

The Influence of New Devices on the Costs of Interventional Procedures

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Abstract

This study compares the costs of different interventional procedures performed in 2,979 patients and examines sources of variability in these costs. Data were obtained from the Emory University Hospital clinical database. Balloon angioplasty was performed in 2,385 (80%) of the 2,979 procedures, and directional atherectomy in 292 (9.8%). A rotoblator was used in 149 (5.0%) of the procedures, an intracoronary stent in 105 (3.5%), and a laser in 48 (1.6%). The device cost rose from \$1,591 ± \$767 with angioplasty to \$4,120 ± \$1,666 with stents. Hospital costs increased from \$9,960 ± \$7,051 with angioplasty to \$20,045 ± \$12,893 with stents. The strongest clinical correlate of hospital cost was the need for coronary surgery. Thus, surgery, when it occurred, added \$17,276 to the cost of the hospitalization, after adjusting for other significant factors. Devices, particularly stents, were the next strongest predictors. The overall ability to predict variation in cost from the models was weak, with a low correlation coefficient (.29) rising to .53 when length of stay was added to the model. Costs are increased by complex procedures (multi-site procedures or those performed with new devices), and by complications, especially coronary surgery after unsuccessful angioplasty. However, the greatest source of variability is prolonged length of stay.

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Interventional cardiology has developed as a field during an era of increasing concern about the costs of medical care. This congruence of trends has led researchers and others to question the appropriateness and costs of coronary angioplasty. In the last 10 years, numerous investigators have studied the costs of this

procedure. The procedure generally is recognized to be expensive, but also as having lower inhospital costs than coronary artery bypass surgery. It is unclear, however, whether this cost savings continues over the long term, as more recurrent procedures are performed after coronary angioplasty than after surgery. Recently, coronary intervention has changed such that many procedures are performed solely with new interventional devices, such as atherectomy and coronary stents, or incorporate them into the operation. These procedures add to cost, although total cost remains less than with coronary surgery.

Neither the sources of variation in the costs of interventional procedures nor the steps that could be taken to reduce costs have been identified clearly. Thus, the purpose of this paper is to present data on the costs of balloon angioplasty and coronary intervention performed with new devices, and to examine sources of variability in costs.

... METHODS ...

Patient Population

We investigated the outcomes and costs in 2,979 patients undergoing interventional procedures at Emory University Hospital between September 1, 1992, and December 31, 1994. This group was selected from among a larger group of 3,336 patients. We eliminated 357 patients for the following reasons: lack of hospital charge data (284 patients); use of more than one new interventional device (33 patients); performance of procedure without use of a device or balloon (28 patients); and use of the TEC device (12 patients). We eliminated patients in whom a TEC device was used because their number was small and eliminated those in whom more than one device was used because that small, heterogeneous group would be difficult to analyze in a meaningful way.

Definitions

We adhered to the following definitions of terms:

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- *Single vessel disease*: greater than or equal to 50% diameter luminal narrowing in either the left anterior descending, left circumflex, or right coronary or a major branch or branches
- *Multiple vessel disease*: the presence of 50% or greater diameter luminal narrowing in two or three major epicardial vessel systems
- *Angiographically successful angioplasty*: all lesions for which repair was attempted improved more than 20% in diameter stenosis and dilated to less than 50% residual diameter stenosis
- *Clinically successful angioplasty*: angiographic success without the complications of myocardial infarction (MI), coronary surgery, or death during the same hospitalization

In addition, the following variables were defined by patient history: hypertension, diabetes, severity of angina, previous MI, and MI during follow up. We used the Canadian Cardiovascular Society Classification for the definition of angina.¹ Congestive failure was defined according to the New York Heart Association criteria.

Procedure and Data Collection

Standard techniques were used to perform all angioplasty procedures.² Baseline and restudy demographic, clinical, angiographic, and procedural data, including data on complications, were recorded prospectively on standardized forms and then entered into a computerized database. All fields were defined in a data dictionary.

