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RESEARCH ARTICLE

Lower Mortality for Abdominal Aortic Aneurysm Repair in High-Volume Hospitals Is Contingent upon Nurse Staffing

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Objective. To determine whether and to what extent the lower mortality rates for patients undergoing abdominal aortic aneurysm (AAA) repair in high-volume hospitals is explained by better nursing.

Data Sources. State hospital discharge data, Multi-State Nursing Care and Patient Safety Survey, and hospital characteristics from the AHA Annual Survey.

Study Design. Cross-sectional analysis of linked patient outcomes for individuals undergoing AAA repair in four states.

Data Collection. Secondary data sources.

Principal Findings. Favorable nursing practice environments and higher hospital volumes of AAA repair are associated with lower mortality and fewer failures-to-rescue in main-effects models. Furthermore, nurse staffing interacts with volume such that there is no mortality advantage observed in high-volume hospitals with poor nurse staffing. When hospitals have good nurse staffing, patients in low-volume hospitals are 3.4 times as likely to die and 2.6 times as likely to die from complications as patients in high-volume hospitals ($p < .001$).

Conclusions. Nursing is part of the explanation for lower mortality after AAA repair in high-volume hospitals. Importantly, lower mortality is not found in high-volume hospitals if nurse staffing is poor.

Key Words. Nurse staffing, nurse practice environment, volume–outcomes, abdominal aortic aneurysm

One of the most consistently observed and frequently reported relationships in health services research is that of the volume–outcomes relationship. Hospitals in which specific surgical procedures are performed more often, or in some cases hospitals in which the volume of specific medical conditions is greater, experience mortality rates for patients that are significantly lower than in other hospitals. This volume–outcomes relationship has led many to endorse referral of high-risk surgeries to high-volume hospitals under the assumption that higher hospital surgical volumes will be associated with better patient outcomes and decreased costs of health care (Leapfrog Group, Evidence Based Hospital Referral 2010). Similarly, a volume–outcomes relationship has been suggested between provider volume and patient outcomes. However, the causal mechanisms that underlie the relationship between volumes, whether it is hospital or surgeon volume, and outcomes are not well understood. This study seeks to examine a potential mediator of the hospital volume–outcomes relationship, specifically nursing.

In the hundreds of studies appearing in the literature on the hospital volumes and mortality association, very few have considered nursing. It has been well established that nursing varies considerably across hospitals and that variation is found in nurse staffing, nurse education, and the quality of the nurse practice environment, and all of these characteristics are associated with mortality (Kane et al. 2007; Aiken et al. 2008). As nursing is a major intervention provided by hospitals, this study seeks to determine whether, and to what extent, nurse staffing, nurse education, and the nurse practice environment explain the relationship between increased hospital volumes of high-risk operations and better patient outcomes. Specifically, this article examines the role of nurse staffing, nurse education, and the nurse practice environment and hospital surgical volume after abdominal aortic aneurysm (AAA) repair to further examine the underlying mechanisms leading to the volume–outcomes relationship.

Background And Significance

Two common hypotheses dominate the discussion of the underlying cause of the volume–outcomes relationship. First, the "practice-makes-perfect" hypothesis suggests that with increased volume, providers become more adept at caring for a specific patient population and thus provide more effective care (Luft et al. 1990). The appeal of this hypothesis is the focus on both the attending physician and the hospital team. Nurses and other staff members who are more familiar with specific patient populations are likely to have

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increased knowledge of patient needs and more refined surveillance skills (Luft et al. 1990; Kutney-Lee, Lake, and Aiken 2009). The second hypothesis is one of "selective referral." This hypothesis posits that volume is higher in hospitals with better outcomes because patients seek care at facilities with a priori reputations of superior performance (Luft et al. 1990). Although there are studies in support of both hypotheses, there is little research showing that increasing volume is actually associated with improved outcomes. As the causal pathways by which volume affects outcomes are not well understood, policies derived from this research may not achieve their expected results.

