Physician's Case Volume of Intensive Care Unit Pneumonia Admissions and In-Hospital Mortality

Herng-Ching Lin[1], Sudha Xirasagar[2], Chi-Hung Chen[3], and Yi-Ting Hwang[4]

[1]School of Health Care Administration, Taipei Medical University, Taipei, Taiwan; [2]Arnold School of Public Health, Department of Health Services Policy and Management, University of South Carolina, Columbia, South Carolina; [3]Intensive Care Unit, Taipei Medical University Hospital, Taipei, Taiwan; and [4]Department of Statistics, National Taipei University, Taipei, Taiwan

Rationale: **Although several studies have investigated volume–outcome relationships for surgical procedures, there has been no such study of intensive care unit (ICU) patients admitted for pneumonia.**
Objectives: **This study examines associations between in-hospital mortality of ICU-admitted pneumonia patients and their attending physician's case volume.**
Methods: **We used 2002–2004 claims data from Taiwan's National Health Insurance for all 87,479 adult ICU admissions for pneumonia. Patients were assigned to one of four groups, on the basis of their physician's ICU pneumonia case volume (low volume, <36 cases; medium volume, 37–114 cases; high volume, 118–314 cases; and very high volume, ⩾315 cases). Generalized estimating equations (conditional on hospital, and unconditional) were used, adjusting for physician demographics and specialty, hospital characteristics, patient characteristics (including clinical severity and comorbidities), and physician-level random effect (clustering effect) to assess whether physicians' case volume predicts in-hospital mortality.**
Measurements and Main Results: **In-hospital mortality systematically declined with increasing physician case volume: 14.7, 14.3, 11.4, and 8.1% from low-volume to very-high-volume groups. Adjusted unconditional odds of mortality among low-volume physicians' patients were 2.04 times those of very-high-volume physicians, 1.35 times that of high-volume physicians, and 1.09 times those of medium-volume physicians (all $P < 0.001$). The relationship is sustained when the odds are estimated conditional on hospital, when initial 5-day mortality is separated from 30-day mortality, and when pulmonologists' and critical care specialists' patients are studied separately.**
Conclusions: **Physician volume significantly predicts inpatient mortality among ICU patients with pneumonia. Detailed study of clinical approaches, decision algorithms, and treatment plans of high-volume physicians is recommended to identify possible mediating factors in this phenomenon.**

Keywords: intensive care unit; pneumonia; outcome assessment

Worldwide, pneumonia is the most frequent cause of communicable disease admissions and inpatient deaths. An estimated 5.6 million cases of community-acquired pneumonia occur annually in the United States (1), with 1.2 million patients hospitalized, and with an inpatient mortality rate of 5.8% (2).

Attending physicians' case volume as a predictor of care outcomes is widely documented, particularly for complex medical conditions and surgical procedures, such as cancer care, coronary artery bypass surgery, and others (3–5). Little documentation on pneumonia case volumes and outcomes is available. Such studies could enable provider-driven and payer-driven strategies to reduce unwarranted variations in outcomes.

(*Received in original form June 4, 2007; accepted in final form January 31, 2008*)

Correspondence and requests for reprints should be addressed to Herng-Ching Lin, Ph.D., School of Health Care Administration, Taipei Medical University, 250 Wu-Hsing Street, Taipei 110, Taiwan. E-mail: henry11111@tmu.edu.tw

Am J Respir Crit Care Med Vol 177. pp 989–994, 2008
Originally Published in Press as DOI: 10.1164/rccm.200706-813OC on February 8, 2008
Internet address: www.atsjournals.org

AT A GLANCE COMMENTARY

Scientific Knowledge on the Subject

Although several studies have investigated volume–outcome relationships for complex surgical procedures, there has been no outcomes study of intensive care unit patients admitted for pneumonia.

What This Study Adds to the Field

This study found that physician volume significantly predicts inpatient mortality among intensive care unit patients with pneumonia.

Durairaj and colleagues reported that medical intensive care units (ICUs) with high respiratory patient volumes had lower risk-adjusted mortality for sicker patients, based on a 29-hospital study in Ohio (6). Respiratory diagnoses could span a heterogeneous range of conditions of diverse origins (e.g., infectious, malignant, degenerative). Therefore, there could be considerable confounding, yielding limited policy and practice implications. Our study uses inpatient claims data from Taiwan with a primary diagnosis of pneumonia and an ICU stay. In Taiwan, all teaching (and many nonteaching) hospitals have state-of-the-art clinical practice guidelines and standard orders set in place for pneumonia (7). We used nationwide, 3-year, population-based (de-identified) data from Taiwan's National Health Insurance (NHI) claims database, released for research purposes, to examined whether physicians with higher case volumes offer ICU patients with pneumonia better outcomes.

