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Physician-Attributable Differences in Intensive Care Unit Costs: A Single Center Study

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ABSTRACT

Rationale: Variation in practice and outcomes, not explained by patient or illness characteristics, is common in health care, including in intensive care units.

Objective: To quantify within-intensive care unit, between-physician variation in resource use in a single medical intensive care unit.

Methods: Prospective, noninterventional study in a medical intensive care unit where 9 intensivists provide care in 14 day rotations. Consecutive sample of 1184 initial patient admissions whose care was provided by a single intensivist. Multivariate models were constructed for average daily discretionary costs, intensive care unit length of stay, and hospital mortality, adjusting for patient and illness characteristics, and workload.

Measurements and Main Results: The identity of the intensivist was a significant predictor for average daily discretionary costs ($p<0.0001$), but not intensive care unit length of stay ($p=0.33$) or hospital mortality ($p=0.83$). The intensivists had more influence on costs than all other variables except the severity and type of acute illness. Average daily discretionary costs varied by 43% across the different intensivists, equating to a mean difference of $1003 per admission between the highest and lowest terciles of intensivists.

Conclusions: There are large differences among intensivists in the amount of resources they use to manage critically ill patients. Higher resource use was not associated with lower length of stay or mortality.

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Key words: Health services research, Costs and cost analysis, Health resources; Intensive care units

INTRODUCTION:

Widespread variation in practice and outcomes, not explained by patient or illness characteristics, is common in health care. Variation is found for many parameters in a broad range of settings (1-12), and is not limited to the U.S. (13-19). Large variation has also been noted in Intensive Care Units (ICU) (1, 7, 10, 16, 20-24). Such variation is important because it suggests that suboptimal care may be common.

Substantial variation in patterns of care and outcomes has been attributed to individual physicians (4, 9, 13, 20, 25-28). However, we are not aware of any published reports that quantitatively address variation in ICU care attributable to individual intensivists.

We hypothesized that there is important within-ICU, between-physician variation in the cost of ICU care that can be specifically attributed to the intensivists. We also hypothesized that intensivists cannot accurately judge the magnitude of resources they use in providing care.

Some of the results of these studies have been previously reported in the form of an abstract (29).

METHODS:

We prospectively collected this data in the 13-bed, closed model, medical ICU of a 520-bed county-owned, university-affiliated teaching hospital between July 2002 and March 2005, excluding March-May 2004 due to personnel limitations. The rotating ICU team comprises a board-certified intensivist, an ICU fellow, and five house officers who take overnight call on a 1-in-5 rotation. Nine intensivists assigned to 14 day intervals shared ICU coverage. Neither the intensivist nor ICU fellow stay in the hospital overnight. More detailed information about the organization and functioning of this ICU are available in the online supplement.

Multivariable linear or logistic models were constructed for average daily discretionary ICU costs, ICU length of stay (LOS), and hospital mortality. We log-transformed cost and LOS, and defined discretionary costs as including pharmacy, radiology (imaging and interventional), laboratories, blood bank and echocardiography. We expressed costs obtained from the hospital's cost analysis system (Trendstar, McKesson Corporation, San Francisco, CA) as $U.S. 2005. ICU LOS was measured in hours. Because transfer out of the ICU is often delayed due to limited ward bed availability, ICU LOS was defined as the interval from ICU admission until transfer was requested. To uniquely associate care with intensivists, we included patients only if the same intensivist was on duty each day of their ICU admission. To avoid erroneous mortality rates we analyzed only initial admissions.

The impact of the intensivists was assessed by including indicator variables in the models. Models included adjustments for demographics, comorbidities, type and severity of acute illness, invasive mechanical ventilation, the source of ICU admission, ICU workload, and any limitations placed of life-supporting therapies prior to ICU admission. Demographics were age, gender, and race dichotomized into Caucasian vs. non-Caucasian. Comorbidity was quantified as the number of comorbid conditions, as described by Elixhauser *et al*. (30). Acute diagnostic grouping was the organ system or illness responsible for ICU admission (respiratory, cardiovascular, gastrointestinal, neurologic, miscellaneous medical conditions, or surgical conditions including trauma). Severity of acute illness was measured as worst value in the initial 24 hours of the Glasgow Coma Scale score (GCS) (31), and the APACHE II acute physiology score excluding it's neurologic subcomponent (APS-N) (32). The source of ICU admission was the emergency department, hospital ward, another ICU, an outside hospital, or other sources. ICU workload was measured as the number of ICU admissions per day, and the ICU census averaged over each patient's ICU LOS. The cost model also included the actual time in the ICU as a covariate. Additional detail on modeling is provided in an online data supplement.

