 (p < 0.001) and \$5,004 ± \$1,764 (p < 0.001), respectively. However, patients treated medically less often had no angina (80.1% vs. 85.7%, p = 0.13) and more frequently had CCS class III or IV angina (6.6% vs. 1.5%, p = 0.009) at the latest follow-up visit.

For patients initially treated with PI, the median incremental costs of subsequent need for a single intervention (\$10,482), more than one intervention (\$16,384) or CABG (\$22,809) were high.

Finally, although models of actual costs rather than log_e cost were not as predictive, death during the follow-up period was independently correlated with cost at both 12 months (\$6,804 increment, p = 0.06) and 36 months (\$24,477 increment, p < 0.001).

Table 8. Overall Correlates of Three-Year Log_e Cost*

	Cost Effect (%)†	95% CI	$ Increment	Multiple p Value‡
Transplant recipient	212	198 to 226	80,262	< 0.001
Initial CABG	34.5	27.1 to 41.9	13,043	< 0.001
Initial medicinal Rx	−19.8	−23.4 to −16.2	−7,485	< 0.001
Late CABG	62.3	51.7 to 72.9	23,581	< 0.001
Baseline unstable angina	18.5	13.7 to 23.3	7,020	< 0.001
Late admission	34.1	27.6 to 40.6	12,908	< 0.001
CAD	23.9	16.6 to 31.2	9,049	< 0.001
Baseline CHF	29.5	20.3 to 38.7	11,160	< 0.001
MI ≤2 wk before cath	19.9	14.1 to 25.7	7,528	< 0.001
Late percutaneous Rx	15.2	8.0 to 22.4	5,736	< 0.001
Arrhythmia indication	38.7	24.0 to 53.4	14,644	0.002
Diuretic Rx	14.2	8.8 to 19.6	5,392	0.004
Jeopardy score	4.0/U	2.6 to 5.4	1,519/U	0.004
Baseline creatinine ≥2 mg%	21.3	10.0 to 32.6	8,046	0.029
Antiarrhythmic Rx	14.9	6.5 to 23.3	5,630	0.042

*Constant = 8.905; adjusted multiple r^2 = 0.741. †See Appendix for definition. ‡Univariate and multivariate p values for variable correlated with cost at an earlier follow-up time not entering this model: baseline angina class III/IV, p = 0.009, p = 0.34; baseline catheterization status, p < 0.001, p = 0.96; baseline left ventricular function, p < 0.001, p = 0.90; baseline positive stress test, p = 0.001, p = 0.42; hospital transfer, p = 0.10, p = 0.90; use of cardiac rehabilitation, p = 0.02, p = 0.23; valvular heart disease, p < 0.001, p = 0.53. Abbreviations as in Tables 1, 3 and 4.

Discussion

More than 1 million cardiac catheterizations are performed annually in the United States (21) and the annual cost of caring for patients with CAD in this country has been estimated to be >\$120 billion (2). These figures provide a potentially large target for cost reduction initiatives. Intelligent resource utilization requires insight into the determinants of cost over time and understanding of the clinical effect of any cost reduction measure. For the care of patients with CAD, major gaps exist in our knowledge in both of these areas.

Previous studies. Factors related to the short- and long-term costs after CABG (particularly, patient age, extent of CAD and left ventricular dysfunction and postoperative complications) (8,14) and the short-term costs of PI (particularly, cardiac, renal and bleeding complications) and delays in making the decision to perform the intervention (22) are well studied. Data reflecting our knowledge of factors affecting long-term costs after an initial strategy of either medical or percutaneous treatments are very limited.

From the Randomized Intervention Treatment of Angina (RITA) (3), Emory Angioplasty Surgery Trial (EAST) (23) and the Bypass Angioplasty Revascularization Investigation (BARI) (5) trials have come compelling evidence that although initial costs are higher with CABG, in patients also eligible for percutaneous transluminal coronary angioplasty, costs associated with the latter equal or nearly equal those associated with CABG over 2 to 4 years. Our data confirm this finding in a practice-based rather than clinical trial-based setting. Scant contemporary data exist allowing comparison of medical with either surgical or interventional costs over time.

The results of the present study 1) reemphasize the impact of the initial treatment strategy (medical therapy alone, PI or CABG) on long-term cost, previously noted in more limited analyses (12,15); 2) demonstrate that age and medical comorbidities have only a minimal effect, except for renal dysfunction, on cost over 3 years in this patient group; 3) underscore the importance of late complications on cost; 4) highlight the

relatively diminutive role of outpatient pharmacy and rehabilitation costs on total cost; 5) suggest a cost-savings role for stress testing before cardiac catheterization (at least for those patients eventually requiring catheterization); and 6) document the very low 3-year costs after catheterization showing normal or nearly normal coronary arteries in patients with previous functional test abnormalities.