Notably absent from studies examining the volume–outcomes relationship is the role of the largest group of health care providers in hospitals—nurses. This exclusion occurs despite a large number of studies in the health services research literature showing an association between nursing care and patient outcomes. Better nurse staffing, higher proportions of bachelors prepared nurses and nurse practice environments have been found to have an association with improved patient outcomes. Research suggests that nurse staffing, nurse education, and the nurse practice environment play significant roles in the outcomes of patients, including but not limited to patients undergoing general, vascular, and orthopedic operations, surgical oncology patients, and patients hospitalized for Acquired Immunodeficiency Syndrome (AIDS), acute myocardial infarction (MI), congestive heart failure, chronic obstructive pulmonary disease, pneumonia, stroke, and septicemia (Aiken et al. 1999, 2008; Needleman et al. 2002, 2011; Tourangeau et al. 2002; Estabrooks et al. 2005; Friese et al. 2008; Van den Heede et al. 2009).

Our interest in the role of nurses in the volumes–outcomes relationship was motivated by our earlier study (Aiken et al. 1999) of the outcomes of dedicated AIDS units where we found, contrary to other AIDS studies (Cunningham et al. 1999), that low-volume hospitals with excellent nursing had significantly better outcomes than hospitals with dedicated AIDS units or specialized AIDS services and higher volumes of AIDS patients. Of the hundreds of articles published on the volume–outcomes relationship, we could identify only five others that considered the role of nursing at all, and none directly studied how nursing might account for the volume–outcomes relationship (Farley and Ozminkowski 1992; Pronovost et al. 1999; Person et al. 2004; Elting et al. 2005; Smith et al. 2007). These five studies suggest the potential importance of nursing when examining the volume–outcomes relationship, although no studies specifically examine the possibility of nursing as the underlying cause of the volume–outcomes relationship, nor do they consider possible interactions between hospital volume and nursing.

Volumes and outcomes in abdominal aortic aneurysm repair: Research on the relationship between hospital surgical volume of AAA repair and patient outcomes has established an association between higher hospital surgical volume and lower patient mortality. Two systematic reviews examining the hospital volume of AAA repairs and patient outcomes found a significant association between the number of AAA repairs a hospital performed and patient mortality (Henebiens et al. 2007; Holt et al. 2007a). Furthermore, recent studies using the Hospital Episode Statistics database in the United Kingdom, a prospective registry from the German Society for Vascular Surgery, and the national analytic files from the Center for Medicare and Medicaid Services in the United States all suggest a significant volume–outcomes relationship in AAA repair (Eckstein et al. 2007; Holt et al. 2007b; Dimick and Upchurch 2008).

Patients undergoing AAA repair were chosen for this study because of recent research finding a significant volume–outcomes effect with AAA repair, the relatively high average national mortality rate (3–6 percent), and their availability in discharge abstract data (Fleming et al. 2005). Furthermore, AAA repairs are high-risk surgical interventions that do not require specialized, expensive operating equipment (e.g., cardiopulmonary bypass), allowing for greater variability in the types of hospitals performing the operation. Although technologically advanced vascular services may perform endovascular AAA repairs in hybrid theater suites, this is not required for AAA repair. Finally, states do not currently have laws that require minimum volume thresholds for performing AAA repairs.

In this study, we examine the association between nursing care and hospital AAA repair volume and patient outcomes. We extend the scope of the volume–outcomes work published to date by examining the extent to which the relationship between hospital surgical volume and patient outcomes is conditional upon nursing, specifically whether the effect of hospital volume interacts with nursing factors such as nurse staffing, nurse education, and the nurse practice environment to explain the better outcomes for high-volume hospitals.

METHODS

The current study is a cross-sectional study of secondary data for hospitals in four states. The study linked data from nurse surveys, hospital patient discharge records, and administrative databases. The data sources included the

Multi-State Nursing Care and Patient Safety Survey; 2005–2006 patient discharge data from California, New Jersey, and Pennsylvania; 2006–2007 patient discharge data from Florida; and the 2005 and 2007 American Hospital Association (AHA) Annual Survey. The databases were merged using unique hospital identifiers common to all of the data sources. Included in this analysis are 517 hospitals for which there were data from 10 or more respondents to the nurse survey and for which there were evidence from the state discharge database that at least one annual AAA repair had occurred. On average, the hospitals in the study had 49 nurse respondents and 39 discharged patients who had undergone AAA repair. The outcomes of interest included 30-day mortality and failure to rescue (FTR), defined as the death of a patient within 30 days of admission after experiencing a postoperative complication in the hospital (Silber et al. 1992, 1995, 1995, 2007; Clarke and Aiken 2003). The units of analysis in the study are 517 hospitals, but the units of observation are variously hospitals, patients, and nurses, and the statistical modeling is with reference to a hierarchical model in which patients are nested within hospitals. The final sample for this study of AAA repair included 25,265 nurses and 20,409 patients in the 517 hospitals.