To evaluate the intensivists' ability to discern their practice styles, after reviewing the observed variation in discretionary costs, each intensivist completed a survey in which he guessed his position on this continuum using a visual analog scale. We assessed how accurately the intensivists judged their relative ranking of discretionary costs using Spearman rank correlation.

Data are presented as mean ± SD, or as proportions. P-values < 0.05 are considered significant. Groups were compared using the t-test, Fisher's exact test, or Hotelling's T-squared test. Statistical analysis was performed using Stata 9.1 (StataCorp LP, College Station, Texas). This study was approved by the Institutional Review Board.

RESULTS:

During the study period there were 1184 patients cared for by a single intensivist during their initial ICU admission. The mean number of patients cared for by the 9 intensivists was 132 ± 67 (range 32-253). These patients' characteristics are shown in Table 1. The respiratory system was the organ system most frequently responsible for ICU admission, comprising 27% of the patients. Three-quarters of admissions were from the emergency department. Slightly less than one-quarter of patients required invasive mechanical ventilation. Mean ICU LOS was 37.8 ± 30.3 hrs (range 0.2-219.5 hrs). The ICU mortality rate was 7.3%, and another 5.3% survived the ICU but died before hospital discharge.

The model for average daily discretionary costs had an adjusted-$R^2 = 0.255$. All the covariates were significantly related to these costs except for race, the presence of an end-of-life order prior to ICU admission, and ICU workload. Gender was of borderline significance ($p=0.053$). The identity of the intensivist was highly significant ($p<0.0001$). To put these changes in perspective, Table 2 shows the relative predictive power of variables in the model. The influence of the intensivist on discretionary costs was less than that of the severity or type of acute illness, but greater than all other predictors, including comorbidities, demographics, the source admission to the ICU, and whether the patient required intubation.

To further illustrate the differences between intensivists, Table 3 shows the adjusted average daily discretionary costs for each intensivist in three different clinical scenarios: (1) a 40 year old Caucasian female with diabetes, admitted for respiratory failure and intubated in the emergency department with GCS=14, APS-N=11, who spent 5 days in ICU, (2) a 68 year old African-American male with 5 major comorbid conditions, admitted to the ICU from an outside hospital for upper gastrointestinal hemorrhage due to hepatic cirrhosis, with GCS=9, APS-N=22, a Do Not Resuscitate order prior to transfer, who died after 70 hrs in the ICU, and (3) a 20 old Caucasian female with no comorbid conditions, admitted to ICU from the emergency department for a suicide attempt via drug overdose, with GCS=15, APS-N=0 who was in ICU for <24 hrs. In these 3 scenarios, the mean adjusted average daily discretionary costs ranged $884-1261, $1578-2250, and $407-581, respectively. Thus, discretionary ICU costs per day varied by 43% depending on which intensivist guided care.

To further investigate intensivists' spending, we compared the total discretionary costs incurred during each patients' entire ICU stay for the three highest-spending intensivists with those of the three lowest-spending ones. Table 4 shows that there is no predominant category of discretionary costs which distinguish higher from lower spenders.

We conducted sensitivity analyses to evaluate the robustness of our findings. We modeled the discretionary costs excluding intensivist I, who had the fewest number of patients in this data set. It showed virtually identical results, with an adjusted-$R^2=0.245$, and a p-value<0.0001 for the intensivist identity. We then modeled discretionary costs limited to the first ICU day in all 2342 patients admitted during the study period. This model had an adjusted-$R^2=0.142$ and the intensivist's identity was statistically significant (p=0.036).

The ICU LOS model had an adjusted-$R^2=0.136$. Significant predictors were age, APS-N, source of ICU admission, intubation status and ICU workload. The intensivist's identity was not significant (p=0.325).

For hospital mortality, significant predictors were age, APS-N, GCS, acute diagnostic group, comorbidity index, and the source of ICU admission. This model had good fit (Hosmer-Lemeshow test p=0.149), good discrimination (c-statistic=0.891), and had adequate information content for the number of independent variables modeled. The intensivist's identity was not significant (p=0.83).

Figure 1 shows the results from the questionnaires administered to the 9 intensivists. The rank correlation coefficient between their actual average daily discretionary costs and the perceptions of this parameter by the intensivists was 0.78 (p=0.013).

