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Interventional Cardiology

The Impact of Statistical Adjustment on Economic Profiles of Interventional Cardiologists

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OBJECTIVES The objective of this study was to identify preprocedure patient factors associated with percutaneous intervention costs and to examine the impact of these patient factors on economic profiles of interventional cardiologists.

BACKGROUND There is increasing demand for information about comparative resource use patterns of interventional cardiologists. Economic provider profiles, however, often fail to account for patient characteristics.

METHODS Data were obtained from Duke Medical Center cost and clinical information systems for 1,949 procedures performed by 13 providers between July 1, 1997, and December 31, 1998. Patient factors that influenced cost were identified using multiple regression analysis. After assessing interprovider variation in unadjusted cost, mixed linear models were used to examine how much cost variability was associated with the provider when patient characteristics were taken into account.

RESULTS Total hospital costs averaged $15,643 (median, $13,809), $6,515 of which represented catheterization laboratory costs. Disease severity, acuity, comorbid illness and lesion type influenced total costs (R^2 = 38%), whereas catheterization costs were affected by lesion type and acuity (R^2 = 32%). Patient characteristics varied significantly among providers. Unadjusted total costs were weakly associated with provider, and this association disappeared after accounting for patient factors. The provider influence on catheterization costs persisted after adjusting for patient characteristics. Furthermore, the pattern of variation changed: the adjusted analysis identified three new outliers, and two providers lost their outlier status. Only one provider was consistently identified as an outlier in the unadjusted and adjusted analyses.

CONCLUSIONS Economic profiles of interventional cardiologists may be misleading if they do not adequately adjust for patient characteristics before procedure. (J Am Coll Cardiol 2001;38:1416–23)

The demand for information about the cost and quality of health care has increased dramatically. Health care purchasers, providers and consumers alike seek information to help them make better decisions in the health care market. Provider profiling has emerged as an appealing method of comparing the quality and cost of services (1). Initial profiling efforts in interventional cardiology compared patient outcomes at the hospital level (2). However, within institutions there can be great variability among physicians in both resource use patterns and clinical outcomes. This individual variability is of concern to patients seeking the best care, to institutions striving to provide efficient, high quality care and to payers trying to minimize health care expenditures (1,3,4).

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A major challenge in comparing procedural outcomes among providers is to adequately adjust for baseline patient characteristics that affect outcomes. Failure to account for differences among providers in patient risk may bias profiles in favor of providers who treat low risk patients (5–9). In some areas, such as cardiac surgery, risk-adjustment models for mortality are well developed and support ongoing profiling efforts (10). Less is known about the impact of patient mix on economic profiles. Available evidence suggests that failure to account for variation among providers in patient characteristics can distort provider comparisons (11). Because the data and statistical resources needed to construct economic profiles that account for patient risk far exceed those required to create unadjusted profiles, it is critical to determine whether unadjusted profiles can suffice.

In this study we examined the impact of baseline patient characteristics on economic profiles of interventional cardiologists. Specifically, we identified patient factors that influence catheterization laboratory and total hospital costs associated with percutaneous coronary intervention. We then assessed variability among providers in the cost of interventions before and after adjusting for baseline characteristics. The results of this study will contribute to the

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Abbreviations and Acronyms

CHF = congestive heart failure
LAD = left anterior descending artery
MI = myocardial infarction
PCI = percutaneous coronary intervention

search for credible and feasible methods that can be used to compare care cost and quality among providers.

METHODS

Patient population. All patients who had a percutaneous coronary intervention (PCI) at Duke University Medical Center between July 1, 1997, and December 31, 1998, were eligible for this study. Patients were excluded if their clinical records could not be linked to corresponding cost records or if critical clinical and/or cost data were missing.

Data sources. Baseline clinical and demographic data were obtained from the Duke Information System for Clinical Computing. For each catheterization laboratory encounter, the database includes demographic data, comorbid illnesses, baseline severity of illness, preintervention procedures and intervention characteristics. Data are entered by cardiology fellows who are not associated with any particular attending interventional cardiologist. Cost data were obtained from the Duke Transition Accounting System. This system contains detailed resource use at the intermediate product level within each department (e.g., hours of care by inpatient unit, number of diagnostic tests by type of test, quantity of abciximab), along with fixed and variable unit costs for each intermediate product. Total and variable costs can be calculated for specific items, for each department and for the entire admission.

