

In-Hospital Costs Associated with New Percutaneous Coronary Devices

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To determine the relative economic impact of alternative methods of coronary revascularization, in-hospital patient accounts were reviewed in 149 patients undergoing elective coronary angioplasty (n = 50), coronary atherectomy (n = 72) or intracoronary stent placement (n = 27) over an 18-month period. Clinical and angiographic features were similar in the 3 groups, except that prior restenosis was seen more often in patients undergoing intracoronary stent placement. Procedural success, obtained in >90% of patients, was independent of the treatment strategy. Total in-hospital stay was significantly longer in patients undergoing intracoronary stent placement than in patients undergoing coronary angioplasty and directional atherectomy (4.9 ± 2.4 days vs 1.5 ± 1.3 and 2.2 ± 3.9 days, respectively; p < 0.0001). Furthermore, the total in-hospital charges were significantly higher in patients undergoing intracoronary stent placement (\$12,574 ± \$4,564 vs \$6,220 ± \$5,716; p < 0.001) and directional atherectomy (\$8,329 ± \$8,588 vs \$6,220 ± \$5,716; p < 0.01) than in patients undergoing coronary angioplasty, reflecting overall differences in room costs, laboratory fees and pharmacy fees. The longer in-hospital stay in the intracoronary stent group was primarily attributed to the time required for anticoagulation with coumadin. It is concluded that a 102 and 34% increase in early hospital charges resulted with stenting or directional atherectomy, respectively, compared with coronary angioplasty. These increased in-hospital charges were chiefly due to the prolonged hospitalization time, device cost, laboratory fees and, in patients with intracoronary stents, the prolonged time needed to achieve systemic anticoagulation.

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Since its introduction in 1977,¹ 2 major limitations have been noted after coronary angioplasty. First, despite pretreatment with antiplatelet agents and heparin, abrupt vessel closure develops in 4 to 7% of cases within 24 hours of the procedure.^{2,3} Second, delayed restenosis, often requiring a repeat revascularization procedure, develops in 30 to 40% of patients within the subsequent 3 to 6 months.⁴ As a result of these shortcomings, alternative mechanical techniques such as intracoronary stenting,⁵⁻⁷ atherectomy,^{8,9} and laser angioplasty¹⁰ have been advocated.

Whereas initial investigation using these new devices has focused on defining safety and clinical efficacy, little attention has been focused on the economic impact of these new technologies. Prior retrospective series have suggested that coronary angioplasty may be less costly than bypass surgery,¹¹⁻¹⁵ but no previous study has compared the incremental costs of the use of alternative mechanical devices with standard coronary angioplasty. Therefore, we analyzed in-hospital charges from 149 patients undergoing coronary angioplasty, coronary atherectomy or intracoronary stenting procedures.

METHODS

Patient population: From January 1, 1989, to June 30, 1990, 1,014 coronary interventions (coronary angioplasty, 858; directional coronary atherectomy, 116; intracoronary stent, 40) were performed at the University of Michigan Medical Center. For the purposes of this analysis, only patients with New York Heart Association class II to III angina undergoing elective coronary revascularization, admitted specifically for the procedure, were selected for the study. To avoid potential bias or imbalance of acuity of illness, patients with acute myocardial infarction, cardiogenic shock or unstable angina were excluded from the analysis. Patients were not excluded with multivessel disease, abnormal left ventricular function, or complex lesion morphology according to American College of Cardiology/American Heart Association guidelines.¹⁶ An intention-to-treat principle was adapted with inclusion of patient data irrespective of the success of the revascularization procedure.

CORONARY ANGIOPLASTY: Random selection of 50 patients undergoing coronary angioplasty was performed

by reviewing every twelfth case record of the 858 angioplasty cases attempted during the study period. Unless contraindicated, all patients were pretreated with aspirin. After administration of a 10,000-unit bolus of heparin, coronary angioplasty was performed using standard methods.^{1,2} Additional heparin was administered hourly and, in the presence of thrombus or dissection, a heparin infusion was continued for an additional 12 to 24 hours, maintaining the partial thromboplastin time 1.5 to 2.5 times control. Patients who developed hemodynamic instability or prolonged myocardial ischemia were admitted to an intensive care unit; patients without complications were admitted to a specialized care unit for observation. Generally, 8Fr sheaths were used for coronary angioplasty and 8 hours of bedrest were prescribed after sheath removal.