Nurse Survey Data

The Multi-State Nursing Care and Patient Safety Survey was collected by Aiken and colleagues at the University of Pennsylvania Center for Health Outcomes and Policy Research (Aiken et al. 2010, 2011; Kendall-Gallagher et al. 2011; McHugh et al. 2011a; McHugh et al. 2011b; Neff et al. 2011). The primary research team collected nurse survey data from California, Pennsylvania, and New Jersey between September 2005 and August 2006 and in Florida between November 2007 and April 2008. Surveys were mailed to 272,783 nurses in the four states: 106,532 in California, 49,385 in Florida, 52,545 in New Jersey, and 64,321 in Pennsylvania. This large mail survey had a response rate of 39 percent owing to the impossibility of targeting the mailings to hospital staff nurses, providing monetary incentives, or undertaking extensive follow-ups with such a large sample. Overall, the researchers obtained information from nine of every ten hospitals in all four states. In addition, a resurvey of 1,300 original nonresponders had a 91 percent response rate and was evaluated for possible bias. The results of this survey suggested no difference in responders and nonresponders in reports of hospital-level organizational features of nursing (Smith 2008; Aiken et al. 2010, 2011). Of those nurses who responded to the initial survey, 35,000 identified themselves as hospital staff nurses and further indicated on the survey their primary place of employment, including both the name of the hospital and the type of unit in which they worked.

The three primary nurse predictor variables employed in our analyses —nurse staffing, nurse education, and the nurse practice environment—were measured at the hospital level, using data obtained from the nurse surveys. Nurses were asked how many nurses and patients were on their units during their last shift, and nurse staffing was calculated for each hospital by dividing the average number of patients reported by nurses on their unit on their last shift by the average number of nurses reported to be working on that unit during the same shift. These measures were aggregated across all of the nurse respondents in a given hospital to estimate the average number of patients per RN (Aiken et al. 2002, 2003, 2008). Nurses were also asked about their educational credentials, and nurse education was also measured at the hospital level by calculating the proportion of nurses at each hospital with a bachelor's degree or higher. Finally, the nurse survey included an inventory of questions referred to as the Practice Environment Scale of the Nursing Work Index (PES-NWI), and three of the five subscales of that index that did not overlap empirically with nurse staffing and nurse education measures were used in our analyses. These included nursing foundations for quality of care; nurse manager ability, leadership, and support; and collegial nurse/physician relationships (Lake 2002; Aiken et al. 2008). This survey measure has been extensively validated (Lake 2007; Aiken et al. 2008; Bonneterre et al. 2008; Friese et al. 2008; Warshawsky and Havens 2011). Nurse responses were aggregated to obtain hospital level means for each of the subscales. Hospitals were then coded to distinguish those that were above and below the medians for each subscale. Hospitals above the median on all three subscales were classified as having good nurse practice environments, hospitals above the median on one or two of the subscales were classified as having mixed nurse practice environments, and hospitals below the median on all three subscales were classified as having poor nurse practice environments.

Patient Discharge Data

Individual-level patient discharge data were linked to the hospital-level measures derived from nurse survey data that are described above using hospital identifiers that were common to both datasets. Discharge data from 2005 to 2006 were used for California, New Jersey, and Pennsylvania, and patient discharge data from 2006 to 2007 were used for Florida because of the slight difference in the timing of the surveys. Patient discharge data were obtained from the Office of Statewide Healthcare Planning and Development in California, the Agency for Health Care Administration in Florida, the Department of Health and Senior Services in New Jersey, and the Health Care Cost Containment Council in Pennsylvania.