Experienced angiographers other than the primary operator who were involved in the procedure measured the preangioplasty, postangioplasty, and restudy angiograms. The angiographic measurements were calibrated to the size of the catheter. The degree of narrowing of each coronary artery lesion was expressed as the percent diameter narrowing of the abnormal segment relative to that of the normal adjacent arterial segments. The diameter stenosis recorded was the mean value determined in two views. These measurements were performed as an ongoing clinical activity; thus, the angiographers were not blinded to the clinical data.

Economic Data and Analyses

We determined the amounts of all hospital charges by examining the UB82 hospital billing form, which is a uniform billing statement that all third-party insurance carriers use. These data were obtained from the hospital finance office. We considered all available codes but did not include charges for catheterizations

performed before the first coronary procedure, or for days the patient spent in the hospital before the procedure.

Costs were estimated from the charge data. The Emory University Hospital Finance Department then used actual resource utilization in each category and variations of microcosting and vertical costing techniques to calculate cost-to-charge ratios. The department determined resource use by measuring, for the procedures, utilization of space, manpower, equipment, and time used for services. The following process was used to determine total charges for specific services and cost centers. After calculating direct costs for each center, the Finance Department added the department-specific indirect cost, according to the step-down allocation methodology used in the Medicare cost reports, as well as an additional amount based on the noncollectible experience of the particular department. An amount for nonpayments then was added. To determine actual hospital resource utilization (costs), the cost-to-charge ratios were calculated from the cost and charge data for each department, and were applied to the sample of patients.

All professional charges were collected through the Emory Clinic. The charges were available for all professional billings for the hospitalization on a subset of 219 of the 2,979 patients.

Statistical Analyses

To compare groups, we used the chi square test (for categorical data) and one-way analysis of variance (for continuous data). When the assumption of normality was violated, largely in the case of the cost data, differences were assessed by the Mann-Whitney or Kruskal-Wallis test. Correlates of cost were determined by multiple regression. As cost data are not normally distributed, the multiple regression was repeated with the natural logarithm of the cost as the dependent variable. We used BMDP and S-Plus statistical software to perform all statistical testing (BMDP Statistical Software, Inc., Los Angeles, CA; S-Plus, MettlySoft, Inc., Seattle, WA).

Data are expressed as proportions or as means plus or minus the standard deviation (\pm SD). Cost data are also expressed as medians.

... RESULTS ...

As shown in Table 1, the following devices or procedures were used to perform the 2,979 interventional procedures: balloon, in 2,385 (80%); directional atherectomy (DCA), in 292 (9.8%); rotoblator, in 149 (5.0%); intracoronary stent, in 105 (3.5%); and laser,

in 48 (1.6%). Although clinical characteristics varied somewhat across the groups, no clear trend was observed. Patients were an average of more than 60 years of age, and the majority in each group were men. Women comprised a smaller percentage of patients in the DCA group than in the other groups. Many patients had diabetes, although they were in the minority in each group. The majority had a history of hypertension, class III or class IV angina, and multi-vessel disease. Congestive failure was less common. Previous MIs were more common in patients in whom balloons or stents were used than in patients in the other groups. Ejection fractions were toward the lower

limit of normal. The majority of patients had undergone previous revascularization procedures, although these procedures were relatively less common in the balloon and DCA groups.

Procedural variables and inhospital outcome are presented in Table 2. Most of the procedures were elective, although the percentage varied among the groups. Multiple-site procedures were performed in a large minority of cases. Vein grafts, performed in a minority, were more common in the stent group than in the other groups.

Angiographic success was achieved in most patients; complications were relatively infrequent.