DIRECTIONAL CORONARY ATHERECTOMY: Of the 112 patients undergoing coronary atherectomy using the Simpson AtheroCathTM (Devices for Vascular Intervention, Redwood City, California) during the study period, 40 were excluded because of unstable symptoms requiring hospitalization before atherectomy ($n = 37$) or because audited accounts were unavailable for review ($n = 3$). The remaining 72 patients were included in the analysis. After premedication as for patients undergoing coronary angioplasty, coronary atherectomy was performed using an 11Fr sheath by the method previously described.¹⁷ After atherectomy, in the absence of ischemic complications or coronary dissection, patients were admitted to a specialized care unit for observation. In general, 11 hours of bedrest were prescribed after sheath removal.

INTRACORONARY STENT PLACEMENT: Of the 40 patients undergoing stent implantation during the study period, 13 were excluded owing to unstable symptoms requiring hospitalization at the time of intracoronary stent placement ($n = 11$) or because audited accounts were unavailable for review ($n = 2$). The 27 remaining patients composed the study group. In addition to aspirin and a calcium antagonist, all patients undergoing intracoronary stent placement were pretreated with dipyridamole and intravenous dextran beginning 4 hours before the procedure. After predilation using standard angioplasty methods, intracoronary stent placement (Palmaz-Schatz Stent, Johnson and Johnson Interventional Systems, Warren, New Jersey) was performed using previously described methods.^{5,18} After stent implantation, patients continued to receive intravenous heparin until adequate oral anticoagulation could be obtained with coumadin (prothrombin time 1.5 times control). A 9 to 11Fr sheath was used for stent placement and was removed within 12 hours after intracoronary stent placement. In the absence of bleeding at the

periaccess site, 9 to 11 hours bedrest after sheath removal were recommended.

Procedural success and in-hospital complications: Procedural success was defined as a final diameter stenosis $<50\%$ and the absence of in-hospital ischemic complications, including coronary bypass surgery, myocardial infarction or abrupt closure. Significant bleeding complications were defined by a decrease in the hematocrit to $<25\%$ or those requiring a blood transfusion. Hematomas were defined as a $>4\text{ cm} \times 4\text{ cm}$ collection of subcutaneous collection of blood at the periaccess site.

Analysis of procedural charges: After patient discharge, the audited in-hospital accounts of the 149 patients used in this analysis were reviewed; only patient expenditures directly related to the procedure performed were included. During the study period of 1989 to 1990, the cost/charge ratio for all services at the University of Michigan Medical Center was 0.76.

CARDIAC CATHETERIZATION CHARGES: Procedure duration (in hours) was used to estimate personnel and equipment allocation for each of the 3 methods of revascularization and a time-adjusted catheterization room charge was determined. Additional charges within the cardiac catheterization laboratory included charges for intravascular sheaths, guiding catheters and balloon dilatation catheters. Under the investigational protocols operational during the study period, expenditures for intracoronary stents and atherectomy devices were not applied to individual patient accounts, but were borne directly by the hospital. To estimate the total procedural costs, the hospital charges by the investigational device manufacturer were added individually to the cardiac catheterization charges. During the study period, per patient hospital charges were \$1,095 for the atherectomy equipment (atherectomy device, \$850; guiding catheter, \$130; motor drive unit, \$90; hemostatic valve, \$25) and \$1,000 for each intracoronary stent. Professional fees for any procedure and charges for out-patient services were not included in the analysis.

PHARMACY CHARGES: During the hospitalization period, pharmacy charges covering intravenous fluids and medications including aspirin, a calcium antagonist and analgesics were tabulated for all patients. In patients with intracoronary stents, the charge for oral coumadin and dextran were also added.