METHODS

Database

We used inpatient claims data for 2002–2004, which include data on every inpatient admission among NHI beneficiaries, more than 21 million citizens (96% of Taiwan's population). The database has ICD-9CM (*International Classification of Diseases, Ninth Revision, Clinical Modification*) codes for the principal diagnosis, and up to four secondary diagnoses. The NHI Bureau implements routine sample crosschecks of each hospital's claims with medical charts, followed by punitive measures for coding infractions, which deters diagnosis up-coding. This deterrent is counterbalanced by the NHI's reimbursement system, which ties a hospital's reimbursement level to its patient severity profile. As a result, hospitals' interests are best served by accurate coding of diagnoses and care items. Although there are no documented sensitivity and specificity studies of coding accuracy, it is generally believed that the NHI's checks and balances foster accurate coding.

Taiwan's NHI provides universal coverage to all citizens, a single plan with generous benefits, low copayments, and free choice of a widely dispersed network of public, private, and not-for-profit providers. These features make these population-based data a valuable resource to examine risk-adjusted outcome variations across a variety of provider characteristics, with minimal confounding.

Study Sample

We selected adult patients admitted with a principal diagnosis of pneumonia (ICD-9-CM: 480–483.8, 485–487.0), with an ICU stay during hospitalization. Of more than 6 million inpatient claims during January 2002 to December 2004, 479,715 were pneumonia admissions; 101,105 of these patients were admitted to ICUs. Of these, 7,384 pediatric cases (<18 yr) and 5,971 cases transferred to or from another hospital were excluded, for a final study sample of 87,479 cases.

Classification of Patients by Their Physician's Case Volume

Using attending physician identifiers in the claims, we classified patients by their physician's total case volume of patients with pneumonia with an ICU stay during the study period. Physicians were sorted, in ascending order of volume, and volume cutoff points were determined, such that the sample was classified into four, approximately equal-sized groups (consistent with the documented methodology for such studies [8–10]). The four volume groups were as follows: low volume (⩽36 cases treated by their attending physician), medium volume (37–117 cases), high volume (118–314 cases), and very high volume (⩾315 cases). The respective volume groups had 21,927, 21,928, 21,883, and 21,741 cases.

Statistical Analysis

The SAS package (version 9.0; SAS Institute, Cary, NC) was used. The outcome measure was "in-hospital mortality," with "patient" as the unit of analysis and "physician volume" measured at physician level. A generalized estimating equation (GEE; unconditional) was used to examine the adjusted relationship of physician volume with in-hospital mortality, controlling for physician, hospital, and patient characteristics, and accounting for clustering of patients within physician panels (physician-level random effect). We also performed a conditional (fixed effects) logistic regression model in which observations are conditioned on hospital, to partition out systematic hospital-specific variation, to address potential confounding by a possible association between high-volume physicians and certain types of hospitals (e.g., teaching hospitals) (11). Finally, a sensitivity analysis was performed to test for the consistency of the volume–outcome relationship under various volume cutoff points.

We adjusted for the following: physician's sex, age, and specialty (pulmonology or critical care medicine vs. another specialty); the hospital's ICU bed strength, its teaching status, and ownership (public, for-profit, and not-for-profit); patient demographics (age and sex); and patient severity. Patient severity was measured by clinical severity of the pneumonia and presence of comorbidities. The proxy for pneumonia severity was twofold: duration of mechanical ventilation use when it was used, as shown in Table 1, and presence of acute respiratory failure (ARF) without significant duration of mechanical ventilation (3,111 patients either rapidly succumbed to the respiratory failure or responded to other medical treatment). Clinical comorbidity was captured using the Charlson Comorbidity Index (CCI) (12), which is used to capture mortality risk in administrative claims data analyses. The CCI is the sum of the patient's weighted scores of the relative mortality risk of 19 conditions (e.g., congestive heart failure, myocardial infarction, liver disease, cancer, dementia) with a score of zero if no comorbid conditions exist.

To verify the role of physician specialty in the volume–outcome relationship, we performed GEE analysis on the subset of patients treated by pulmonologists and critical care specialists. To further clarify whether the relationship is sustained when early (5 d) mortality is separated from delayed mortality (6–30 d), we linked our data to Taiwan's Department of Health cause-of-death data to include post-discharge death. Separate GEE regressions were conducted using each mortality indicator as the dependent variable. Finally, to verify the volume–mortality association among the most severe pneumonia cases, we applied similar GEE analyses to the subsample with ARF. A two-sided P value of 0.05 was used.