Hospital surgical volume was measured by the number of AAA repairs performed in each hospital over the 2-years period. This information was determined by scanning both the primary and secondary procedure codes in the patient discharge databases for each of the four states. Patients were included in the study if they had procedure codes 38.34, 38.44, 38.64, or 39.71, based on the *International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM).* A total of 20,409 patients were included.

Hospitals were initially separated into tertiles based on annual volume of AAA repairs. However, the low- and medium-volume tertiles were combined and then compared with the high-volume category after preliminary analyses revealed no differences in mortality and failure-to-rescue rates between the low- and medium-volume groups. The low/medium-volume hospitals performed an average of 22 AAA repairs per year, whereas the high-volume group performed an average of 142 AAA repairs per year.

Elixhauser et al.'s risk-adjustment approach was used, which involved coding 28 comorbidities that were identified in the patient discharge data (excluding fluid and electrolyte disorders and coagulopathy) as present or absent and including them as dummy variables in our regression analyses (Elixhauser et al. 1998). Additional risk-adjustment factors included patient age, race/ethnicity, transfer status, type of medical insurance, type of AAA repair (open vs endovascular), and exigency of the repair (urgent, emergent, or elective). The full list of risk-adjustment variables included in the analyses can be found in the body and footnote of Table 2.

AHA Annual Survey Data

Adjustments in our models for differences in patient outcomes due to hospital characteristics not related to nursing included measures of teaching status and technology. Measurements for these two variables were obtained from the AHA Annual Survey data from 2005 for California, New Jersey, and Pennsylvania, and from AHA data from 2007 for Florida. Hospitals were placed into one of three teaching categories based on the number of residents and/or fellows per hospital bed: nonteaching hospitals had zero residents/fellows; minor teaching hospitals had a ratio of 1 : 4 or less; and major teaching hospitals had a ratio greater than 1 : 4. The level of technological sophistication within a hospital was analyzed as a dichotomous variable. A hospital was defined as having a high level of technological sophistication if it provided services for open-heart operations and/or major organ transplantation.

Outcome Variables

The outcomes of interest included 30-day mortality and FTR. Patient discharge files from each state were examined for patients expiring within 30 days of admission. The use of 30-day mortality allowed the delay between hospital admission and presumably poor quality of care to manifest within 30 days of admission rather than within the limited time frame of inpatient hospitalization, which varied by hospital and by state (Chassin et al. 1989). FTR was defined as the death of a patient within 30 days of admission after experiencing a postoperative complication in the hospital (Silber et al. 1992, 1995, 1995, 2007; Clarke and Aiken 2003). Patients experiencing complications were identified from the patient discharge databases from each state using a previously defined compilation of secondary diagnoses and procedure codes documented by Silber and colleagues (Silber et al. 2007).

Data Analysis

Descriptive statistics are presented showing (1) the characteristics of the study hospitals, (2) the numbers and percentages of patients and nurses in each of the types of hospitals defined by these characteristics, and (3) the characteristics of the patients who underwent AAA repair, including the percentages with different comorbidities and the percentages that died. Both logistic regression and random-effects models were used to estimate the effects of hospital volume of AAA repairs, nurse staffing, and the nurse practice environment on both patient mortality and FTR before and after controlling for patient and hospital characteristics. The final model we describe includes a significant interaction between nurse staffing and surgical volume, and we use main and interaction effect coefficients from that model to estimate how the effect of staffing varies as a function of hospital volume, and vice versa. Although multivariate analysis included both robust regression models and random-effects models, the results were unaffected by the choice of modeling procedure. Thus, we show only the logistic regression models in this study in keeping with prior studies use of these models when studying the volume–outcomes effect. All models were corrected for the lack of independence (or the clustering) of nurses and patients within hospitals by using Huber-White (robust) procedures to adjust the standard errors. All analyses were conducted using STATA version 11 (STATA Corp., College Station, TX, USA), with $p < .05$ to indicate statistical significance.