Outcomes assessed. Both total hospital cost and variable catheterization costs were examined in this study. Total hospital cost includes variable and fixed costs for the admission and reflects procedural resource use as well as costs arising from any postprocedure complications. However, it also includes the cost of preprocedure care that may have little to do with the procedure itself. Variable catheterization costs include only the costs directly associated with the procedure itself and, therefore, reflect resource use that is most directly under the control of the provider.

Explanatory variables. In our investigation of patient factors that influence cost, candidate variables included baseline characteristics previously found to affect either the resource use or mortality associated with PCI (12–15). For admissions with more than one interventional procedure, baseline risk was determined by clinical status at the time of the first procedure. Explanatory variables considered included demographic characteristics (age, gender, race), comorbid illnesses (diabetes, prior stroke, chronic pulmonary disease, peripheral vascular disease, cerebrovascular disease, liver disease, renal disease), baseline severity of illness (myocardial infarction [MI], ejection fraction, number of diseased vessels, prior coronary bypass, prior PCI), and intervention characteristics (number, location and percent stenosis of attempted lesions). We also controlled for pre-intervention diagnostic catheterizations. For multivessel interventions, a hierarchical definition of target vessels was developed after examining the cost and frequency of intervention location combinations. The hierarchy included four levels, the first of which was graft, followed by right coronary artery, left anterior descending artery (LAD) or left main and left circumflex artery. The attending interventional cardiologist was included as an explanatory variable in order to assess the extent to which individual providers exerted an influence on cost.

Statistical analysis. Patient characteristics and costs were first examined for the entire sample using descriptive statistics. To assess the extent of variation in cost among providers, before taking into account the patient's baseline characteristics, the providers were treated as random effects in a linear model (Proc Mixed, SAS Institute, Cary, North Carolina). Next, the influence of patient characteristics on cost was explored using multiple linear regression models. For variables with missing values (ejection fraction, number of diseased vessels, congestive heart failure [CHF], race), the value of missing was incorporated as a separate level in a categorical variable. Finally, we incorporated patient factors found in the linear regression analyses to influence cost as fixed effects in mixed linear models to examine how much variability in cost was associated with the provider after adjusting for these patient factors. These mixed models take into account the correlation among patients within providers and in addition provide shrunken estimates that adjust for variability arising from small provider sample sizes (16).

In each of the statistical models, the dependent variable was log-transformed so that residuals would be more normally distributed. The terms in these models are additive on the log scale (e.g., $\log \text{Cost} = a + b_1X_1 + b_2X_2 + \ldots$). Thus, when exponentiated, the parameter(s) operate as effect multiplier(s) on the outcome variable (total hospital cost, variable catheterization cost). For example, the presence of a certain baseline characteristic with a multiplier of 1.1 signifies a 10% increase in costs associated with that variable. A provider multiplier $>$1.0 suggests that the provider's patients tended to consume more resources than other providers' patients, whereas a multiplier of $<$1.0 indicates that the provider's patients had lower resource use. A multiplier of 1.0 (corresponding to a parameter estimate of 0.0) indicates that the provider performing the procedure had no independent effect on cost.

RESULTS

Sample selection. A total of 2,445 hospitalizations at Duke University Medical Center involved percutaneous coronary interventions during the study period (July 1, 1997, to December 31, 1998). Of these, 255 (10%) were excluded

Table 1. Baseline Patient Characteristics

Demographics	
Age (yrs; mean ± SD)	61 ± 12
Gender (% male)	65
Race (% white)*	83
Severity of illness (% of patients)	
MI	
≤6 h	4
>6–24 h	3
1–7 days	27
>7 days	21
None	45
Ejection fraction*	
<30%	4
30–39%	7
40–55%	32
>55%	57
Number of diseased vessels*	
1	81
>1	19
Prior coronary artery bypass graft	21
Prior PCI	23
Comorbid illness (% of patients)	
CHF*	19
Creatinine	
<1.5 mg/dl	93
1.5–2 mg/dl	5
>2 mg/dl	2
Peripheral vascular disease	13
Cerebrovascular disease	9
Diabetes	28
Chronic obstructive pulmonary disease	8
Intervention characteristics (% of patients)	
Number of attempted lesions	
1	69
2	23
3	6
>3	2
Maximum percent stenosis	
75%	19
95%	71
100%	10
Preintervention diagnostic catheterization	
Prior to intervention (same admission)	43
During same catheterization laboratory visit as intervention	13
Location(s)	
Graft	10
Right coronary artery	38
LAD	36
Left circumflex artery	28
Left main artery	1

*Missing values: race, 14%; ejection fraction, 26%; multivessel disease, 3%; congestive heart failure, 2%.