DISCUSSION

Our analysis demonstrates large differences between ICU physicians in the amount of resources used to manage critically ill patients in a single medical ICU. Differences in the use of diagnostic and therapeutic interventions were not associated with mortality or ICU length of stay.

The effect of physicians on discretionary costs was large. The only influences that exceeded that of the intensivists were the severity and type of acute illness. For example, the intensivists' influence on daily discretionary costs was 2.4-fold larger than the effect of comorbid conditions, and 3-fold larger than that of patients' demographic characteristics (Table 2). These differences are economically relevant, with the top tercile of intensivists spending $1003 more on discretionary costs over the average ICU admission compared to the bottom tercile. Table 4 also shows that higher-spending intensivists order more in each subcategory of discretionary resources compared to their lower-spending colleagues. Such consistent differences in resource use, without concomitant differences in outcomes, allows for identification of differing "practice styles" among intensivists.

Variation is health care has been extensively studied and is ubiquitous (1-12). Differences exist by geographic region (1-3), hospital (4-6), insurance status or system (7-12) and physician specialty (9). ICUs share this phenomenon (1, 7, 10, 16, 20-24). For example, the odds ratio across 34 ICUs for using pulmonary artery flotation catheters varied by 38% according to the patient's race and 33% according to insurance status, but by 200-400% according to how the ICU was organized and staffed (22).

Prior studies in non-ICU settings showed that there is substantial variation in patterns of care and outcomes attributable to individual physicians or physician characteristics (4, 9, 13, 20, 25-28). After adjustment for severity of illness, the identity of the physician was associated with 40% variation in hospital charges and 57% variation in length of stay for general medical ward patients (26). This 40% variation in hospital charges is very close to the 43% figure for discretionary ICU costs we observed. Also similar to our findings, other investigations have found that the amount of variation attributable to individual physicians is comparable to or greater than the amount due to patient and illness characteristics (4, 13, 25, 33). In a study on the costs of inpatient care related to birth, physicians accounted for approximately the same amount of variation as did patient characteristics, but physicians' characteristics (e.g.. years in practice, board certification) accounted for just 10% of the influence of the physicians (25). This interesting result suggests that the differences between physicians in their practice styles transcend objective characteristics related to their training. The only prior work that quantified the effect of physicians on ICU care found that risk-adjusted mortality varied from 21 to 34% across five groups of physicians in a medical ICU, with risk-adjusted length of stay varying by 3 days across these groups (20).

Contrary to our secondary hypothesis, the survey data show that the intensivists have an accurate sense of the ICU costs they generate (Figure 1). Perhaps the higher-spenders believe their practice style produces better outcomes. Alternatively, practice styles may derive from a complex interaction between training and personality traits such as response to uncertainty (34-36). We are not aware of any prior studies that have compared physicians' self-assessments with objective measurement of their practice patterns or outcomes.

There are a number of observations to make about our findings. First, the lack of influence of the intensivists on ICU LOS may reflect, at least in part, the reality that decisions to transfer patients out of this ICU are often influenced by bed availability within and outside the ICU. Support for this claim can be found in the observation that both ICU workload variables are significant predictors of ICU LOS. For example, an increase of one patient per day in the average ICU admission rate results in a 6.2 hr decline in ICU LOS. Although in previous work from an ICU under less bed pressure we found that ICU LOS is physician-dependent (20), the current findings indicate that length of stay is not a reliable way to assay for variations in patterns of care; more robust measures reflecting daily resource use are superior. Second, we used rigorous model building methods to ensure that artifacts, a broad range of potentially confounding factors, and erroneous assumption of linear relationships did not confuse the results (37). Third, while the models for ICU costs and LOS were highly significant, their overall predictive power, as indicated by the R^2, were modest. Fourth, the models were limited to patients with only a single intensivist involved in their ICU care. This was done because the major goal of the study was to examine the influence of individual physicians on care. It would be difficult to clearly identify the role of the intensivists for any patient cared for by more than one of them. However, this restriction produced a cohort with characteristics different from the 1158 ICU patients admitted during the study who were cared for by multiple intensivists. This is expected since the longer patients stay in ICU, the more likely they are to have more than one intensivist participating in their care. In particular, compared to patients cared for by a single intensivist, those with multiple intensivists had longer ICU LOS (114±130 hrs vs. 38±30 hrs, $p<0.001$), were sicker (APS-N 13.6±6.3 vs. 11.4±6.0, $p<0.001$) and had higher hospital mortality (16.8% vs. 12.6%, $p=0.005$). They did not, however, differ in daily discretionary costs ($1053±1022 vs. $1084±1235, $p=0.50$). Evidence that our findings are not dependent on special characteristics of the cohort studied comes from modeling discretionary costs from the initial ICU date for all 2342 patients. In this model, differences between intensivists were still statistically significant ($p=0.036$). Fifth, seasonal differences could potentially confound our findings. However, this is unlikely since there was no difference in the seasonal distribution of the ICU assignments among the nine intensivists ($p=0.86$, Fisher's exact test). Sixth, the attending intensivists in this ICU function within an organizational structure that includes house officers at the resident and fellow levels. Since these other physicians did four week rotations in the ICU, it is possible that their presence across the rotations of two different intensivists (who did two week rotations) would partially obscure differences in care by the intensivists. Thus, variation attributable to intensivists might be even larger in ICUs without housestaff.