LABORATORY CHARGES: Routine plasma chemistries and hematologic profiles were obtained in all patients before and after the procedure. Coagulation profiles including a thrombin clotting time and heparin units were obtained in patients who continued to receive intravenous heparin after the procedure and in patients

TABLE I Clinical and Angiographic Features Before Revascularization

Feature	Coronary Angioplasty (n = 50)	Directional Atherectomy (n = 72)	Intracoronary Stenting (n = 27)
Age (years)	60 ± 12	58 ± 11	58 ± 11
Gender (% men)	33 (66)	56 (78)	89 (24)
Coronary risk factors			
Cigarette smoking (%)	26 (52)	31 (43)	15 (56)
Systemic hypertension (%)	20 (40)	30 (42)	7 (26)
Diabetes mellitus (%)	5 (10)	10 (14)	5 (18)
Hypercholesterolemia (%)	24 (48)	44 (61)	16 (59)
Family history (%)	23 (46)	46 (64)	17 (63)
Prior cardiac history			
Previous infarction (%)	17 (34)	27 (38)	17 (63)*
Coronary bypass (%)	11 (22)	13 (18)	8 (30)
Prior coronary angioplasty (%)	12 (24)	22 (31)	25 (93)*
Time from angioplasty (mos)	6.5 ± 4.6	7.5 ± 9.0	4.8 ± 4.4
Multivessel disease (%)	20 (40)	28 (39)	13 (48)
Target artery			
Left anterior descending (%)	17 (34)	4 (6)†	7 (25)
Right coronary (%)	14 (28)	19 (26)	10 (39)
Left circumflex (%)	17 (34)	7 (10)	6 (21)
Saphenous vein graft (%)	2 (4)	3 (4)	3 (11)
Left main (%)	0 (0)	1 (1)	1 (4)
Medication			
Nitroglycerin (%)	26 (52)	35 (49)	13 (50)
Calcium antagonists (%)	32 (64)	54 (75)	9 (68)
β blockers (%)	14 (28)	13 (18)	12 (43)
Aspirin (%)	50 (100)	67 (93)	25 (93)

*p < 0.05 for intracoronary stent versus angioplasty/atherectomy.
†p < 0.05 for atherectomy versus angioplasty/intracoronary stent. Systemic hypertension defined by a diastolic blood pressure > 105 mm Hg; hypercholesterolemia defined by a total serum cholesterol > 240 mg/dl.

undergoing intracoronary stent placement, until therapeutic oral anticoagulation was achieved. Remaining laboratory tests and any indication for blood transfusion was left to the discretion of the individual physicians caring for the patients.

ROOM CHARGES: In general, patients were admitted to a specialized care unit with continuous cardiac monitoring after the procedure. Daily hospital charges for this classification of hospital bed were \$606 to \$656/day. Patients with prolonged myocardial ischemia, hemodynamic compromise or other cardiac complications admitted to the intensive care unit were charged \$1,545/day.

INCIDENTAL CHARGES: All patients also received accounts for incidental charges. These charges included the charge for telemetry, respiratory care therapy equipment, extra lines required for intravenous therapy and use of infusion pumps.

Ambulatory status during hospitalization: To determine the relative patient dependency during hospitalization, medical records were reviewed to determine ambulatory status of patients during hospitalization. The following classification was used: (1) bedrest-sheath in place — time from completion of the procedure

TABLE II Procedural Success and In-Hospital Complication Rate

Event	Coronary Angioplasty (n = 50)	Directional Atherectomy (n = 72)	Intracoronary Stenting (n = 27)
Procedural outcome			
Primary success (%)	46 (92)	66 (92)	2 (93)
Primary failures (%)	3 (6)	5 (7)	25 (7)
Urgent CABG (%)	1 (2)	1 (1)	0 (0)
In-hospital complications			
Subacute closure (%)	1 (2)	0 (0)	1 (4)
Recath-chest pain (%)	0 (0)	0 (0)	5 (19)
Femoral artery			
Bleed (%)	0 (0)	0 (0)	4 (15)*
Hematoma (%)	1 (2)	6 (8)	3 (11)*
Vascular repair	0 (0)	1 (1)	2 (7)
CNS complication (%)	0 (0)	1 (1)	0 (0)