CHF = congestive heart failure; LAD = left anterior descending artery; MI = myocardial infarction; PCI = percutaneous coronary intervention.

because of incomplete data or because clinical data could not be linked with cost data. We then restricted the sample to the first admission of each patient during the study period (n = 1,957). Analyses are reported for the 13 providers with caseloads of ≥50 procedures (n = 1,949).

Overall patient characteristics. The mean age of patients was 61 years (SD = 12) (Table 1). Most patients were men (65%) and white (83%). Over half had a history of MI, with 7% having an event in the 24 h preceding their procedure. Of the patients, 11% had a low ejection fraction (<40%) and 19% had CHF. Most patients (81%) had single-vessel disease. Prior revascularization was common; 21% of patients had a history of bypass surgery and 23% had undergone a previous PCI. Diabetes was the most common comorbid illness (28%), followed by peripheral vascular disease (13%), chronic obstructive pulmonary disease (8%) and renal insufficiency (7%). Most interventions (69%) targeted a single lesion, and 10% of interventions involved a totally occluded vessel. The most frequently targeted vessels were the right coronary artery and LAD (38% and 36%, respectively). Of the interventions 10% involved a graft.

Resource use: Overall and among providers. Total hospital cost averaged $15,643 (median, $13,809), $9,033 (58%) of which was variable (Table 2). Mean total length of stay was 3.7 days (median, 3 days), with a mean postprocedure stay of 2.4 days (median, 1 day). Variable catheterization costs accounted for over two-thirds of variable cost, followed by routine room cost (9%), intensive care unit cost (5%) and emergency room cost (4%) (Table 2). Use of both stents and abciximab was fairly high (82% and 73% of cases, respectively) and together accounted for half of catheterization expenses. Other major catheterization expenses were for balloons and hospital-based labor.

Using the multiplier estimates from the random effects models, median total and catheterization costs were calculated for each provider. Median total hospital costs ranged among providers from $12,922 to $15,501 (Fig. 1). The random effects model for total cost indicated that the overall provider effect approached significance ($p = 0.09$), but accounted for little (2%) of the variation. The model identified a low and a high outlier (providers F and K, respectively, in Fig. 1). The provider effect on variable catheterization costs was slightly stronger than for total cost, with 3% of variation being explained ($p = 0.06$). Median variable catheterization costs ranged among providers from $5,235 to $6,547 (Fig. 2). Two high-cost outliers (providers K and M) and one low-cost outlier (provider J) were identified. Underlying this variation in catheterization costs was considerable variability in the use of stents and abciximab. Abciximab use ranged from a low of 52% of cases to a high of 90% of cases. Stent use was slightly less variable, with rates ranging from 67% to 89% of cases.

Influence of patient characteristics on cost. Multiple linear regression was used to identify baseline patient factors that were associated with total cost and catheterization cost. Patient characteristics associated with both higher total cost and catheterization cost included MI (with higher cost for more recent events), more attempted lesions, higher percent stenosis and graft interventions (Table 3). Patients who had prior PCIs tended to have lower costs. As anticipated, a diagnostic catheterization performed before the procedure increased both total cost and catheterization cost. Total cost was also influenced by age, extent of disease and comorbid

Table 2. Mean Variable and Total Cost, by Department*

	Variable Cost ($)	Percent of Variable	Total Cost ($)	Percent of Total
Catheterization laboratory				
Balloons	961	11	1,424	9
Stents	2,172	23	3,219	0
Abciximab	1,142	13	1,494	9
Guide catheters/wires	318	4	472	3
Contrast dye	481	5	713	5
Hospital-based labor	880	10	2,114	6
Other	561	6	832	4
Catheterization laboratory subtotal	6,515	72	10,268	66
Intensive care	457	5	975	6
Routine/stepdown care	753	9	1,791	12
Emergency	407	4	850	5
Pharmacy	238	3	406	3
Labs	179	2	378	2
Diagnostic tests/procedures	276	3	528	3
Respiratory therapy	95	1	244	2
Operating room	73	1	139	1
Other	40	< 1	64	< 1
Grand total	9,033	100	15,643	100