Table 1. Clinical and Angiographic Characteristics

	Balloon (n = 2,385)	Laser (n = 48)	Rotoblator (n = 149)	Atherectomy (n = 292)	Stent (n = 105)	P Value
Age (yr)	63 ± 11	66 ± 11	66 ± 11	60 ± 11	63 ± 11	0.07
Female (%)	29	29	31	15	27	<0.0001
Diabetes (%)	24	21	20	18	25	0.16
Systemic Hypertension (%)	56	60	55	56	59	0.94
Class 3-4 Angina (%)	83	83	77	82	88	0.2
	(n = 2,294)	(n = 47)	(n = 146)	(n = 287)	(n = 99)	
Congestive Failure (%)	7.7	6.5	6.8	4.5	10.7	0.23
Previous MI (%)	51	36	34	41	59	<0.0001
	(n = 2,242)	(n = 47)	(n = 140)	(n = 277)	(n = 99)	
Multivessel Disease (%)	63	73	64	50	79	<0.0001
Ejection Fraction	54 ± 11	54 ± 9	55 ± 11	55 ± 12	50 ± 14	0.64
	(n = 2,238)	(n = 44)	(n = 137)	(n = 270)	(n = 94)	
Previous Interventional Procedure (%)	42	56	54	42	57	0.0002
Previous Coronary Surgery (%)	29	46	29	24	54	<0.0001

MI = myocardial infarction.

Table 2. Procedure and Outcome

	Balloon (n = 2,385)	Laser (n = 48)	Rotoblator (n = 149)	Atherectomy (n = 292)	Stent (n = 105)	P Value
Emergent (%)	4.9	0	0.7	4.8	3.8	0.08
Multiple Sites (%)	27	31	35	33	30	0.10
Vein Graft Procedure (%)	12	17	3	16	45	<0.0001
Angiographic Success (%)	94	90	95	95	89	0.11
Acute Closure (%)	0.3	2.1	1.3	0.7	3.8	<0.0001
Q Wave MI (%)	0.5	0	1.3	1.7	4.8	<0.0001
Coronary Surgery (%)	1.3	6.2	0	1.7	12.4	<0.0001
Death in Hospital (%)	0.38	4.17	1.34	0.34	1.9	0.0009
Clinical Success (%)	93	88	93	95	80	<0.0001

MI = myocardial infarction.

Table 3. Length of Stay, Charges, and Cost

	Balloon (n = 2,385)	Laser (n = 48)	Rotoblator (n = 149)	Atherectomy (n = 292)	Stent (n = 105)	P Value
Length of Stay (days)	2.4 ± 2.6 (2)	4.8 ± 10.2 (2)	2.4 ± 1.6 (2)	2.5 ± 2.2 (2)	7.4 ± 4.3 (6)	<0.0001
Device Cost (\$)	1,591 ± 767 (1,341)	3,153 ± 1,141 (2,657)	3,554 ± 1,118 (3,439)	2,903 ± 981 (2,697)	4,120 ± 1,666 (3,765)	<0.0001
Hospital Charge (\$)	12,367 ± 9,262 (9,865)	20,706 ± 41,400 (8,470)	14,958 ± 5,396 (13,877)	14,698 ± 9,589 (11,586)	26,380 ± 19,129 (19,922)	<0.0001
Hospital Cost (\$)	9,960 ± 7,051 (8,248)	15,449 ± 27,924 (7,234)	11,833 ± 4,148 (10,930)	11,450 ± 6,694 (9,233)	20,045 ± 12,893 (16,278)	<0.0001

Numbers in parentheses are medians.

Acute closure, which varied among groups, was highest in the stent patients. Q wave MIs, which were observed in only a small percentage of cases, were most common in the stent patients, as was coronary surgery. Although mortality was highest in the laser group, this patient population was small. Clinical success was highest in the balloon, rotoblator, and atherectomy groups and was lowest in the stent group, reflecting the clinical situations in which stents were used.

Mean and median charges were \$13,353 ± \$11,264 and \$10,513, respectively; mean and median costs were \$10,643 ± \$8,194 and \$8,707, respectively; and, for the 219 patients with professional billings, mean

and median total professional charges were \$4,885 ± \$2,302 and \$7,720. Length of stay and hospital costs are shown in Table 3. Length of stay increased from 2.4 ± 2.6 days in the case of balloon angioplasty to 7.4 ± 4.3 days in the stent group. The device cost rose from \$1,591 ± \$767 for balloon angioplasty to \$4,120 ± \$1,666 for stents. Similar results for hospital charges and cost were observed, with costs rising from \$9,960 ± \$7,051 with balloon angioplasty to \$20,045 ± \$12,893 with stents.