*p < 0.05 compared with coronary angioplasty and directional atherectomy.
CABG = coronary artery bypass grafting; CNS = central nervous system event; Recath = repeat cardiac catheterization.

until the sheath removal; (2) bedrest-sheaths removed — period after the sheath removal until ambulation, and including any time required because of hematomas or femoral artery bleeding; and (3) ambulatory — time from ambulation until discharge, including the period of oral anticoagulation in patients undergoing intracoronary stent placement.

Statistical analysis: Continuous variables are expressed as mean ± 1 standard deviation. Differences between continuous variables were analyzed using analysis of variance for multiple comparisons and differences in frequencies were analyzed using chi-square analysis. Nonparametric analysis was applied when appropriate. Differences at p < 0.05 were considered significant.

RESULTS

Clinical characteristics, procedural outcome and in-hospital complications: Clinical findings in patients undergoing coronary revascularization are listed in Table I. Procedural success obtained in >90% of procedures did not vary significantly by treatment strategy (Table II). Repeat angiography for recurrent chest pain in patients undergoing intracoronary stent placement was performed for chest discomfort and any suggestive electrocardiographic changes of ischemia. In the 5 patients undergoing repeat coronary arteriography for recurrent chest pain in this group, abrupt closure was demonstrated in only 1. Femoral artery rebleeding and hematoma formation were more frequent in patients undergoing intracoronary stent placement, although hematoma formation was not significantly different from patients undergoing directional atherectomy. Notably, patients undergoing intracoronary stent placement had

significantly longer periods of bedrest-sheaths in place, bedrest-sheaths removed, and in-hospital ambulatory status than patients undergoing coronary angioplasty or directional atherectomy (Figure 1).

In-hospital charge analysis: Although the in-hospital stay was similar for patients undergoing coronary angioplasty and directional atherectomy, significantly longer hospital stays were required in patients undergoing intracoronary stent placement (Table III). This longer in-hospital period was associated with higher room charges, laboratory and pharmacy fees, and total hospital charges in the intracoronary stent group. Thus, the total in-hospital charges for intracoronary stent placement was slightly more than double that of standard coronary angioplasty and >30% greater than di-

rectional atherectomy ($p < 0.001$) (Figure 2). Directional coronary atherectomy was also associated with 34% higher hospital charges than coronary angioplasty.

DISCUSSION

Because of limitations of coronary angioplasty, including abrupt vessel closure^{2,3} and late restenosis,⁴ alternative methods of coronary revascularization have been investigated.⁵⁻¹⁰ Despite encouraging angiographic and clinical results using these alternative techniques,¹⁹ little attention has been focused on the potential economic cost of their more widespread application. To define the relative resource allocation required by coronary angioplasty and 2 of these alternative methods, directional atherectomy and intracoronary stent-

TABLE III Duration of Hospitalization and Itemized In-Hospital Charges

	Coronary Angioplasty (n = 50)	Directional Atherectomy (n = 72)	Intracoronary Stenting (n = 27)
Hospital duration (days)	1.5 ± 1.3	2.2 ± 3.9	4.9 ± 2.4*†
In-hospital charges (\$)			
Cath laboratory charge	4,044 ± 974	3,406 ± 1,289	5,518 ± 1,546*†
Device cost	Included	1,260 ± 386	1,150 ± 362
Pharmacy charges	158 ± 231	313 ± 787	454 ± 287*†
Laboratory charges	290 ± 470	582 ± 1,144*	989 ± 805*†
Room charges	964 ± 1,019	1,703 ± 2,961	3,376 ± 2,308*†
Miscellaneous	763 ± 3,730	1,066 ± 4,032	1,087 ± 887
Total charges (\$)	6,220 ± 5,716	8,329 ± 8,588*	12,574 ± 4,564*†
% Increase over coronary angioplasty	—	+34	+103

*p < 0.01 compared with coronary angioplasty; †p < 0.01 compared with directional atherectomy. Cath = catheterization.