The major limitation of this study is that it evaluated a single ICU, raising concern about the generalizability of our results. However, as described in the online supplement, the nature, organization, operation, staffing and case mix of our ICU is within the mainstream of large academic medical centers. While other ICUs, which differ in type, organization, structure, case mix, geographic location, etc., may have less or more between-physician variation, we expect that all ICUs experience such variation to some degree. For example, there may be even greater variation in the ICUs of private, community, nonteaching hospitals that comprise the majority of all ICUs in the United States (38). ICUs in such institutions are often less structured, with less care provided by intensivists, care provided by multiple groups of physicians with varied training instead of a cohesive team led by an intensivist from a single group, no in-hospital physician coverage after usual business hours, and absence of house officers (38-40).

Another concern relating to generalizability is that more comprehensive use of care protocols in other ICUs may reduce or eliminate the variation we observed in our unit. Though care pathways and other types of protocols are increasingly used, those currently in wide use apply to only a fraction of the conditions treated and situations encountered in ICUs. Moreover, most evidence indicates that the presence of clinical practice guidelines is not a very effective method of changing physicians’ practice (41-43). Few protocols comprehensively guide use of the varied categories of costs we considered, e.g. imaging studies. Indeed, even patients whose care is highly protocolized, such as those undergoing coronary artery bypass surgery, experience substantial cost variability unrelated to their clinical characteristics (44, 45). In an attempt to discern whether our findings apply to a less heterogenous subset of patients, we modeled total discretionary ICU costs for our largest diagnostic subset, those with respiratory diagnoses. For this subset, the identity of the intensivist was still statistically significant (p=0.017).

In the end, further studies are required to evaluate the generalizability of our results. While a multicenter study would have advantages regarding generalizability, the need to standardize for between-ICU variation presents complex challenges in assessing between-physician variation. Our single center study allows for easier and potentially more valid comparisons between individual physicians.

We this single-ICU study we showed large differences in ICU resource use that are attributable to differences in physicians' practice styles. Higher spending intensivists did not generate better outcomes than their lower-spending colleagues. It appears possible to reduce ICU costs without worsening outcomes if we can alter physicians' practice styles. However, since we also found that higher-spending intensivists were generally aware that they are higher spenders, getting them to change their practice style will require more than providing them with this information. Indeed, audit and feedback has limited utility in changing physician practice (46). While more research is needed to understand the origin of practice styles and how to change them (47-49), we do not believe that efforts targeting individuals can solve the problem of variation in health care. Instead we believe that variation, like medical errors, can most effectively be reduced by a paradigm shift where medicine evolves into a "culture" that explicitly promotes consistency of care across physicians (43, 50, 51).

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FIGURE LEGEND

FIGURE 1: Actual vs. Intensivists' Perceptions of their Average Daily Discretionary ICU Costs.

ρ, Spearman rank correlation coefficient.