Results

Table 1 provides information about the characteristics of the 517 hospitals included in the study, including the numbers and percentages of patients and nurses in each of the types of hospitals defined by these characteristics. More than one third of the study hospitals were located in California (38 percent), whereas Florida (28 percent) and Pennsylvania (22 percent) had slightly fewer hospitals. New Jersey had the fewest number of hospitals in the study, representing 12 percent of the sample. Roughly 45 percent of the hospitals had average patient-to-nurse ratios of 4 or less, whereas about one in four of the hospitals had average patient-to-nurse ratios of 6 or more. The nurse practice environment varied across hospitals, with nearly 30 percent of hospitals having poor practice environments and nearly 30 percent having good nurse practice environments. Twice as many hospitals were designated as low/medium volume hospitals with respect to AAA repairs (347 or 67 percent) compared with hospitals designated as high volume (170 or 33 percent). A similar number of hospitals in the sample were identified as institutions with increased levels of technological sophistication (50 percent) compared with hospitals with less technology available to them (50 percent). The majority of hospitals in the sample were either nonteaching hospitals (47 percent) or minor teaching hospitals (45 percent), with only 8 percent of hospitals in the sample being characterized as major teaching institutions. It is noteworthy that while less than one third of the hospitals in our sample were high volume and less than half were high technology, high-volume and high-technology hospitals provided care to more than three fourths of the patients in the study. Major teaching hospitals also provided care to a disproportionately high number of AAA patients.

Table 2 provides information on selected characteristics of the patients included in the analyses. Of the 20,409 AAA patients included in the study, the vast majority were male (79 percent) and white (88 percent). The average age of the patients in the sample was 73 years. Slightly more than half of the study sample underwent elective AAA repair (53 percent), and the majority of patients had an endovascular repair (58 percent). The most common

Table 1: Numbers and Percentages of Study Hospitals with Different Characteristics, and Number and Percentages of Patients and Nurses in Study Hospitals

	Hospitals (n = 517)		*Patients (n = 20,409)*		*Nurses (n = 25,265)*	
Hospital Characteristic	*No.*	*(%)*	*No.*	*(%)*	*No.*	*(%)*
Location						
California	196	(37.9)	5,945	(29.1)	7,794	(30.8)
Florida	145	(28.0)	6,914	(33.9)	5,594	(22.1)
New Jersey	64	(12.4)	2,090	(10.2)	5,521	(21.9)
Pennsylvania	112	(21.7)	5,460	(26.8)	6,356	(25.2)
Nurse staffing (Patients/nurse)						
4 or fewer	230	(44.5)	906	(4.4)	12,265	(60.4)
5	153	(29.6)	3,400	(16.7)	2,564	(12.6)
6	76	(14.7)	5,821	(28.5)	2,061	(10.1)
7 or more	58	(11.2)	10,282	(50.4)	3,422	(16.8)
Nurse practice environment						
Poor	150	(29.0)	4,108	(20.1)	5,833	(23.2)
Mixed	216	(41.8)	9,131	(44.7)	10,750	(42.7)
Good	151	(29.2)	7,170	(35.1)	8,575	(34.1)
Volume						
Low/medium	347	(67.1)	4,596	(22.5)	11,786	(46.8)
High	170	(32.9)	15,813	(77.5)	13,372	(53.2)
Technology						
Not high technology	261	(50.5)	4,719	(23.1)	9,170	(36.5)
High technology	256	(49.5)	15,690	(76.9)	15,988	(63.5)
Teaching status						
None	240	(47.2)	7,496	(37.0)	9,973	(40.0)
Minor	226	(44.5)	8,828	(43.6)	11,112	(44.6)
Major	42	(8.3)	3,931	(19.4)	3,835	(15.4)

comorbidity exhibited by the sample was hypertension (66 percent), followed by peripheral vascular disease (35 percent), chronic pulmonary disease (35 percent), and diabetes (14 percent). Roughly 36 percent of these AAA patients had complications during their hospitalization. Overall, 6 percent of the patients died within 30 days of admission.