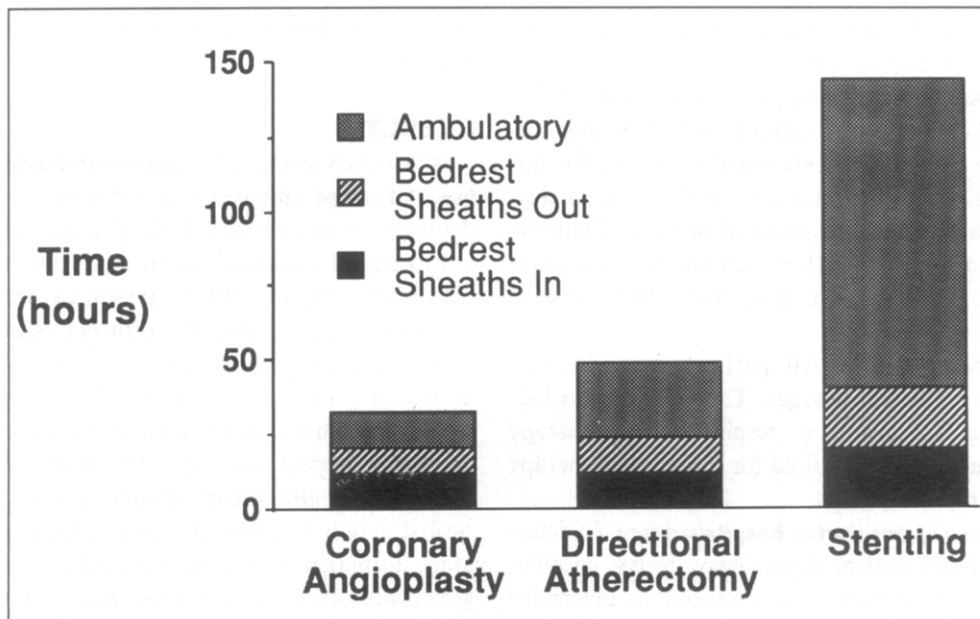


FIGURE 1. Ambulation status of patients undergoing nonsurgical coronary revascularization. Patients undergoing intracoronary stenting had significantly longer in-hospital stays, primarily reflected by longer periods of bedrest with sheaths out and ambulation before hospital discharge than coronary angioplasty or directional atherectomy.

ing, the present study was performed by reviewing the in-hospital accounts of 149 patients undergoing elective revascularization using one of these techniques. Compared with patients undergoing coronary angioplasty, in-hospital charges were 102% higher in patients undergoing intracoronary stent placement and 34% higher in patients undergoing directional atherectomy. Significantly longer hospitalization periods required in patients undergoing stent placement accounted for most of the increased in-hospital charges.

Prior studies estimating the economic costs of coronary angioplasty have, in general, reviewed audited in-hospital and 1-year total charges.¹²⁻¹⁵ However, the use of hospital charges as a substitute for true economic costs may have important limitations.²⁰ In-hospital charges are often discounted by third-party payers, so that reimbursement may actually be less than the aver-

age true economic cost of a service.¹⁵ To compensate for losses in one area, hospitals may "cost-shift," charging more than the true economic cost for other services that are more substantially reimbursed by third-party payers.²⁰

Hlatky et al²¹ used standard cost-accounting methods to relate direct costs plus allocated hospital overhead, an index of true economic cost, to hospital charges. In the 389 patients evaluated, direct costs plus allocated hospital overhead were 0.78 of hospital charges, not dissimilar from the estimated cost-charge ratio of 0.76 in the present study. Provided that hospital charges for each service would be discounted by the same cost/charge ratio — an assumption that may be inaccurate in the event of "cost-shifting" — the results of the present study would suggest that intracoronary stent placement may require more than twice the im-