TABLE 1. Patient characteristics and outcomes

Number	1184
Age (yrs)	55.0 ± 18.4
Gender (% males)	52.1
Race (% nonwhite)	36.9
APS-N *	11.4 ± 6.0
Diagnostic grouping (%):	
-Respiratory disorders	27.2
-Cardiovascular disorders	19.6
-Neurologic disorders	16.1
-Gastrointestinal disorders	15.6
-Miscellaneous disorders (various)	20.8
-Surgical disorders or trauma	0.7
ICU admission source (%):	
-emergency room	74.7
-ward	20.7
-other ICU	1.3
-outside hospital	1.2
-others/miscellaneous	2.1
Glasgow Coma Scale score	12.1 ± 4.0
Number of comorbid illnesses	3.0 ± 1.7
Intubated (%)	23.5
Limitations on life support prior to ICU (%)	1.9

Average ICU census	12.5 ± 2.5
Average ICU admissions/day	3.2 ± 1.1
Average daily discretionary ICU costs ($US 2005)	1084 ± 1235
ICU length of stay[†] (hrs)	37.8 ± 30.3
Actual time in ICU (hrs)	45.3 ± 32.7
Hospital length of stay (hrs)	160.9 ± 158.8
ICU mortality (%)	7.3
Hospital mortality (%)	12.6

Mean ± SD

[*] APS-N, APACHE II acute physiology score, excluding the neurologic subscore;

[†] ICU length of stay, time from ICU admission until death or request to transfer patient out of ICU.

TABLE 2. Change in adjusted-R^2 for models of average daily discretionary ICU costs nested within the full model.

Omitted Variable(s)	**adjusted-R^2 x 100**	**{(adjusted-R^2 of full model) - {adjusted-R^2) } x 100**
None (full model)	25.54	---
APS-N [*] and GCS [†]	18.63	6.91
Diagnostic grouping	21.23	4.31
Intensivist identity	***23.32***	***2.22***
Source of ICU admission	23.53	2.01
# of comorbid conditions	24.63	0.91
Age, gender and race	24.79	0.75
Intubation status	25.14	0.41

[*] APS-N, APACHE II Acute Physiology Score excluding the neurologic component ; [†] GCS, Glasgow Coma Scale score

Final column represents the variability in discretionary costs explained by omitted variables.

TABLE 3. Adjusted average daily discretionary ICU costs/day

Intensivist	*Scenario#1*	*Scenario#2*	*Scenario#3*
A	884 (731-1070)	1578 (943-2639)	407 (285-581)
B	989 (791-1237)	1765 (1039-2998)	456 (321-646)
C	1010 (805-1266)	1801 (1065-3049)	465 (333-649)
D	1026 (835-1260)	1830 (1090-3073	472 (341-655)
E	1067 (871-1307)	1903 (1139-3182)	491 (355-681)
G	1116 (896-1389)	1990 (1171-3383)	514 (367-719)
H	1153 (926-1436)	2058 (1219-3473)	531 (376-750)
F	1172 (951-1444)	2091 (1231-3551)	540 (383-760)
I	1261 (969-1641)	2250 (1287-3934)	581 (399-846)

Mean (95% CI) $U.S. 2005; Scenario#1, 40 year old white female with diabetes, admitted for respiratory failure and intubated in the emergency department with a Glasgow Coma Scale score (GCS)=14 and a non-neurologic APACHE II Acute Physiology Score (APS-N)=11, who spent 5 days in ICU; Scenario#2, 68 year old African-American male with 5 major comorbid conditions, admitted to ICU from an outside hospital for upper gastrointestinal hemorrhage due to hepatic cirrhosis, with GCS=9, APS-N=22, who had a Do Not Resuscitate order prior to transfer and spent 70 hours in ICU; Scenario#3, 20 old white female with no comorbid conditions, admitted to ICU from the emergency department after attempted suicide by drug overdose, with GCS=15 and APS-N=0, who was in ICU for <24 hrs.