RESULTS

The study sample distribution by patient variables is shown in Table 1: 63.5% were male, 62.8% were 74 years or older, 65.7% had pneumonia complicated with ARF, and 62.1% received mechanical ventilation during hospitalization. Mean length of stay and hospitalization costs were 24.8 days (± 18.1 d) and Taiwan New Dollars (TWD $) 281,508 (±TWD $228,772; US $1 = TWD $33 in 2004), respectively.

TABLE 1. CHARACTERISTICS OF PATIENTS ADMITTED TO THE INTENSIVE CARE UNIT FOR THE TREATMENT OF PNEUMONIA IN TAIWAN, 2002–2004

Variables	Value
Patient sex, n (%)	
Male	55,563 (63.5)
Female	31,916 (36.5)
Patient age, n (%)	
<65 yr	13,672 (15.6)
65–74 yr	18,912 (21.6)
>74 yr	54,895 (62.8)
Patient age, mean yr (SD)	75.1 (13.4)
Charlson Comorbidity Index score, n (%)	
0	36,564 (41.8)
1	26,484 (30.3)
2	12,293 (14.1)
3	6,788 (7.8)
4 or more	5,350 (6.1)
Acute respiratory failure, n (%)	
Yes	57,443 (65.7)
No	30,036 (34.3)
Mechanical ventilation, n (%)	
Continuous mechanical ventilation of unspecified duration	3,696 (4.2)
Continuous mechanical ventilation for less than 96 consecutive hours	6,389 (7.3)
Continuous mechanical ventilation for 96 consecutive hours or more	44,247 (50.6)
No	33,147 (37.9)
Length of stay, mean days (SD)	24.8 (18.1)
Hospitalization costs, mean TWD $ (SD)	281,508 (228,772)
In-hospital mortality rate, n (%)	10,591 (12.1)

* Total patient sample = 87,479.

The bivariate sample distribution by physician volume and physician characteristics is shown in Table 2. For the total 3,667 attending physicians of the sample patients, the mean case volume was 25.8 patients. Very-high-volume physicians were more likely to be male and specialize in pulmonary or critical care medicine (both $P < 0.001$), and have older patients, with lower average CCI scores and higher incidence of ARF and mechanical ventilation use, compared with physicians in other volume groups (all $P < 0.001$).

Table 3 shows the crude and GEE-adjusted odds of in-hospital mortality by physician volume. Low-volume physicians' patients had significantly higher crude mortality likelihood than high- and very-high-volume physicians (14.7 vs. 11.4 and 8.1%, respectively; both $P < 0.001$). GEE estimates adjusting for patient characteristics (sex, age, duration of mechanical ventilation, ARF without mechanical ventilation, and CCI score), attending physician characteristics (age, sex, and specialty), hospital characteristics (ownership, teaching status, and ICU bed strength), and physician-level random effect (patient clustering by physician) show that the odds of in-hospital death among low-volume physicians' patients were over twice the mortality odds among very-high-volume physicians' patients (odds ratio [OR], 2.04; reciprocal of 0.49; $P < 0.001$), and ORs were 1.35 and 1.09, respectively, relative to high-volume and medium-volume physicians' patients (both $P < 0.001$). Sensitivity analysis showed that the results are robust to changes in the volume cutoff points (data not shown).

Table 3 also presents the regression results of conditional logistic regression modeling, showing that the physician volume–outcome relationship is sustained after conditioning on hospital. This confirms an independent effect of physicians' experience on mortality, regardless of the hospital in which they practice,

TABLE 2. PHYSICIAN AND PATIENT CHARACTERISTICS IN TAIWAN, BY PHYSICIAN INTENSIVE CARE UNIT PNEUMONIA VOLUME GROUPS, 2002–2004