*Costs in 1998 U.S. dollars.

illness: cost increased with ejection fractions <40%, renal insufficiency, CHF and multivessel disease. Gender was significant only in the catheterization model, with female patients having higher costs. Overall, the models explained 38% of variation in total cost and 32% of variation in catheterization cost.

Variation among providers in patient factors associated with cost. There was significant variation among providers in baseline patient factors found to influence cost (Table 4). For example, the proportion of elderly patients ranged from 7% to 26%, the proportion of patients having their intervention within 24 h of an MI ranged from 4% to 14%, the proportion with a multilesion intervention ranged from 18% to 44%, and the proportion of cases involving a totally occluded vessel ranged from 6% to 28%.

Provider variation in cost after adjustment for patient characteristics. Given the variability among providers in both baseline patient characteristics and cost, we reexamined the influence of provider on total cost and catheterization cost after accounting for patient factors using mixed linear models. After adjustment, total cost no longer varied among providers (0.4% of variation explained; $p = 0.39$) (Fig. 3). In contrast, the overall provider effect on variable catheterization costs persisted after taking into account patient risk (3% of variation explained; $p = 0.06$) (Fig. 4). Furthermore, despite the small absolute size of the provider effect, the pattern of variation among providers changed. Two new high outliers (providers B and L) and one new low outlier (provider I) were identified by the model. The two providers who had been identified as high outliers in the

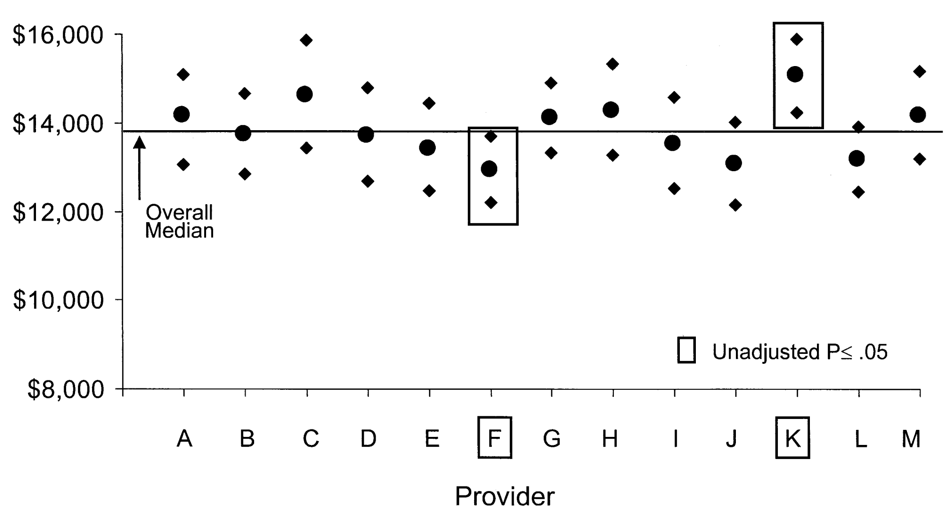

Figure 1. Provider variation in unadjusted total cost. Median unadjusted total cost **(circles)** and associated confidence interval **(diamonds)**, as estimated by the random effects model, are presented for each provider. The overall median is represented by the **solid line**. Data points and labels of outlier providers are outlined with **rectangles**.