Table 3 shows odds ratios, as well as 95 percent confidence intervals and the probabilities associated with them, from various models that were fit to describe the effects of hospital volume, nurse staffing, nurse education, and the nurse practice environment on mortality (in the upper panel of the table) and FTR (lower panel) subsequent to AAA surgeries. The odds ratios in the first row of each panel are unadjusted odds ratios from bivariate models which

Table 2: Characteristics of Surgical Patients Included in Analyses

	All Patients (n = 20,409)	
Characteristic	*No.*	*(%)*
Men	16,177	(79.3)
Age, mean (SD)	73	(9)
Race		
White	17,992	(88.2)
Black	728	(3.6)
Other	1,689	(8.3)
Type of admission		
Urgent/emergent	9,639	(47.3)
Elective	10,761	(52.8)
Type of repair		
Open	8,603	(42.2)
Endovascular	11,806	(57.8)
Medical history (comorbidity)*		
Hypertension	13,457	(65.9)
Peripheral vascular disorders	7,098	(34.8)
Chronic pulmonary disease	7,032	(34.5)
Diabetes, uncomplicated	2,773	(13.6)
Deficiency anemias	2,048	(10.0)
Renal failure	1,900	(9.3)
Hypothyroidism	1,214	(6.0)
Obesity	1,084	(5.3)
Other neurologic disorders	547	(2.7)
Depression	543	(2.7)
Solid tumor without metastasis	498	(2.4)
Alcohol abuse	484	(2.4)
Mortality	1,243	(6.1)
Complications	7,486	(36.7)

*Other comorbidities used to risk adjust our models included congestive heart failure, cardiac arrhythmias, valvular disease, diabetes with complications, liver disease, metastatic cancer, rheumatoid arthritis/collagen vascular diseases, weight loss, pulmonary circulation disorders, paralysis, blood loss anemias, drug abuse, psychoses, peptic ulcer disease, HIV and AIDS, and lymphoma. All of these comorbidities were exhibited by fewer than 2 percent of all patients.

estimate the effect of each factor on mortality and failure when the other factors, and other potential confounds more generally, are ignored. The odds ratios in the second row of each panel are from fully adjusted “main-effects” models, which estimate the effects of each factor simultaneously while controlling for differences in patient characteristics and other hospital characteristics. The odds ratios in the third row of each panel are from multivariate models that are like the main-effects models in that they include all three of the hospital variables identified in the table as well as the different patient characteristics and other hospital characteristics. However, in this model the effects of nurse staffing and hospital volume are allowed to interact, and the odds ratios describing these interactions are shown in the third row of each panel. We also evaluated models that included an interaction between the nurse practice environment and hospital volumes, and nurse education and hospital volumes, but the interactions were found to be insignificant.

The unadjusted odds ratios suggest that when the effect of each variable is considered independently, staffing, practice environment, and volume have significant effects on both mortality and FTR. Higher workload (or each additional patient per nurse) increases the odds on patients dying and being involved in a FTR, by factors of 1.12 and 1.08, respectively. Better practice environments decrease the odds on deaths and failures, by factors of .85 and .88, respectively. Finally, patients in low-volume hospitals have higher odds on deaths and failures than patients in high-volume hospitals by factors of 4.0 and 2.4.

The estimated effects of the nurse practice environment are largely unaffected by estimating it while controlling for patient characteristics and other hospital characteristics. That is, the odds ratios from the fully adjusted main-effects model for the nurse practice environment are similar to the unadjusted odds ratios. Interestingly, the effect of hospital volume is somewhat attenuated in the adjusted model, from .25 to .45 in the case of mortality and from .41 to .51 in the case of FTR. So after taking account of differences in nurse staffing and practice environments, patients in low-volume hospitals have higher odds on deaths and failures than patients in high-volume hospitals, by factors of 2.2 (rather than 4.0) and 1.9 (rather than 2.4). Ultimately, we find that the main-effects specification is not entirely consistent with the data and that the significant interaction between staffing and volume on both outcomes (shown in the far right column of Table 3) is significant and provides a better fit of model to data. The implications of the interaction are shown in Table 4.