	Physician ICU Pneumonia Volume Group (*n* = *87,489 patients*)											
	Low (1–36 patients)			Medium (37–117 patients)			High (118–314 patients)			Very High (⩾315)		
Variables	n	%	Mean (*SD*)	n	%	Mean (*SD*)	n	%	Mean (*SD*)	n	%	Mean (*SD*)
Physician characteristics												
No. of physicians (n = 3,667)	3,136			369			133			29		
Pneumonia volume			7.6 (8.0)			65.2 (22.0)			177.0 (52.8)			797.3 (964)
Age, yr			40.6 (7.6)			40.4 (6.7)			39.7 (6.5)			39.1 (9.4)
Sex												
Male	2,897	92.4		349	94.6		125	94.0		28	96.6	
Female	239	7.6		20	5.4		8	6.0		1	3.4	
Specialty												
Pulmonary and critical care medicine	202	6.4		154	41.7		80	60.2		25	86.2	
Other	2,934	93.6		215	58.3		53	39.8		4	13.8	
Patient characteristics (n = 87,479)												
Total no. of patients	21,927			21,928			21,883			21,741		
Age, yr			73.0 (14.3)			74.9 (13.8)			75.1 (13.1)			77.3 (12.1)
Sex												
Male	14,019	63.9		13,932	63.5		13,897	63.5		13,715	63.1	
Female	7,908	36.1		7,996	36.5		7,986	36.5		8,026	36.9	
Charlson Comorbidity Index score												
0	7,943	36.2		8,933	40.7		8,171	37.3		11,517	53.0	
1	6,602	30.1		6,906	31.5		7,426	33.9		5,550	25.5	
2	3,562	16.2		3,216	14.7		3,085	14.1		2,430	11.2	
3	2,055	9.4		1,671	7.6		1,816	8.3		1,246	5.7	
4 or more	1,765	8.1		1,202	5.5		1,385	6.3		998	4.6	
Acute respiratory failure												
Yes	11,867	54.1		14,032	64.0		14,983	68.5		16,561	76.2	
No	10,060	45.9		7,896	36.0		6,900	31.5		5,180	23.8	
Mechanical ventilation												
Yes	9,605	43.8		10,858	49.5		12,577	57.5		14,966	68.8	
No	12,322	56.2		11,070	50.5		9,306	42.5		6,775	31.2	

although the odds show a drop in magnitude. Table 3 also shows that patients of pulmonologists and critical care specialists have lower mortality odds (OR, 0.66; $P < 0.001$) relative to other specialties.

Table 4 shows the association of physician volume with in-hospital mortality among the subsample (50,064 patients) treated by pulmonologists and critical care specialists. The relationship is sustained: low-volume specialists' patients have about twice the risk-adjusted mortality odds as those of very-high-volume and high-volume physicians (OR, 1.89 and 2.13, respectively).

The volume–outcome relationship is sustained on examining 30-day mortality, shown in Appendix 1. The relationship is also sustained on separating early mortality (5 d) and delayed mortality (6–30 d), although the magnitude of mortality odds by volume groups are smaller for 5-day mortality compared with delayed mortality (presented in Appendix 1). The volume–outcome relationship is also sustained on GEE modeling of the subsample with the highest clinical severity (those with ARF), using the same control variables, shown in Appendix 2.

DISCUSSION

This article reports on the volume–mortality relationship for adult ICU pneumonia cases on the basis of nationwide, population-based data, covering 87,479 patients treated by 3,667 physicians. Adjusted for relevant confounders, and robust to a sensitivity

TABLE 3. CRUDE AND ADJUSTED ODDS RATIOS FOR HOSPITAL IN-PATIENT FATALITIES IN TAIWAN, BY PHYSICIAN INTENSIVE CARE UNIT PNEUMONIA VOLUMES, 2002–2004*

	Discharge Status							
	Alive		Deceased		Unconditional GEE Model		Conditional Logistic Regression Model	
Variables	No. of Patients	%	No. of Patients	%	Crude OR (*95% CI*)	Adjusted OR† (*95% CI*)	Crude OR (*95% CI*)	Adjusted OR (*95% CI*)
Physician ICU pneumonia volume								
⩽36	18,714	85.4	3,213	14.7	1.00	1.00	1.00	1.00
37–117	18,799	85.7	3,129	14.3	0.97 (0.92–1.06)	0.92 (0.85–0.97)	0.98 (0.93–1.04)	0.93 (0.86–0.098)
118–314	19,397	88.6	2,486	11.4	0.78 (0.70–0.79)	0.74 (0.69–0.78)	0.87 (0.84–0.96)	0.85 (0.78–0.93)
⩾315	19,978	91.9	1,763	8.1	0.50 (0.47–0.55)	0.49 (0.45–0.53)	0.63 (0.52–0.70)	0.57 (0.51–0.65)
Physician specialty								
Pulmonary and critical care medicine	45,180	90.2	4,884	9.8	0.52 (0.48–0.57)	0.66 (0.59–0.74)		
Other	31,708	84.8	5,707	15.3	1.00	1.00		

Definition of abbreviations: CI = confidence interval; GEE = generalized estimating equation; ICU = intensive care unit; OR = odds ratio.