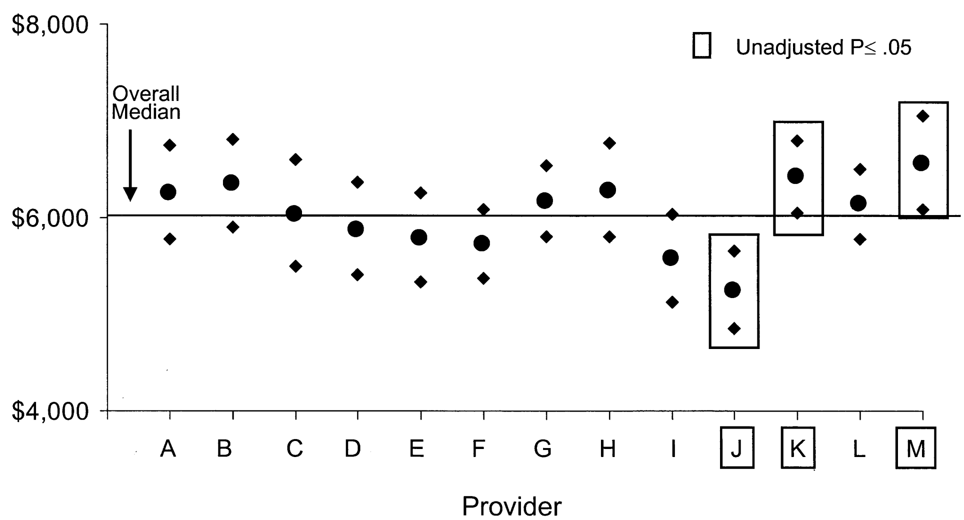

Figure 2. Provider variation in unadjusted catheterization cost. Median unadjusted catheterization cost **(circles)** and associated confidence interval **(diamonds)**, as estimated by the random effects model, are presented for each provider. The overall median is represented by the **solid line**. Data points and labels of outlier providers are outlined with **rectangles**.

unadjusted analyses lost their outlier status. Only one provider (provider J) was consistently identified as a low outlier in both the adjusted and unadjusted analyses.

DISCUSSION

This study examined the impact of risk-adjustment on economic profiles of interventional cardiologists. Our results suggest that economic profiles that fail to take into account patients' baseline characteristics may incorrectly identify some providers as outliers, while failing to recognize true outliers. Thus, unadjusted economic profiles cannot contribute to efforts to understand and optimize resource use in PCI.

Impact of patient factors on provider comparisons. The importance of statistically adjusting cost for the influence of patient characteristics stems from two factors. First, preprocedural patient factors had a major effect on the use of both catheterization laboratory and total hospital resources, explaining one-third of variation in the cost of each. Second, the severity of illness of patients varied among providers. If all providers treated a similar mix of patients, statistically adjusting for patient characteristics would not be critical in provider comparisons, regardless of the strength of association of patient factors with cost. However, variation in patient mix among providers is likely to exist in many institutions owing to differences in providers' experience, skill, and willingness to attempt high-risk cases. Our findings support the results of studies in other therapeutic areas that examined the impact of statistical adjustment for patient factors on interprovider comparisons of resource use (7,11). Our results are also consistent with studies of the impact of risk-adjustment on provider profiles of mortality (6,8,17).

Previous research. This study represents the first analysis of provider effect on PCI cost that appropriately accounts for the correlation among patients within providers and for the varying sample sizes for individual providers. One previous analysis found a much larger provider effect on total and catheterization costs (15). This divergent finding could be due to several factors, including the method of analysis, the small sample size and the fact that providers from different practice settings were included (both university-based and private practice).

Factors associated with cost. Ours is also the first study to explore the major cost drivers for coronary intervention patients since the widespread adoption of stents and GP IIb/IIIa inhibitor therapy. We found that these two new technologies accounted for almost half of catheterization laboratory expenses. Consistent with earlier analyses of percutaneous intervention costs, both total cost and catheterization costs were significantly influenced by the characteristics of patients undergoing the procedure (13–15,18). In particular, variables reflecting disease severity, acuity, comorbid illness and lesion type influenced total costs, whereas catheterization costs were primarily affected by acuity and lesion type. It is important to note that several of the important variables influencing total cost and most of the factors affecting catheterization costs are not available in administrative databases. Therefore, it appears unlikely that profiles of physician costs could be appropriately adjusted for patient risk using readily available claims data.