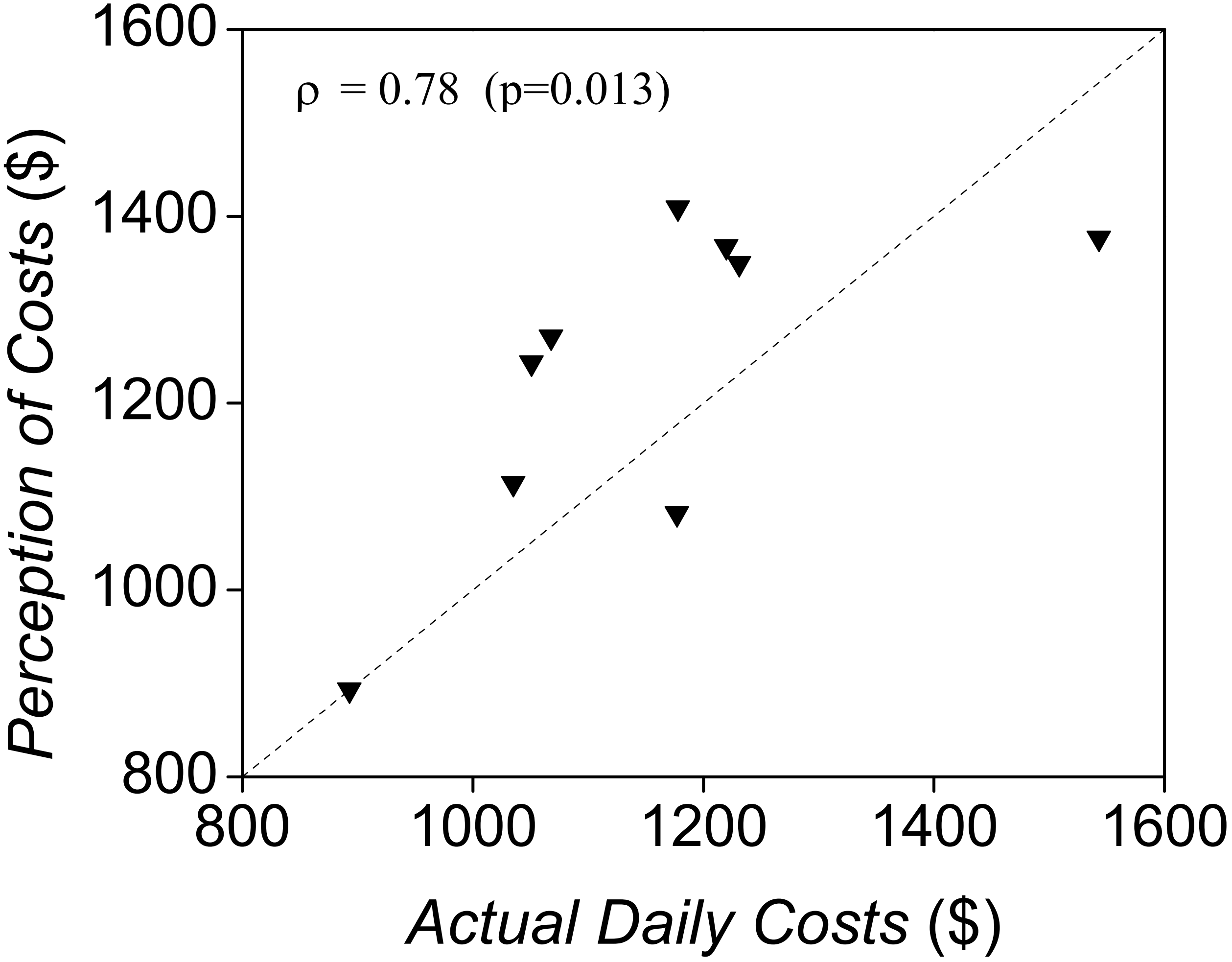
TABLE 4: Comparison of total ICU discretionary costs between highest and lowest spending terciles of intensivists

	Highest 3	Lowest 3	Highest tercile - Lowest tercile	p-value
Number of patients	272	476		
Actual time in ICU (hrs)	48 ± 34	45 ± 33		0.11
Total ICU discretionary costs ($)	3596 ± 4281	2593 ± 2974	1003	<0.0001
Total pharmacy costs ($)	596 ± 1253	391 ± 472	205	<0.0001[*]
Total radiology costs ($)	1078 ± 2297	849 ± 1927	229	
Total laboratory costs ($)	1164 ± 1285	891 ± 1031	273	
Total blood banking costs ($)	552 ± 1452	341 ± 960	211	
Total echocardiography costs ($)	206 ± 359	120 ± 300	86	

Mean±SD; Highest 3/Lowest 3 refer to the 3 intensivists with the highest/lowest average daily discretionary costs;

[*] Hotelling's T-squared test.

FIGURE 1


ρ = 0.78 (p=0.013)
Perception of Costs ($)
Actual Daily Costs ($)
1600
1400
1200
1000
800
800
1000
1200
1400
1600

--Online Data Supplement--

Physician-Attributable Differences in Intensive Care Unit Costs: A Single Center Study

Allan Garland, Ziad Shaman, John Baron, and Alfred F. Connors, Jr.