* n = 87,479.

† Adjusted for patient's sex, age, acute respiratory failure without mechanical ventilation, duration of mechanical ventilation, Charlson Comorbidity Index score; and attending physician's age, sex, and specialty; hospital ownership; ICU bed strength; and teaching status. Unconditional GEE model includes a physician random effects term. Conditional GEE model conditioned each observation on specific hospital where treated, and included a physician-level clustering variable.

TABLE 4. CRUDE AND ADJUSTED ODDS RATIOS FOR HOSPITAL IN-PATIENT FATALITIES IN TAIWAN, BY PHYSICIAN INTENSIVE CARE UNIT PNEUMONIA VOLUMES FOR PHYSICIANS SPECIALIZING IN PULMONARY AND CRITICAL CARE MEDICINE, 2002–2004*

	Discharge Status					
	Alive		Deceased			
Variables	No. of Patients	%	No. of Patients	%	Crude OR (*95% CI*)	Adjusted OR† (*95% CI*)
Physician ICU pneumonia volume						
⩽36	10,885	86.1	1,752	13.9	1.00	1.00
37–117	11,019	90.0	1,230	10.0	0.68‡ (0.63–0.72)	0.72‡ (0.65–0.79)
118–314	11,993	93.5	841	6.6	0.42‡ (0.38–0.47)	0.47‡ (0.42–0.54)
⩾315	11,282	91.4	1,061	8.6	0.56‡ (0.52–0.63)	0.53‡ (0.46–0.57)

Definition of abbreviations: CI = confidence interval; ICU = intensive care unit; OR = odds ratio.

* n = 50,064.

† Adjusted for patient's sex, age, acute respiratory failure without mechanical ventilation, duration of mechanical ventilation, Charlson Comorbidity Index score, attending physician's age and sex, hospital ownership, ICU bed strength and teaching status, and physician random effect (unconditional GEE model).

‡ $P < 0.001$.

analysis, low-volume physicians' patients have twice the mortality odds of patients of very-high-volume physicians. Importantly, the finding holds even among the subsample of patients treated by pulmonologists and critical care specialists. (However, within the total sample, these specialists have clearly lower adjusted mortality odds [0.66] relative to other specialties.)

Conditional logistic regression analysis eliminates potential confounding by unmeasured hospital variables on many counts. First, high-volume physicians likely practice at better equipped and/or teaching hospitals, which could potentially account for the superior outcomes of high-volume physicians, due to these hospitals' infrastructure and staffing advantages. Conditional logistic regression essentially evaluates the volume–outcome association among physicians within each hospital and then averages these effects across hospitals. We found that the physician volume–outcome association is sustained in the conditional logistic regression model, although some mitigation of the ORs is observed. The latter suggests that intrahospital variables do mediate part of the physician volume–outcome relationship, but the magnitude of the drop also shows that most of the mortality differentials are driven by the independent effect of the physicians' case volume (experience), regardless of the hospital in which they practice. Our findings suggest that previously documented associations between hospital volume and mortality (13–15) may have been confounded by more experienced physicians practicing in larger volume hospitals.

Durairaj and coworkers reported lower risk-adjusted mortality among ICU patients with a respiratory diagnosis who were admitted to high-volume hospitals compared with those admitted to low-volume hospitals (6), and many studies show that higher ICU patient volumes are associated with superior outcomes among critically ill patients (13–18), all consistent with our findings.

Our study contributes to the literature by demonstrating that, after isolating the effect of most institutional and patient confounders, the attending physician's volume independently predicts mortality in severely ill patients with pneumonia. The adequacy of our adjustments for patient severity could be questioned. Several study attributes mitigate this concern. First, we restricted our study sample to inpatients with an admission diagnosis of pneumonia and who needed ICU care, itself an indictor of significantly higher severity. Second, we adjusted for ARF, which significantly drives mortality in pneumonia cases. We used specific operational variables that mediate the role of ARF in mortality outcomes: whether the patient survived the initial onset of ARF, and the duration for which mechanical ventilation had to be used. We have accounted for both these variables, captured as ARF without mechanical ventilation, and duration of continuous use of mechanical ventilation among survivors. These two variables, together with our sample selection criterion of an ICU stay should capture most of the significant impact of pneumonia severity, and may have mitigated the utility of the Pneumonia Severity Scale in this study.