Use of economic profiles. The information provided by this study is necessary but not sufficient to compare the practice efficiency of individual providers. Ideally, risk-adjusted economic profiles would be combined with clinical outcomes, such as rates of target vessel revascularization, MI, and death at six-month follow-up in order to assess the relative benefits of various practice styles. Such an integrated assessment of both resource use and patient outcomes is needed to determine which (if any) changes in practice

Table 3. Multiple Regression Analysis of Total Cost and Length of Stay (n = 1,949)*

Explanatory Variable	Log Total Hospital Cost		Log Variable Catheterization Cost	
	Multiplier†	p Value	Multiplier†	p Value
Intercept	8,041		4,518	
Age (per 10 yrs)	1.02	0.02	n/a	n/a
Gender (reference = male)	n/a	n/a	0.94	< 0.001
MI (reference = none)		< 0.001		< 0.001
≤6 h	1.52		1.07	< 0.01
>6–24 h	1.49		1.11	
1–7 days	1.22		1.06	
>7 days	1.07		1.04	
Ejection fraction (reference = ≥55%)		< 0.001	n/a	n/a
≤29%	1.15			
30–39%	1.25			
40–55%	1.03			
Missing	1.09			
Multivessel disease (reference = single)		0.002	n/a	n/a
>1 vessel	1.07			
Missing	1.03			
Prior PCI	0.87	< 0.001	0.89	< 0.001
CHF		< 0.001	n/a	n/a
Yes	1.07			
Missing	0.87			
Creatinine (reference = <1.5 mg/dl)		< 0.001	n/a	n/a
1.5–2 mg/dl	1.11			
>2 mg/dl	1.23			
Cerebrovascular disease	n/a	n/a	n/a	n/a
Diabetes	n/a	n/a	n/a	n/a
No. of attempted lesions (reference = 1)		< 0.001		< 0.001
2	1.24		1.37	
3	1.38		1.67	
>3	1.66		1.94	
Maximum % stenosis (reference = 75%)		< 0.001		< 0.001
95%	1.04		1.06	
100%	1.18		1.22	
Target vessel (reference = left circumflex artery only)		0.003		< 0.001
Graft	1.10		1.13	
Right coronary artery	1.08		1.08	
LAD/left main artery	1.04		1.03	
Diagnostic catheterization preceding intervention	1.36	< 0.001	1.20	< 0.001
Concomitant diagnostic catheterization	1.10	0.003	n/a	n/a
Model performance (R^2)	0.38		0.32	

*n/a = variable not in final model. †Exponentiated parameter estimates from log models.
Abbreviations as in Table 1.

patterns would minimize cost while maintaining quality of care. However, the economic profiles alone can provide valuable objective information regarding interprovider differences in resource use. As such, they can serve as a starting point for discussions among providers about the range and relative merits of alternative approaches to percutaneous intervention cases.

Study limitations. Detailed cost and clinical data were needed to construct the adjusted economic profiles in this study. While we characterized patient risk as completely as possible, some risk factors that may influence cost and clinical outcome, such as lesion complexity, were not available in the clinical database. In addition, a small but significant proportion of patients had to be excluded from our study because of clinical or cost data that were invalid, missing, or could not be linked. Integrated economic and clinical data systems would significantly reduce the cost and

Table 4. Range Among Providers in Baseline Patient Characteristics

Characteristics	Minimum	Maximum
Sample size	50	302
Risk factors (% of patients)		
Age ≥75 years	7	26
Diabetes	20	34
Creatinine >1.5 mg/dl	3	13
Severity of illness (% of patients)		
CHF	12	23
Prior PCI	16	31
Multivessel disease	6	26
MI ≤24 h	4	14
Ejection fraction <40%	6	17
Intervention type (% of patients)		
100% stenosis	6	28
Multilesion	18	44
Location = graft	3	15

Abbreviations as in Table 1.