The top panel of Table 4 shows the effect of higher patient to nurse ratios on both death and FTR, first in hospitals with a low volume of AAA repairs and then in hospitals with a high volume of AAA repairs. In low-volume hospitals the effect of staffing is virtually nil, whereas in high-volume hospitals adding one additional patient per nurse increases the odds of patient death by a factor of 1.13 (or by 13 percent) and the odds of FTR by a factor of 1.10 (or by 10 percent). The bottom panel of the table shows the effect of hospital volume of AAA repairs on mortality and failure in hospitals with varying levels of nurse staffing. In hospitals with patient-to-nurse ratios of 8 : 1, the effect of hospital volume of AAA repairs on both outcomes is insignificant. In hospitals

Table 3: Odds Ratios Indicating the Unadjusted and Adjusted Effects of Nurse Staffing, the Nurse Practice Environment, and Hospital AAA Repair

	Nurse Staffing (Patients per Nurse)		*Nurse Practice Environment (Favorable/ Unfavorable)*		*Nurse Education (Proportion of Nurses with BSN)*		*Hospital AAA Repair Volume (No. of AAA Repairs Annually)*		*Staffing × AAA Volume (Interaction)*	
Model	*OR (95% CI)*	*p*	*OR (95% CI)*	*p*	*OR (95% CI)*	*p*	*OR (95% CI)*	*p*	*OR (95% CI)*	*p*
Odds ratios from models for patient mortality										
Unadjusted	1.12 (1.038–1.202)	.003	0.85 (0.762–0.957)	.007	0.35 (0.189–0.631)	.001	0.25 (0.203–0.320)	<.001		
Fully adjusted*	1.07 (0.990–1.165)	.086	0.89 (0.796–0.986)	.027	0.58 (0.304–1.125)	.108	0.45 (0.337–0.589)	<.001		
Fully adjusted* with staffing interaction/ Regression	0.84 (0.721–0.988)	.034	0.89 (0.800–0.989)	.031	0.63 (0.326–1.230)	.177	0.09 (0.036–0.233)	<.001	1.34 (1.127–1.583)	.001
Odds ratios from models for failure to rescue										
Unadjusted	1.08 (1.015–1.156)	.016	0.88 (0.792–0.975)	.015	0.57 (0.323–1.004)	.052	0.41 (0.323–0.510)	<.001		
Fully adjusted*	1.07 (0.985–1.156)	.113	0.90 (0.804–0.998)	.047	0.85 (0.436–4.641)	.621	0.51 (0.390–0.672)	<.001		
Fully adjusted* with staffing interaction/ Regression	0.91 (0.775–1.074)	.270	0.90 (0.806–1.000)	.050	0.89 (0.458–1.735)	.734	0.19 (0.071–0.485)	.001	1.21 (1.013–1.436)	0.036

*Odds ratios and CIs were derived from robust regression models that accounted for clustering of observations within hospitals and adjusted for patient's age, gender, race, type of admission, insurance status, comorbidities, state, and hospital technology and teaching status.

Table 4: Odds Ratios Indicating (a) The Effect of Nurse Staffing in Hospitals with Various AAA Repair Volumes, and (b) the Effect of the Hospital Volume of AAA Repairs at Various Staffing Levels

	The Odds Ratio Indicating the Effect of Nurse Staffing is...	
When the Hospital Volume of AAA Repairs is...	*On Mortality (95% CI)*	*On Failure to Rescue (95% CI)*
Low/medium volume	0.844* (0.721–0.988)	0.912 (0.775–1.074)
High volume	1.127* (1.036–1.227)	1.100* (1.012–1.196)
	The Odds Ratio Indicating the Effect of Hospital Volume of AAA Repairs is...	
When the Hospitals Patient-to-Nurse Ratio is...	*On Mortality (95% CI)*	*On Failure to Rescue (95% CI)*
Four patients per nurse	0.292** (0.207–0.412)	0.394** (0.278–0.557)
Six patients per nurse	0.521** (0.388–0.699)	0.573** (0.426–0.770)
Eight patients per nurse	0.929 (0.545–1.585)	0.833 (0.482–1.440)

Note. All values were derived from robust regression models that accounted for clustering of observations within hospitals and adjusted for patient's age, gender, race, type of admission, insurance status, comorbidities, state and hospital technology, and teaching status.
*p value $< .05$.
**p value $< .001$.

with 6 : 1 ratios; however, patients in hospitals with high volume are less likely to die and fail than patients in low-volume hospitals, by factors of .52 and .57, respectively. And in hospitals with 4 : 1 patient-to-nurse ratios, the differences between high- and low-volume hospitals is even more pronounced. Patients in the high-volume hospitals are less likely than those in low-volume hospitals to die or fail by factors of .29 and .39, respectively, which implies that, even after all of the effects of all of the other patient and hospital characteristics are controlled for, patients in well-staffed low-volume hospitals are 3.4 times as likely to die and 2.6 times as likely to fail as patients in well-staffed high-volume hospitals.