In our sample, patients of high-volume physicians had higher incidence of ARF, and received longer durations of mechanical ventilation, indicating higher critical severity. Therefore, differential case severity should have aggravated high-volume physicians' outcomes, not improved them. Our adjustment for these variables emphasizes the superior outcomes of high-volume physicians. Another source of confounding could be unmeasured differences in clinical severity between the volume groups, such as pre-pneumonia conditions, hemodynamic status, hyperglycemia, and others. It is highly implausible that these factors were systematically higher among low-volume physicians' patients. Moreover, because patients with pneumonia are admitted to an ICU when their condition is clinically severe enough, it is unlikely that systematic unmeasured differences in severity exist between low-volume and high-volume physicians' patients in our sample.

Three explanations could be hypothesized for the volume–outcome relationship (each having different policy implications):

1. High-volume hospitals may implement systems-based practices that improve outcomes (e.g., multidisciplinary care rounds, high nurse-to-patient ratios).
2. Practice makes perfect (i.e., physicians who accumulate experience with caring for certain types of patients provide and direct better care, causing improved outcomes).
3. Selective patient self-referral to reputed hospitals or physicians may cause better outcomes through two mechanisms: higher volumes of these reputed hospitals confound their inherently superior outcomes as a volume effect, projected to its physicians essentially a halo effect. Patient self-referral also implies that those with less severe disease can "shop for" a "reputed" hospital regardless of distance, whereas the severely ill settle for the nearest hospital (in Taiwan, patients have full choice of any physician or hospital in the country, without referral). Such selection bias should cause high-volume hospitals to have disproportionately less severe patients and therefore better outcomes.

If hypothesis 1 is empirically sustained, then smaller hospitals should be required to adopt the systems-based practices of larger hospitals. If hypothesis 2 is supported, payers should consider reimbursing consultations with an experienced physician until each physician completes a threshold number of ICU pneumonia cases, regardless of specialty status. Our study confirms that, regardless of the hospital in which they practice, high-volume physicians perform better. Disproportionately higher severity among high-volume physicians' panels (age, ARF, and duration of mechanical ventilation) argues against selection bias due to selective self-referral.

Overall, our results suggest that practice makes perfect, supporting the latter policy implication. Cost of care differences alone may justify such expense, apart from being potentially life-saving. At the same time, a statistically significant contribution by the hospital effect (reduction in mortality odds in the conditional model) implies that payers should consider requiring all hospitals to implement the systems-based practices of larger hospitals, as well as regionalization of care for severe pneumonia cases.

Finally, the consistency of the volume–outcome relationship among the subsample of respiratory specialists' patients and among the subsample with ARF, and on separating early 5-day mortality from delayed, 6–30-day mortality, all suggest strong support for the "practice makes perfect" hypothesis. Other studies concerning volume–outcome relationships for other diagnoses/procedures in Taiwan also consistently demonstrate that physician volume is a more critical factor for patient outcome than hospital volume (19–21). It has been suggested that high-volume physicians can better manage unexpected problems and medical situations (7).

This study has several strengths. Because it used a nationwide population-based dataset from a single-payer insurance system, its findings are noteworthy for clinicians and policy makers, who often have to contend with indeterminate findings from studies using data from pluralistic health systems with multiple insurers, and limited patient panels. Second, its large sample size has provided ample statistical power to detect differences between study groups, after adjusting for many confounding variables.

There are some study limitations. The accuracy of comorbidity documentation is generally questioned when claims data are used for research. As indicated earlier, there are built-in checks and balances in the NHI's oversight and reimbursement system. Measures such as routine sampling of patient charts to crosscheck with claims, detailed audits for outlier hospitals, and punitive fines for fraudulent claims deter diagnoses and care up-coding. Concurrently, the reimbursement system favors accuracy in the opposite direction. Because each hospital's reimbursement rate is tied to its patient severity profile, the incentive is to ensure accurate and complete coding of comorbidities to realize a severity-appropriate reimbursement rate. Therefore, it is generally believed that coding is largely accurate, although the lack of systematic sensitivity analyses documentation makes this issue a potential study limitation.

Conclusions

There are several policy implications. First, similar studies need to be replicated in other countries and settings, examining diagnosis-specific volume–outcome relationships in ICUs for pneumonia. Second, policy makers should consider routinely paying for second-opinion consultations with experienced physicians until each physician crosses a critical threshold of case volume. This should save considerable costs as well as lives. Third, our supplementary analysis showed higher costs incurred toward aggressive treatment procedures among patients of high-volume physicians, and higher drug and lab diagnostic costs (results not presented). This finding suggests that much will be gained from clinician-led peer reviews of the differences in clinical approaches and care processes between high-volume and low-volume physicians. This should enable more detailed explication of decision algorithms for use by all providers.