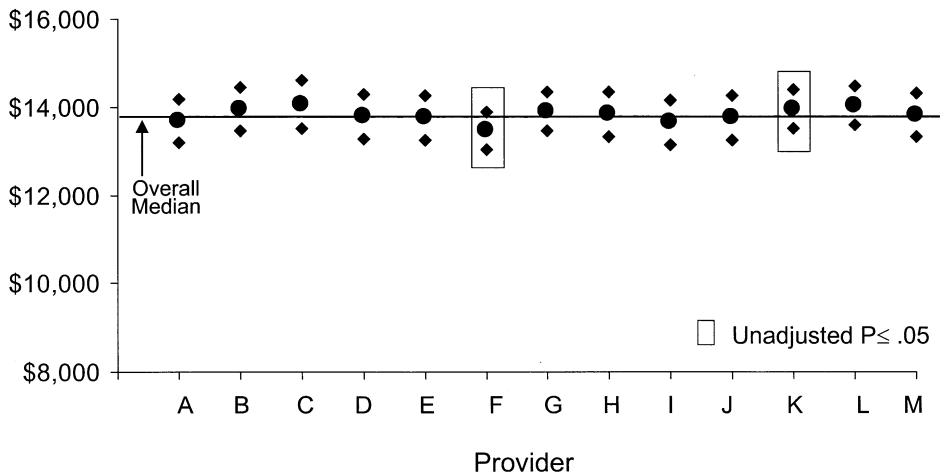

Figure 3. Provider variation in adjusted total cost. Median adjusted total cost **(circles)** and associated confidence interval **(diamonds)**, as estimated by the mixed effects model, are presented for each provider. The overall median is represented by the **solid line**. No outlier providers were identified. For reference, data points of outlier providers identified in the unadjusted analysis are outlined with **rectangles**.

time lag associated with economic profiling. Timely results are critical in the field of interventional cardiology owing to the continual adoption of new devices and adjunctive therapies.

Generalizability. Although this study clearly demonstrates the importance of statistically adjusting economic profiles of interventional cardiologists, the specific findings may not be generalizable to other institutions or time periods. The absolute magnitude of variation associated with providers in this study was relatively small (<5% of the total variation). This may be due to the tendency of providers working together at one institution to develop similar practice patterns over time. Variation might be greater among providers practicing in different institutions or based in different settings (e.g., a mix of private practice and university-based providers). The findings also reflect the particular time period studied, which was after the widespread adoption of both stents and abciximab at Duke University Medical Center. With the recent evidence suggesting eptifibatide may be an effective GP IIb/IIIa inhibitor in PCI, considerably more diversity in practice patterns may develop.

Conclusions. This study demonstrates the perils associated with economic profiling without statistical adjustment for patient characteristics. Although it may be relatively inexpensive and tempting to compare provider resource use and costs using unadjusted administrative data, the results may be misleading and potentially harmful to quality-improvement efforts. Payers and providers will need to invest in integrated clinical and cost data systems so as to have meaningful comparative outcomes data with which to guide clinical practice.

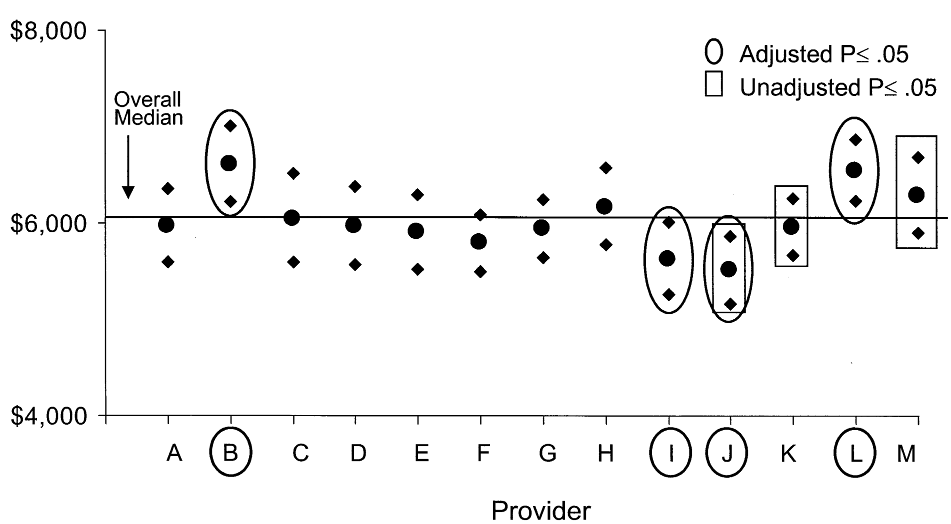

Figure 4. Provider variation in adjusted catheterization cost. Median adjusted catheterization cost **(circles)** and associated confidence interval **(diamonds)**, as estimated by the mixed effects model, are presented for each provider. The overall median is represented by the **solid line**. Data points and labels of outlier providers are outlined with **ovals**. For reference, data points of outlier providers identified in the unadjusted analysis are outlined with **rectangles**.

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