Tables 4 through 6 present comparisons of stents used electively or for suboptimal results (in this study, "elective" stents) with stents used for "bailout" required in cases of acute closure or probable acute closure. Ninety-one patients had elective stents; 14 had bailout stents. Although the clinical characteristics of the two subgroups were similar (Table 4), more patients who had had previous coronary surgery were in the elective subgroup. It follows, naturally enough, that more vein graft procedures were performed in the elective subgroup than in the bailout subgroup (Table 5). More to the point, relative to the elective subgroup, a smaller percentage of patients in the bailout subgroup experienced angiographic success, and larger percentages had Q wave MIs and underwent coronary surgery. In addition, a trend of in-hospital death in the bailout subgroup was observed. Device costs and hospital charges were higher in the bailout subgroup, and this subgroup exhib-

Table 4. Clinical and Angiographic Characteristics in Patients with Stents

	Elective (n = 91)	Bailout (n = 14)	P Value
Age (yr)	64 ± 11	59 ± 11	0.15
Female (%)	25	36	0.62
Diabetes (%)	25	21	0.76
Systemic Hypertension (%)	59	57	0.88
Class 3-4 Angina (%)	86	100	0.41
	(n = 88)	(n = 11)	
Congestive Failure (%)	11.2	7.1	0.64
Previous MI (%)	59	54	0.94
	(n = 86)	(n = 13)	
Multivessel Disease (%)	81	64	0.27
Ejection Fraction	49 ± 14	55 ± 12	0.24
	(n = 83)	(n = 11)	
Previous Interventional Procedure (%)	54	79	0.15
Previous Coronary Surgery (%)	63	0	<0.0001

MI = myocardial infarction.

ited a trend for relatively longer length of stay (Table 6).

Determinants of hospital charges and hospital costs are displayed in Tables 7 and 8, respectively. Univariate and multivariate correlates are shown with the added charge or cost, 95% confidence intervals (CIs), and *P* values displayed. In the case of categorical variables, the added cost is for the presence of the variable or event. In the case of continuous variables, the dollar value is for a change of one unit of value. The strongest clinical correlate of hospital cost was the need for coronary surgery. Surgery, when it occurred, added \$17,276 to the cost of the hospitalization, after adjusting for the other significant factors. Devices, particularly stents, were the next strongest predictors after surgery. Cost rose \$45 for each year of age and fell \$34 for each increased point in ejection fraction.

The models could predict variations in costs only weakly ($R^2 = .29$). Using the natural log of cost as the dependent variable failed to produce a higher correlation coefficient ($R^2 = .29$ and $.28$ for charges and costs, respectively). The need for coronary bypass surgery, the use of devices, and multisite procedures remained the strongest correlates of charges and cost. When length of stay was added to the models, R^2 rose to $.62$ for charges, and to $.53$ for costs. Interestingly, the added cost of a coronary stent fell to only \$1,441 (95% CI, \$615 to \$2,269).

... DISCUSSION ...

In this study, we have shown both that coronary interventional procedures remain expensive and that considerable variability in their costs exists. More complicated procedures involving multiple sites or the use of intracoronary stenting result in greater expense and prolonged lengths of stay. Recent efforts to avoid prolonged heparinization after coronary stenting promises to decrease this source of higher cost. Consequently, as cost data become available on patients receiving stents without

heparinization and prolonged hospitalizations, these data will be useful mostly for purposes of comparison. Complications also drove up the cost of an intervention, and major complications did so quite dramatically. Not surprisingly, therefore, bailout stenting was more expensive than elective stent placement. Nonetheless, the clinical variables explained only 29% of the variability in the cost of interventions, and adding length of stay to the model increased this percentage to only 53%. Thus, more detailed information must be obtained to explain other sources of variations in costs.