DISCUSSION

Our findings suggest that the volume of AAA repairs in hospitals to which patients are admitted has a pronounced effect on the likelihood of AAA patients dying, with or without complications, and that nurse staffing and the quality of the nurse practice environment also have effects on both outcomes. We anticipated finding that the two nurse factors might account for the volumes effect, as it seemed likely that high-volume hospitals may be better staffed and have better work environments. When we restricted our attention to main-effects models, we found some support for this, especially with respect to mortality. Before taking account of the nursing factors, it appeared that patients in low-volume hospitals were about 4 times as likely to die as patients in high-volume hospitals, but after taking account of the nursing factors, patients in low-volume hospitals were only slightly more than 2 times as likely to die as patients in high-volume hospitals. It turned out to be slightly more complicated than that, inasmuch as ultimately we found that the effect of volumes was very much conditional on, if not explained by, nurse staffing. In poorly staffed hospitals increased volume made little difference on mortality, but in well-staffed hospitals it made a pronounced difference. In hospitals in which the patient-to-nurse ratio was around 4 : 1, patients had lower odds of dying when hospitals had high volumes of AAA patients rather than lower volumes, by factors of .39 (or over 60 percent lower) and .57 (over 40 percent lower) for mortality and FTR. Thus, in poorly staffed hospitals, an increased hospital volume of AAA repairs does not affect mortality as it does in well-staffed hospitals.

The results of this analysis depart from previous findings examining the role of nurses' education on patient outcomes (Aiken et al. 2003). Specifically, the association between the proportion of nurses with a bachelor's degree or higher and patient outcomes was not significant. However, the results of this study are based on a much smaller sample size than previous work. When comparing the education coefficients between previous publications with this work, the size of the coefficients is not that different. This suggests that the absence of a significant association between nurses' education and mortality outcomes seen in this study may be a result of sample size.

Our data are cross-sectional, which limits the extent to which causal inferences can be made. Furthermore, while our procedure for risk adjusting the patient characteristics in the different hospitals is fairly standard and involves controlling for, among other things, a large number of comorbidities, it is possible that omitted variables could be affecting our estimates. Also, our nurse-based estimates of the workloads and practice environments are subject to some error. This error might be larger in smaller hospitals where the estimates are derived from smaller numbers of nurse respondents, and workload estimates could also be affected by the relative number of nurse respondents in a hospital working in ICUs or other units where workloads are lower. However, our prior research has convinced us that the measure of staffing we are employing is better than alternatives (i.e., has greater predictive validity), and there is no reliable alternative measure of the work environment. Our study focuses on a single patient group, AAA repairs, and our result will need be replicated with other groups. Finally, our data sources are from 2005 to 2007 and we cannot account for technological advances that may have occurred since that time that could affect patient outcomes.

The results here suggest, quite strongly, that future research should consider whether hospital volume has an effect on other groups of patients, and under what conditions. Whereas a great deal of attention in research is focused on the issue of whether critical variables have been omitted, less attention has been paid to whether the nature of the effects of the variables included in the study have been properly specified, and in particular to whether effects are interactive.

The primary policy recommendation arising from research documenting a volumes–outcomes relationship has been to regionalize care. Regionalization, however, poses potential risks for poor outcomes by removing patients from close proximity to their support networks. We show that outcomes are not always better in high-volume hospitals. Indeed, there is no mortality advantage for patients undergoing AAA repairs in high-volume hospitals in the absence of good nurse-to-patient staffing ratios. As such, regionalizing care for AAA repairs to improve outcomes might best be accompanied by a consideration of the nurse work environments and most especially the nurse staffing in the hospitals in which the care is provided.

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