Conflict of Interest Statement: None of the authors has a financial relationship with a commercial entity that has an interest in the subject of this manuscript.

References

1. Bartlett JG, Dowell SF, Mandell LA, File TM Jr, Musher DM, Fine MJ. Practice guidelines for the management of community-acquired pneumonia in adults. Infectious Diseases Society of America. *Clin Infect Dis* 2000;31:347–382.
2. Lindenauer PK, Behal R, Murray CK, Nsa W, Houck PM, Bratzler DW. Volume, quality of care, and outcome in pneumonia. *Ann Intern Med* 2006;144:262–269.
3. Luft HS, Bunker JP, Enthoven AC. Should operations be regionalized? The empirical relation between surgical volume and mortality. *N Engl J Med* 1979;301:1364–1369.
4. Flood AB, Scott WR, Ewy W. Does practice make perfect? Part I: the relation between hospital volume and outcomes for selected diagnostic categories. *Med Care* 1984;22:98–114.
5. McGrath PD, Wennberg DE, Malenka DJ, Kellett MA Jr, Ryan TJ Jr, O'Meara JR, Bradley WA, Hearne MJ, Hettleman B, Robb JF. Operator volume and outcomes in 12,998 percutaneous coronary interventions: Northern New England Cardiovascular Disease Study Group. *J Am Coll Cardiol* 1998;31:570–576.
6. Durairaj L, Torner JC, Chrischilles EA, Vaughan Sarrazin MS, Yankey J, Rosenthal GE. Hospital volume-outcome relationships among medical admissions to ICUs. *Chest* 2005;128:1682–1689.
7. Hwang KL, Su WW, Soon MS, Wu SS, Chen YY, Chen MY. Evaluation of the implementation of clinical guidelines for transcatheter arterial chemo-embolization of patients with hepatocellular carcinoma [in Chinese]. *Taiwan J Public Health* 2005;24:284–295.
8. Hannan EL, Racz M, Ryan TJ, McCallister BD, Johnson LW, Arani DT, Guerci AD, Sosa J, Topol EJ. Coronary angioplasty volume-outcome relationships for hospitals and cardiologists. *JAMA* 1997;277:892–898.
9. Jollis JG, Peterson ED, Nelson CL, Stafford JA, DeLong ER, Muhlbaier LH, Mark DB. Relationship between physician and hospital coronary angioplasty volume and outcome in elderly patients. *Circulation* 1997; 95:2485–2491.
10. Birkmeyer JD, Siewers AE, Finlayson EV, Stukel TA, Lucas FL, Batista I, Welch HG, Wennberg DE. Hospital volume and surgical mortality in the United States. *N Engl J Med* 2002;346:1128–1137.
11. Localio AR, Berlin JA, Ten Have TR, Kimmel SE. Adjustments for center in multicenter studies: an overview. *Ann Intern Med* 2001;135:112–123.
12. Charlson ME, Pompei P, Ales KL, MacKenzie CR. A new method of classifying prognostic comorbidity in longitudinal studies: development and validation. *J Chronic Dis* 1987;40:373–383.
13. Glance LG, Li Y, Osler TM, Dick A, Mukamel DB. Impact of patient volume on the mortality rate of adult intensive care unit patients. *Crit Care Med* 2006;34:1925–1934.
14. Kahn JM, Goss CH, Heagerty PJ, Kramer AA, O'Brien CR, Rubenfeld GD. Hospital volume and the outcomes of mechanical ventilation. *N Engl J Med* 2006;355:41–50.
15. Phibbs CS, Baker LC, Caughey AB, Danielsen B, Schmitt SK, Phibbs RH. Level and volume of neonatal intensive care and mortality in very-low-birth-weight infants. *N Engl J Med* 2007;356:2165–2175.
16. Marcin JP, Song J, Leigh JP. The impact of pediatric intensive care unit volume on mortality: a hierarchical instrumental variable analysis. *Pediatr Crit Care Med* 2005;6:136–141.
17. Jones J, Rowan K. Is there a relationship between the volume of work carried out in intensive care and its outcome? *Int J Technol Assess Health Care* 1995;11:762–769.
18. Iapichino G, Gattinoni L, Radrizzani D, Simini B, Bertolini G, Ferla L, Mistraletti G, Porta F, Miranda DR. Volume of activity and occupancy rate in intensive care units: association with mortality. *Intensive Care Med* 2004;30:290–297.
19. Wen HC, Tang CH, Lin HC, Tsai CS, Chen CS, Li CY. Association between surgeon and hospital volume in coronary artery bypass graft surgery outcomes: a population-based study. *Ann Thorac Surg* 2006;81:835–842.
20. Lien YC, Huang MT, Lin HC. Association between surgeon and hospital volume and in-hospital fatalities after lung cancer resections: the experience of an Asian country. *Ann Thorac Surg* 2007;83:1837–1843.
21. Xirasagar S, Lien YC, Lin HC, Liu TC, Tsai J. Procedure volume of gastric cancer resections versus 5-year survival. *Eur J Surg Oncol* 2008;34:23–29.