TABLE IV Prior Trials Comparing Coronary Angioplasty and Coronary Bypass Surgery

Study	No. of Vessels	No. of Pts.	Hospital Days		In-Hospital Charges (\$)		Ratio	Follow-Up Period
			PTCA	CABG	PTCA	CABG		
Jang (1984) ¹¹	Single	361	4 ± 2	12 ± 5	5,313 ± 2,159	15,580 ± 2,159	2.9	In-hospital
Reeder (1984) ¹²	Single	168	9.4	13.1	11,384	13,387	1.2	1 year
Kelly (1985) ¹³	Single	112	5 ± 4	10 ± 4	7,689	13,559	1.8	1 year
Black (1988) ¹⁴	Multi-	200	5	13	9,138	22,771	2.5	1 year
Barbash (1986) ¹⁵	Multi-	52	6 ± 5	—	8,500 ± 4,700	—	*	In-hospital
Hlatky (1990) ²¹	Single	389	7 ± 4	14 ± 6	9,556 ± 5,251	19,644 ± 9,157	2.0	In-hospital
Present study	Multi-	50	2 ± 1	—	6,220 ± 5,176	—	*	In-hospital

*Includes only elective coronary angioplasty.
CABG = coronary artery bypass grafting; multi- = multivessel; PTCA = coronary angioplasty; ratio = ratio of in-hospital charges of coronary bypass surgery/coronary angioplasty.

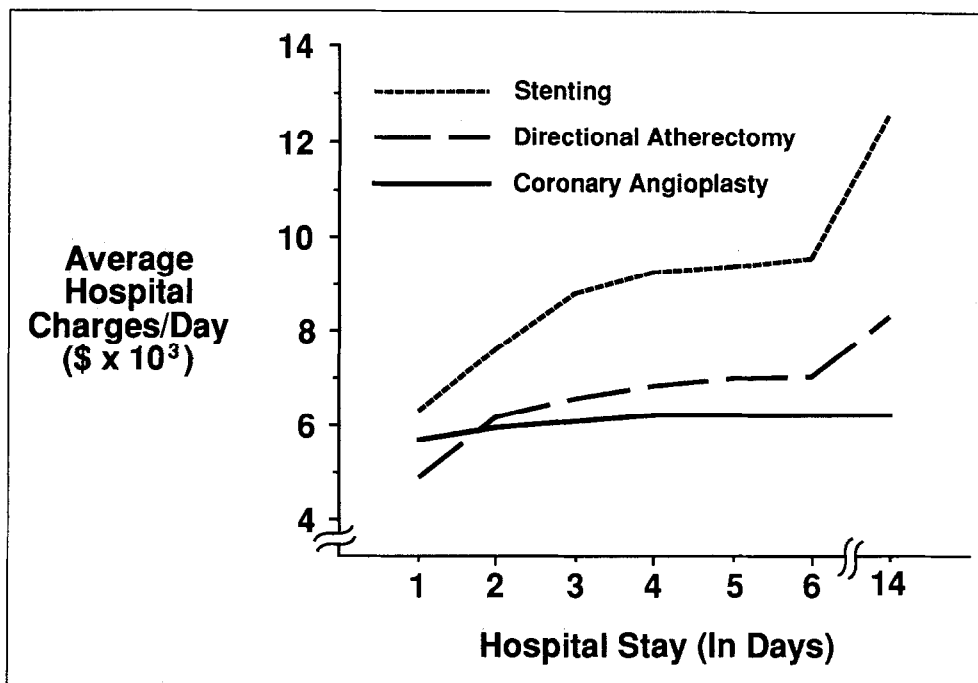


FIGURE 2. Average in-hospital cumulative daily charges for patients undergoing nonsurgical revascularization. Patients undergoing intracoronary stenting had significantly higher in-hospital charges throughout the hospital period.

mediate in-hospital economic resources as standard coronary angioplasty; directional coronary atherectomy may require nearly 40% more resources than coronary angioplasty.