Several studies have analyzed the determinants of the costs of percutaneous transluminal coronary angioplasty (PTCA). Mark³ proposed analyzing the cost determinants of this procedure in four categories: (1) patient-specific factors; (2) hospital-specific fac-

Table 5. Procedure and Outcome in Patients with Stents

	Elective (n = 91)	Bailout (n = 14)	P Value
Emergent (%)	3.3	7.1	0.48
Multiple Sites (%)	27	43	0.39
Vein Graft Procedure (%)	52	0	0.0009
Angiographic Success (%)	96	43	<0.0001
Acute Closure (%)	0	28.6	<0.0001
Q Wave MI (%)	2.2	21.4	0.01
Coronary Surgery (%)	0	92.9	<0.0001
Death in Hospital (%)	1.1	7.1	0.62
Clinical Success (%)	92	0	<0.0001

MI = myocardial infarction

Table 6. Length of Stay, Charges, and Cost in Patients with Stents

	Elective (n = 91)	Bailout (n = 14)	P Value
Length of Stay (days)	7.1 ± 4.1 (6)	9.0 ± 5.4 (7.5)	0.13
Device Cost (\$)	3,906 ± 1,541 (3,576)	5,510 ± 1,837 (5,472)	0.0006
Hospital Charge (\$)	22,559 ± 14,738 (18,731)	51,217 ± 25,634 (46,353)	<0.0001
Hospital Cost (\$)	17,481 ± 9,860 (15,149)	36,709 ± 17,660 (33,841)	<0.0001

Numbers in parentheses are medians.

tors; (3) treatment-specific factors; and (4) geographic-economic factors. After analyzing patient-specific factors, Topol et al⁴ concluded that charges for PTCA were higher in older patients, women, and

Table 7. Determinants of Hospital Charges

	Univariate		Multivariate ($R^2 = 0.34$; $n = 2,485$)	
	Added Charge (\$)	P Value	Added Charge (\$)	P Value
Emergency Coronary Surgery	34,117 (31,104–37,129)	<0.01	30,040 (22,730–28,590)	<0.01
Inhospital Death	52,373 (45,442–59,304)	<0.01	33,722 (27,522–39,921)	<0.01
Stent	8,928 (3,430–10,426)	<0.01	6,738 (5,456–8,020)	<0.01
DCA/Roto/Laser	4,464 (3,715–5,213)	<0.01	3,369 (2,728–4,010)	<0.01
Multisite Procedure	2,986 (2,145–3,827)	<0.01	3,001 (2,290–3,712)	<0.01
Emergent Procedure	8,824 (6,466–11,182)	<0.01	7,340 (5,340–9,339)	<0.01
Q Wave MI	27,179 (23,026–31,332)	<0.01	12,937 (9,180–16,694)	<0.01
Congestive Failure	4,294 (2,736–5,852)	<0.01	3,196 (1,873–4,519)	<0.01
Age	71 (38–104)	<0.01	64 (35–93)	<0.01
Acute Closure	34,379 (29,018–39,740)	<0.01	10,269 (5,398–15,139)	<0.01
Ejection Fraction	-112 (-145– -79)	<0.01	-55 (-84– -25)	<0.01
Multivessel Disease	2,164 (1,376–2,952)	<0.01	1,161 (477–1,845)	<0.01
Hypertension	1,225 (453–1,997)	<0.01	862 (217–1,507)	0.01
Female	1,052 (190–1,914)	0.02	839 (96–1,582)	0.03
Previous MI	1,615 (849–2,381)	<0.01	262 (-10–534)	0.06
Class 3–4 Angina	1,780 (753–2,807)	<0.01	814 (-44–1,672)	0.06
Previous Coronary Surgery	792 (-51–1,635)	0.07	—	NS
Graft Procedure	1,456 (321–2,591)	0.01	—	NS