APPENDIX 1. CRUDE AND ADJUSTED ODDS RATIOS FOR MORTALITY WITHIN 30 DAYS OF HOSPITALIZATION*

	Discharge Status					
	Alive		Deceased			
Variables	No. of Patients	%	No. of Patients	%	Crude OR (*95% CI*)	Adjusted OR† (*95% CI*)
30-d Mortality (*n = 87,479*)						
Physician case volume						
⩽36	17,425	79.5	4,502	20.5	1.00	1.00
37–117	17,605	80.3	4,323	19.7	0.85‡ (0.82–0.89)	0.89‡ (0.83–0.94)
118–314	18,014	82.3	3,869	17.7	0.84‡ (0.81–0.89)	0.86‡ (0.80–0.93)
⩾315	18,657	85.8	3,084	14.2	0.48‡ (0.44–0.50)	0.53‡ (0.47–0.57)
Early (5 d) Mortality (*n = 87,479*)						
Physician ICU pneumonia volume						
⩽36	19,817	90.4	2,110	9.6	1.00	1.00
37–117	19,904	90.8	2,024	9.2	0.98 (0.89–1.04)	0.96 (0.83–1.07)
118–314	20,060	91.7	1,823	8.3	0.86§ (0.80–0.91)	0.87§ (0.80–0.95)
⩾315	19,997	92.0	1,744	8.0	0.81‡ (0.76–0.87)	0.80‡ (0.71–0.91)
Delayed (6–30 d) Mortality (*n = 79,789*)						
Physician ICU pneumonia volume						
⩽36	17,433	87.9	2,392	12.1	1.00	1.00
37–117	17,870	88.6	2,299	11.4	0.93 (0.88–1.02)	0.89§ (0.82–0.96)
118–314	17,818	89.7	2,046	10.3	0.83§ (0.78–0.89)	0.82‡ (0.74–0.89)
⩾315	18,591	93.3	1,340	6.7	0.52‡ (0.48–0.56)	0.51‡ (0.46–0.57)

Definition of abbreviations: CI = confidence interval; ICU = intensive care unit; OR = odds ratio.

* The first 5-day and late (6–30 d) mortality in Taiwan, by physician ICU pneumonia volumes, 2002–2004.

† Adjusted for patient's sex, age, acute respiratory failure without mechanical ventilation, duration of mechanical ventilation, Charlson Comorbidity Index score, and attending physician's age, sex, and specialty, hospital ownership, ICU bed strength and teaching status, and physician random effect (unconditional GEE model). The 30-day mortality included in-hospital as well as postdischarge death within 30 days of admission.

‡ $P < 0.001$.

§ $P < 0.01$.

APPENDIX 2. CRUDE AND ADJUSTED ODDS RATIOS FOR HOSPITAL INPATIENT FATALITIES IN TAIWAN*

	Discharge Status					
	Alive		Deceased			
Variables	No. of Patients	%	No. of Patients	%	Crude OR (*95% CI*)	Adjusted OR† (*95% CI*)
Physician ICU pneumonia volume						
⩽36	9,819	82.7	2,049	17.3	1.00	1.00
37–117	11,774	83.9	2,258	16.1	0.92‡ (0.86–0.98)	1.05 (0.94–1.11)
118–314	13,182	88.0	1,801	12.0	0.63§ (0.59–0.69)	0.82§ (0.73–0.92)
⩾315	15,152	91.5	1,409	8.5	0.42§ (0.40–0.46)	0.72§ (0.64–0.79)

For definition of abbreviations, *see* Appendix 1.

* By physician ICU pneumonia volumes for patients with acute respiratory failure, 2002–2004 (n = 57,443).

† Adjusted for patient's sex, age, acute respiratory failure without mechanical ventilation, duration of mechanical ventilation, Charlson Comorbidity Index score, attending physician's age, sex, and specialty, hospital ownership, ICU bed strength and teaching status, and physician random effect (unconditional GEE model).

‡ $P < 0.05$.

§ $P < 0.001$.