Several factors influenced in-hospital charges for the 3 treatment strategies. The postprocedural in-hospital stay for patients undergoing balloon angioplasty (2 ± 1 days) was substantially shorter than the in-hospital stay reported in prior studies (range 5 to 14 days) (Table IV). Furthermore, accounting for 1989 dollars, the in-hospital charges for balloon angioplasty were also lower in the present report, reflecting the elective nature of the study population, the same day admission policy for coronary angioplasty, and more rapid hospital discharge with uncomplicated patients. As a result, the comparatively high in-hospital charges with directional atherectomy and intracoronary stent may simply reflect the evolution of lower in-hospital charges associated with coronary angioplasty. In fact, the 5-day hospital stay for patients with an intracoronary stent in the present study is not substantially different from the length of stay with historic cohorts of coronary angioplasty (Table IV). Vascular complications occurred more often in patients undergoing stent placement and directional atherectomy than in patients undergoing coronary angioplasty, often prolonging the hospitalization period. Whereas increased operator experience and modification in equipment design may reduce the noted vascular complication rate, the requirement for systemic anticoagulation in patients undergoing stent placement necessitates longer periods of in-hospital observation. Potentially, the development of nonthrombogenic stents will permit shorter periods of in-hospital observation in the future.

Admittedly, the present study examines only the immediate in-hospital charges associated with coronary angioplasty, directional atherectomy and intracoronary stenting. Estimation of the overall economic cost of these procedures would require inclusion of the subsequent "induced-costs" associated with late restenosis.²² In a previous study examining the economic costs associated with coronary angioplasty, restenosis was associated with \$10,641 of additional hospitalization charges, although the number of patients treated with coronary bypass surgery for restenosis was high.¹² Despite multiple pharmacologic approaches aimed at its prevention, restenosis still develops in up to 40% of patients within the 3 to 6 months after coronary angioplasty.⁴ Although it is hoped that restenosis will be lower using directional atherectomy and intracoronary stenting, it has been reported in patients undergoing these procedures.^{17,18} A definitive reduction in restenosis and associated induced-costs using these techniques will require randomized trials.

Several previous studies have compared hospital charges associated with coronary angioplasty and coronary bypass surgery (Table IV), convincingly demonstrating the potential economic savings of coronary angioplasty in patients with single^{11,12} and multivessel coronary artery disease.^{14,15,21} Whereas the duration of follow-up has varied in these different studies, the ratio of hospital charges associated with coronary bypass surgery to coronary angioplasty has ranged from 1.2 to 2.9. Notably, many patients undergoing intracoronary stent placement in the present study had unsuccessful coronary angioplasty 1 or more times. Before introduction of the intracoronary stent, these patients would have been candidates for coronary bypass surgery alone, and compared with surgical patients from these historic controls, the in-hospital days and hospital charges associated with intracoronary stent placement are still quite favorable.

The present study has several important limitations. First, these comparative data are derived from a non-randomized study with new device use in a relatively early stage of development. Modifications in equipment design and operator technique may result in future reductions of in-hospital charges for these alternative devices. Second, as previously noted, the present study includes only immediate in-hospital charges, and does not include either charges associated with late restenosis, charges associated with the increased surveillance associated with intracoronary stents such as coagulation profile monitoring required during 2 to 3 months of anticoagulation, or the social impact of these devices on patient lifestyle and back-to-work status. Therefore, the long-term economic benefits of these devices may not be fully realized. Finally, the technique of coronary angioplasty is in constant evolution. Whereas patient selection criteria have broadened, hospitalization days have shortened and in-hospital charges have been lower. Similarly, the major source of increased in-hospital charges in patients undergoing intracoronary stent placement in the present study was a prolonged in-hospital stay, partially attributed to an increased bleeding complication rate and requirement for systemic anticoagulation associated with intracoronary stenting. Earlier sheath removal and alternative anticoagulation schemes, such as an adjusted subcutaneous dose of heparin²³ and bedside coagulation monitoring, and the development of nonthrombogenic intracoronary stents may substantially reduce the required hospitalization time in future studies.

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