DCA = directional atherectomy; MI = myocardial infarction; NS = not significant

Table 8. Determinants of Hospital Costs

	Univariate		Multivariate ($R^2 = 0.29$; $n = 2,485$)	
	Added Cost (\$)	P Value	Added Cost (\$)	P Value
Emergency Coronary Surgery	22,991 (20,684–25,298)	<0.01	17,276 (15,002–19,550)	<0.01
DCA/Roto/Laser	3,162 (2,598–3,726)	<0.01	2,415 (1,917–2,913)	<0.01
Stent	6,324 (5,196–7,452)	<0.01	4,930 (3,834–5,826)	<0.01
Multisite Procedure	2,493 (1,862–3,124)	<0.01	2,461 (1,908–3,013)	<0.01
Inhospital Death	33,617 (28,347–38,887)	<0.01	20,595 (15,783–25,407)	<0.01
Emergent Procedure	6,657 (4,885–8,429)	<0.01	5,834 (4,283–7,384)	<0.01
Q Wave MI	18,644 (15,506–21,782)	<0.01	8,752 (5,836–11,668)	<0.01
Congestive Failure	3,308 (2,138–4,478)	<0.01	2,625 (1,600–3,650)	<0.01
Acute Closure	29,519 (19,470–27,568)	<0.01	7,514 (3,735–11,293)	<0.01
Age	51 (26–76)	<0.01	45 (22–69)	<0.01
Multivessel Disease	1,714 (1,124–2,304)	<0.01	983 (452–1,514)	<0.01
Ejection Fraction	-76 (-101– -51)	<0.01	-34 (-58– -10)	<0.01
Hypertension	939 (358–1,519)	<0.01	673 (171–1,175)	0.01
Female	656 (7–1,305)	0.05	498 (-28–1,074)	0.09
Class 3–4 Angina	1,160 (388–1,932)	<0.01	504 (-162–1,170)	0.14
Previous MI	1,020 (444–1,596)	<0.01	144 (-68–367)	0.18
Previous Coronary Surgery	707 (74–1,340)	0.03	—	NS
Graft Procedure	1,069 (634–1,504)	0.01	—	NS

DCA = directional atherectomy; MI = myocardial infarction; NS = not significant.

patients with a history of previous MI. With respect to hospital-specific factors, teaching hospitals had significantly lower charges than did nonteaching hospitals, except in the Midwestern United States. As might be expected, complications increase costs. According to analysis of the fourth category, the West had the highest charges, and the Midwest had the lowest ones. Compared with an initially successful procedure, unsuccessful PTCA more than doubles hospital charges.⁵ Charges are higher for nonelective procedures, for procedures in patients with more severe symptoms, and in older patients.⁶

Guzman et al⁷ compared the hospital cost of atherectomy (n = 126) with that of angioplasty (n = 126). The cost of atherectomy was 28% higher than the cost of angioplasty (\$9,345 ± \$8,856 versus \$7,301 ± \$4,637, respectively). In another study,⁸ the researchers reduced charges to costs, using departmental cost-to-charge ratios, and then used 1991 data to compare the costs of angioplasty (n = 113), atherectomy (n = 34), stenting (n = 64), and coronary surgery (n = 89). Costs of stenting were higher than those of angioplasty or atherectomy, but none were as expensive as coronary surgery. Dick et al⁹ also found atherectomy and stenting to be more expensive than balloon angioplasty. None of these studies included professional costs.

In a recent study, which bears some similarity to the present one, Ellis et al¹⁰ examined the correlates of the cost of angioplasty. Baseline characteristics, complications, and length of stay partly accounted for variability in costs. Cohen et al¹¹ analyzed in-hospital and 1-year costs in patients in the STRESS trial who were randomized to coronary stenting or balloon angioplasty. Initially, coronary stenting added approximately \$2,200 to hospital costs. Because relatively less additional revascularization developed after stenting, however, the difference fell to approximately \$800 by 1 year.