EXPANDED DESCRIPTION OF METHODS:

The data for this study were collected prospectively in the 13-bed medical ICU of a 520-bed urban, county-owned, university-affiliated teaching hospital located in the Midwestern United States. The data span July 14, 2002 to March 31, 2005, excluding March-May 2004 when data collection was suspended because of personnel limitations. This ICU is a closed unit in which all patients are cared for by a rotating team comprising a board-certified intensivist, an ICU fellow, and a group of five house officers who take overnight call on a 1 in 5 rotation. Formal rounds on all patients are made twice daily by this team. ICU coverage was shared by 9 intensivists assigned to 14 day blocks of time. The ICU fellow and house officers rotate on a 4 week schedule. Neither the intensivist or ICU fellow stay in the hospital overnight. The nurse:patient ratio averages 1:2.

To evaluate the impact of individual intensivists on resource use and outcomes, multivariable linear or logistic models were constructed for average daily discretionary ICU costs, ICU length of stay (LOS), and hospital mortality. We defined discretionary ICU costs as those generated during the patient's ICU stay from pharmacy, radiology (imaging and interventional radiology), laboratories, blood bank and echocardiography. Costs were obtained from the hospital's cost analysis system (Trendstar, McKesson Corporation, San Francisco, CA) and expressed in 2005 U.S. dollars. ICU LOS was measured in hours. To compensate for their skewed distributions, log-transformed cost and length of stay were used in modeling, with unbiased back-transformation by Duan's method using separate smearing factors for each intensivist (E1). Because of limitations in ward bed availability, it is not rare for patients to remain in the ICU for some time after a transfer request is initiated. The median delay in discharging patients from the ICU was 4.9 hours, but 6.3% of patients stayed in ICU an extra 24 hours or more. For this reason ICU LOS was taken as the interval from ICU admission until the transfer request was made. To uniquely associate care with an intensivist, we included patients only if the same intensivist was on duty for each day of their ICU admission. We only analyzed initial admissions to avoid erroneous mortality rates due to patients with multiple ICU admissions.

The impact of the intensivists was assessed by including a set of indicator variables in the models (E2). Models included adjustments for potential confounding due to patient demographics, comorbidities, type and severity of acute illness, a need for invasive mechanical ventilatory support, the source of ICU admission, ICU workload, and any limitations placed of life-supporting therapies prior to ICU admission, including cardiac resuscitation. Demographics were age, gender, and race dichotomized into Caucasian vs. non-Caucasian. Comorbidity was quantified as the number of comorbid conditions, as described by Elixhauser *et al.*(E3). Acute diagnostic grouping was coded by indicator variables representing the organ system or type of illness responsible for ICU admission (cardiovascular, gastrointestinal, neurologic, miscellaneous medical conditions, and surgical conditions including trauma, with respiratory as the reference group). Severity of acute illness was measured as the Glasgow Coma Scale score (GCS) (E4), and the APACHE II acute physiology score excluding it's neurologic subcomponent (APS-N) (E5); both of these measures were taken as the worst value in the initial 24 hours in the ICU. The source of admission to the ICU was represented by indicator variables (hospital ward, another ICU, an outside hospital, other sources, with the emergency department as the reference group). ICU workload corresponding to each patient was measured as two variables averaged over the ICU LOS for each patient: (i) the number of ICU admissions per day, and (ii) the ICU census, defined as the total number of patients who were in the ICU for any length of time on a given day. Because we expected daily costs to be greater toward the beginning of the ICU stay, the cost model also included the actual elapsed time in the ICU as a covariate. Linearity of continuous covariates on the dependent variables was assessed graphically (E2), by use of the Box-Tidwell power transformation (E6), fractional polynomials (E7), and cubic spline decomposition (E2, E8, E9); cubic splines, polynomials or indicator variables were substituted if linearity did not hold. To better account for heteroscedasticity, the Huber-White robust sandwich estimator was used to calculate standard errors (E8).

For the linear regression models, goodness of fit was assessed as the adjusted-R^2 parameter. Statistical significance of variables was assessed by F-tests. The relative predictive power of variables was assessed by comparing the adjusted-R^2 of nested models.

Discrimination of logistic regression model for average daily discretionary cost was evaluated by the c-statistic. Model calibration was addressed via the Hosmer-Lemeshow H-statistic, for which a nonsignificant p-value indicates adequate calibration (E10). The statistical significance of variables was assessed by likelihood ratio testing of nested models. The shrinkage estimation method was used to ensure that the model was not overfitted (E8).

To evaluate the ability of the intensivists to discern their own practice styles, in October 2005 we administered a written questionnaire to the 9 intensivists. After reading about the variation in discretionary costs across the group, the intensivists guessed their position on this continuum using a visual analog scale. For visual display we scaled these ratings to the actual range of costs. Spearman rank correlation was used to assess how accurately the intensivists judged their relative ranking of discretionary costs.