Implications for cost analyses. Comparisons between treatment strategies or providers must account for potential differences in the characteristics of patients receiving treatment. Both cardiac anatomy (e.g., "jeopardy score" or number of diseased vessels) and functional status (degree of angina and heart failure) were strongly associated with an increased 2- to 3-year cost in the present study. Furthermore, patients transferred from another hospital or with renal dysfunction had augmented costs. Perhaps more surprisingly, treatment of cardiac arrhythmia increased cost very considerably over time, and factors such as age and diabetes mellitus were not demonstrated to be particularly important over the time period studied. (Given the very high costs after heart transplantation, such patients should be considered separately.) Finally, these data provide a framework for estimation of future costs given known baseline patient or patient group characteristics, which may be helpful to managed care organizations and their contractors.

Implications for cost containment. The opportunities for cost reduction suggested by these data are in many ways not surprising, but for many, their relative magnitude has not previously been revealed. For patients with CAD, the cost of revascularization and clinical complications drive overall cardiac costs. Any delay in performing revascularization or any reduction in its cost or the cost of related complications will result in substantial savings—if they are not offset by later morbidity and cost. If these results can be generalized, and one assumes that 50% of costs are variable (unpublished data, Division of Finance, The Cleveland Clinic Foundation, 1994), a 10% reduction in the cost of hospital stay for CABG, for example, with a less invasive approach (24), could save ~$600 million annually in the United States alone. A treatment reducing restenosis after PI by an absolute 10% would save ~$1.0 billion annually. Conversely, it would take at least a 50% reduction of the cost of outpatient medications or from referral to cardiac rehabilitation for the ~1 million patients undergoing catheterization yearly to match these savings.

Finally, the savings engendered by the prevention or delay of later myocardial infarction or cardiac death with treatments such as CABG (25) or use of statin-class lipid-lowering agents (26), measured either in dollars or quality of life, cannot be ignored.

Limitations. Several limitations of this study should be acknowledged: 1) the study reflects data from only a moderate-sized, somewhat self-selected, cohort of patients from a single institution over a relatively short period of time. Cost and charges are recognized to vary, depending on hospital type and location (10). A longer period of follow-up of more patients and more care providers would be useful. 2) Costs associated with newer therapies (e.g., stents placed without adjunctive anticoagulation or use of new platelet inhibitors [6]) are not fully considered. Treatment of CAD is rapidly evolving, and it will always be difficult in such situations to have long-term data that reflect contemporary treatment. 3) This study provides something between a micro and macro clinical perspective. Direct costs from bleeding requiring blood transfusion or potential savings achievable by "streamlining patient care" using critical care pathways cannot be ascertained. 4) Cardiac rather than all medical costs were evaluated. Age and major comorbidities might have had a larger impact were all costs evaluated. 5) The perspective taken, that of the health care provider, does not consider all costs to society (27,28).

These data provide a more comprehensive appraisal of the determinants of cardiac cost in a heterogenous cohort of patients with CAD over time than has previously been available. Their implications for prediction of patient costs and for comparisons of providers and strategies of care are notable.

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Appendix

Statistical Equations and Variables Contributing Independent Prognostic Information in Subset Modeling

Equations:

$$\text{Cost effect} = \text{Incremental cost}/(\text{Cost} - \text{Incremental cost}),$$

where

$$\text{Incremental cost} = \exp(\text{Constant} + \text{Coefficient}) - \exp(\text{Constant}),$$

and

$$\text{Constant} = \text{Constant from regression equation} + (\text{Incidence or mean}_x)(\text{Coefficient}_x) + (\text{Incidence or mean}_y)(\text{Coefficient}_y) + \cdots,$$

where x,y are all covariates in the regression equation, except for the variable being analyzed.

Percutaneous intervention versus coronary artery bypass surgery: (In-hospital)/jeopardy score, congestive heart failure, catheterization status; recent myocardial infarction, creatinine ≥2 mg%, angina class III/IV, hospital transfer, patient age; (12 month)/congestive heart failure, valvular heart disease, creatinine ≥2 mg%, catheterization status; (36 month)/congestive heart failure, left ventricular ejection fraction, catheterization status.

Medical versus percutaneous intervention: (In-hospital)/jeopardy score, recent myocardial infarction, arrythmia indication, previous bypass surgery, catheterization status, unstable angina, angina grade III/IV, positive stress test, height; (12 months)/congestive heart failure, valvular heart disease, recent myocardial infarction, catheterization status, unstable angina, arrythmia indication; (36 months)/jeopardy score, catheterization status, valvular heart disease.

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