Several studies compared charges for PTCA and coronary artery bypass grafting (CABG). Length of stay is considerably shorter with PTCA than it is for CABG, and resource use during the initial hospitalization is two to three times less for uncomplicated PTCA.^{5,12-14} Although charges at 1 year also are lower for PTCA, restenosis may limit the cost advantage of the procedures.⁵ The major factors in the cost of PTCA that contributed to overall costs were the early failure (30%) rate (with early crossover to CABG) and the 33% restenosis rate; more than 80% of these patients required repeat revascularization.

The study by Black et al¹⁴ was the only one of these nonrandomized, comparative-charge studies, specifi-

cally to consider patients with multivessel disease. The authors examined direct hospital and professional charges for 100 patients undergoing PTCA and 100 patients undergoing CABG. Although charges for angioplasty were lower than those for coronary surgery, charges were used as a proxy for costs, and indirect costs were not calculated.

Weintraub et al¹⁵ estimated costs for 787 patients with two-vessel coronary artery disease (CAD) whose treatment consisted of either PTCA or CABG. Despite a cumulative increase in costs in the PTCA group over time, overall costs at 5 years remained significantly lower than CABG costs. In a Dutch study,¹⁶ the initial cost of coronary surgery was more than twice that of angioplasty. However, because patients who had had angioplasty required additional procedures, the cost differential had decreased by 1 year.

Hlatky et al¹⁷ examined in-hospital resource utilization in patients undergoing CABG or PTCA. The investigators developed four scales to compare the economic costs of the two procedures: (1) cost of supplies; (2) cost of personnel and supplies; (3) average direct costs; and (4) average direct costs plus hospital overhead. Using charges as a proxy for economic costs overstates the cost difference between CABG and PTCA when the proxy method is compared with any of the four accounting methods. Furthermore, the estimated differences between CABG and PTCA decrease as the stringency of the definition of marginal costs increases (ie, the differences are smallest when scale 1 is used and greatest when scale 4 is used).

Two randomized, controlled trials in the United States—the Emory Angioplasty vs Surgery Trial (EAST)¹⁸ and the Bypass Angioplasty Revascularization Investigation Substudy of Economics and Quality of Life (BARI SEQOL)¹⁹—currently are studying the short- and long-term cost differences between PTCA and CABG in patients with multivessel CAD. EAST is a 392-patient trial conducted at Emory in which eligible patients with multiple-vessel coronary disease were randomized to angioplasty or coronary surgery. At 3 years, no differences between treatment arms were observed either in the primary composite end point of death, Q wave MI, or large ischemic thallium defect or in any component of the primary end point. However, the difference in additional revascularization procedures required was substantial, as the group randomized to angioplasty had much higher rates of additional coronary surgery and coronary angioplasty.

In the trial, costs were measured as hospital costs plus professional charges.²⁰ Hospital costs were derived from charges by applying departmental cost-to-

charge ratios, reducing the charge from each department to costs, and totaling the derived costs. The sum of hospital costs and professional charges, in 1987 dollars, was \$16,223 ± \$11,552 for the angioplasty group and \$24,005 ± \$6,222 for the surgery group ($P < 0.0001$). After inflating to 1993 dollars, these figures would have been \$24,821 ± \$17,675 and \$36,728 ± \$9,520 for angioplasty and surgery, respectively. At 3 years, in 1987 dollars, the sum of professional charges and hospital costs was \$23,734 ± \$15,798 for coronary angioplasty (median, \$19,059) and \$25,310 ± \$7,480 for coronary surgery (median, \$23,572). The difference, although small, was statistically significant ($P < 0.0001$). Inflated to 1993 dollars, the sum would have been \$36,313 ± \$24,171 for angioplasty (median, \$29,160) and \$38,724 ± \$11,444 (median, \$36,065) for surgery. Thus, because the angioplasty group required additional procedures, most, although perhaps not all, of the initial cost advantage of angioplasty over surgery for multivessel disease was lost by 3 years.