Continuous data are presented as mean ± SD. Categorical data are presented as proportions. P-values < 0.05 are considered significant. Groups were compared using the t-test, Fisher's exact test, or Hotelling's T-squared test. Statistical analysis was performed using Stata 9.1 (StataCorp LP, College Station, Texas).

ICU ORGANIZATION AND FUNCTIONING

This study was performed in the 13-bed, closed model, medical ICU of a 520-bed county owned, university-affiliated teaching hospital. The ICU is staffed by the Department of Medicine by a rotating ICU team comprising a board-certified intensivist, an ICU fellow, and five PGY2 house officers who take overnight call on a 1-in-5 rotation. Nine intensivists assigned to 14 day intervals shared ICU coverage. The trainees are assigned to the ICU for four week blocks of time.

Our hospital and ICU share characteristics of large, academic centers in the U.S.. As a county hospital, it is among the 20% of non-federal hospitals that are owned by state or local governments (E11); such hospitals contain 15% of all ICUs (E12). The hospital's size places it in a category which encompasses 19% of U.S. hospital beds, and for which dedicated medical ICUs comprise 18% of the critical care units (E11, E12). In addition to the medical ICU, our hospital also has surgical, trauma, pediatric, neonatal and cardiac care ICUs. With the exception of organ transplantation, our center provides a full range of medical, surgical, and intensive care modalities and technology.

The structure and pattern of care within our medical ICU is typical of that which the authors have observed in the dozens of similar units that they have visited over 20 years. During morning care rounds, lasting 3-4 hours, the housestaff present overnight admissions and the intensivist guides the fellow and the residents towards a complete diagnostic and therapeutic plan for each patient. Between the morning and early evening rounds, the intensivist's presence is variable and the fellow ensures smooth operation of care. In the late afternoon or early evening a second set of patient care rounds occurs, where the intensivist goes over new admissions and reviews the ongoing plans for all patients with the house staff. Neither the intensivist or fellow stay in the hospital overnight, typically leaving between 6-10 p.m. The resident on call overnight initially discusses all new admissions and other questions with the fellow by telephone; the fellow similarly discusses new admissions, and any other issues about which he/she is uncertain, with the intensivist. Several protocols exist in our medical ICU. At the start of the study period these included protocols for sedation of mechanically ventilated patients, daily screening to liberate patients from mechanical ventilation, analgesia, use of physical and chemical restraints, use of intravenous heparin, and pathways for evaluation and management of exacerbations of asthma and COPD. During the study period we also implemented a protocol to achieve rigorous control of serum glucose levels.

The patients entering this ICU are similar to those in other reported series. To make these comparisons we considered all 2,342 patients admitted to our ICU during the study period. Their age (56 ± 18 years), gender (52% male), and total APACHE II score (20.6 ± 9.7) are similar to those in other reports (E5, E13-E17). The mix of admission diagnoses we observed is similar to those described in other studies of medical ICUs. Specifically, the four largest diagnostic categories (respiratory, cardiovascular, neurologic and gastrointestinal causes) accounted for 82% of admissions, consistent with the 64-90% reported elsewhere (E13, E16-E21). The 32% of our patients who required mechanical ventilation is somewhat lower than the 44-46% from two older studies (E21, E22). Our main sources of medical ICU admissions are the emergency department and general inpatient wards (69% and 26% of patients, respectively) also in concurrence with prior reports (E16, E20, E21). The 8.6% ICU mortality we observed is comparable to 8.5% in the SAPS III North American cohort (E19), but lower than in two other reports (E16, E23). The mean ICU LOS of 3.5 ± 4.3 days is similar to that from the large cohort from the Cleveland Health Quality Choice study, which included the ICUs from 28 hospitals in our city during 1991-95 (E15).

At the start of the study the 9 intensivists had a mean age of 43 years (range 37-52) and had been practicing ICU medicine for a mean of 9 years (range 1-22). All are married, all but two are males, and all but two are Caucasian. All are board certified in Internal Medicine, Pulmonary Medicine and Critical Care Medicine. All received their entire medical training in the U.S. For comparison, the COMPACCS study found that the mean age of practitioners in Pulmonary and Critical Care Medicine is 48 years, with 79% being trained in Internal Medicine, 9.5% being women and 60-81% being board certified in Critical Care Medicine (E24).

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