BARI is a multicenter trial that has enrolled 1,800 patients and includes prospective information on economic costs and quality of life, which are anticipated. Two European randomized trials of PTCA and CABG also include economic end points. The Randomised Intervention Treatment of Angina (RITA) is a British study of 1,011 patients.^{21,22} In a partial simulation, the initial cost of angioplasty was 50% that of surgery; the 2-year cost was 80% that of surgery, with a difference of £1,011. The second European trial, the German Angioplasty Bypass Intervention (GABI) study, has enrolled 358 patients.²³ Initial procedure costs were \$16,562 for CABG and \$5,000 for PTCA. After 1 year, although little increase in cumulative costs had occurred in the CABG group, cumulative costs in the PTCA group had risen to \$11,250. Similarly, in a randomized trial of PTCA versus coronary artery bypass surgery conducted in Argentina,²⁴ the in-hospital and 1-year costs of surgery were higher than those of angioplasty.

Measurement of cost has proved to be a challenging enterprise in medicine. In-hospital cost generally is not measured directly. Consequently, average charges from hospital finance departments probably are the most common source of cost data. In so-called "top-down" cost accounting, the relationship of cost to charge, by department, is used to estimate average costs from charge data. More recently, "bottom-up," or activity-based, cost accounting has attempted to determine the cost of services directly from the services provided. Any determination of cost must be viewed as an estimate, however, because the cross-subsidization inherent in a financial organization as

complicated as a hospital makes the direct determination of cost quite difficult.

In addition, most cost studies have measured average costs, as opposed to marginal costs. The marginal cost of a procedure is the cost of one additional procedure of the same type. Marginal cost is of particular importance to administrators, as this type of cost reflects the value to the institution of performing additional procedures; payers are more interested in average costs. Which type of cost is of greatest interest depends on the question asked, and who is asking.

Determining physician professional costs also is a significant challenge. Studies of the economics of revascularization rarely have measured professional charges. Furthermore, it is essential that all professional charges—rather than only procedural charges—be included in any such estimate. Moreover, there is no empiric reason to believe that professional charges are meaningful estimates of costs. Although the Resource Based Value Scale is a possible alternative tool for determining professional charges,^{25,26} it has been used only infrequently in clinical series or trials to estimate costs.²⁷ Given these various measurement challenges, any presentation of costs must be viewed as an estimate, and actual measurement of resource utilization an unobtainable goal. This problem limits comparisons of costs across studies and across institutions.

Although reducing or containing the costs of coronary revascularization has become a major priority, attempts to do so must be made with caution. Recognition of measurement challenges, such as those discussed here, constitutes an initial necessary step. Cost reductions should not affect care adversely or, as shown by cost-effectiveness analysis, should have an acceptable impact on care. Determining an acceptable level of risk associated with cost-saving measures is beyond the scope of this paper. However, some comments are in order. In evaluations of new therapies, cost per quality-adjusted life-year saved has been found to be acceptable to values as high as \$100,000. If a patient who undergoes angioplasty is expected to live 20 years, then an amount on the order of \$2 million should be saved before the loss of one life can be considered reasonable. Thus, it would seem that cost savings must be accomplished at very low risk indeed. Attempts to save money in ways that may pose a risk to the welfare of patients should best be evaluated in clinical trials.

In attempting to minimize cost, it is important to first recognize whose costs are being reduced. In principle, the goal is to reduce costs to society so that precious resources might be used for other purposes.

25. Becker ER, Dunn D, Hsiao WC. Relative cost differences among physicians' specialty practices. *JAMA* 1988;16:2397-2408
26. Hsiao WC, Braun P, Dunn D, Becker ER. Resource-based relative values. *JAMA* 1988;16:2347-2360.

27. Becker ER, Mauldin PD, Weintraub WS, King SB III. Physician profiles of coronary revascularization in the Emory Angioplasty vs Surgery Trial: Understanding physician differences using Resource-Based Relative Values. (Abstract) *J Am Coll Cardiol* 1995;25:344A.