A Longitudinal Analysis of the Relationship between In-Hospital Mortality in New York State and the Volume of Abdominal Aortic Aneurysm Surgeries Performed

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This study uses New York State hospital discharge data to examine the relationship between in-hospital mortality for a patient receiving an abdominal aortic aneurysm resection and the volume of aneurysm operations performed in the previous year at the hospital where the operation took place and by the surgeon performing the operation. Previous research on this topic is extended in several respects: (1) A three-year data base is used to examine the manner in which hospital and surgeon volume jointly affect mortality rate and to examine ruptured and unruptured aneurysms separately; (2) a six-year data base is used to study the "practice makes perfect" hypothesis and the "selective referral" hypothesis; and (3) the degree of

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specialization of high-volume surgeons is contrasted with that of other surgeons. The results demonstrate a significant inverse relationship between hospital volume and mortality rate for unruptured aneurysms. Further, very few surgeons substantially increased their aneurysm surgery volumes in the six-year study period. Weak selective referral effects were found for both surgeons and hospitals, and higher-volume aneurysm surgeons tended to have much higher specialization rates.

In recent years, numerous studies have demonstrated that hospitals performing higher volumes of certain operations have better outcomes (lower in-hospital mortality rates, fewer complications and shorter lengths of stay) than hospitals performing the operations less frequently (Farber, Kaiser, and Wenzel 1981; Flood, Scott, and Ewy 1984a, 1984b; Fowles, Bunker, Oda, et al. 1987; Freeland, Hunt, and Luft 1987; Hannan, O'Donnell, Kilburn, et al. 1989; Hughes, Garnick, Luft, et al. 1988; Hughes, Hunt, and Luft 1987; Kelly and Hellinger 1987, 1986; Luft, Hunt, and Maerki 1987; Luft 1980; Luft, Bunker, and Enthoven 1979; Luft, Garnick, Mark, et al. 1987; Maerki, Luft, and Hunt 1986; Pilcher, Davis, and Ashikaga 1980; Roos et al. 1986; Shortell and LoGerfo 1981; Showstack, Rosenfeld, Garnick, et al. 1987; Sloan, Perrin, and Valvona 1986) after accounting for severity of illness. Also, a few studies have found that higher-volume surgeons have better results than other surgeons in performing certain operations (Fowles, Bunker, Oda, et al. 1987; Hughes, Garnick, Luft et al. 1988; Kelly and Hellinger 1987; Luft, Bunker, and Enthoven 1979; Luft, Garnick, Mark, et al. 1987; Maerki, Luft, and Hunt 1986), although many other studies have not found surgeon volume effects (Hughes, Hunt, and Luft 1987; Kelly and Hellinger 1987; Pilcher, Davis, and Ashikaga 1980; Roos et al. 1986; Shortell and LoGerfo 1981).

One of the operations whose success has proved to be affected by provider volume is abdominal aortic aneurysm surgery. Several studies (Flood, Scott, and Ewy 1984b; Hannan, O'Donnell, Kilburn, et al. 1989; Kelly and Hellinger 1986; Luft, Hunt, and Maerki 1987; Luft 1980; Luft, Bunker, and Enthoven 1979; Maerki, Luft, and Hunt 1986; Pilcher, Davis, and Ashikaga 1980) found that hospitals performing higher volumes of abdominal aortic aneurysm operations had lower mortality rates than lower-volume hospitals. Two studies (Luft, Hunt, and Maerki 1987; Luft 1980) investigated the causal direction of the relationship between hospital volume and the mortality rate for aneurysm resections.

Demonstrated surgeon volume-mortality relationships for aneurysm surgery have been rare. Only three studies (Hannan, O'Donnell, Kilburn, et al. 1989; Kelly and Hellinger 1986; Pilcher, Davis, and Ashikaga 1980) investigated surgeon volume for aneurysm resections and only the first two studies found that high-volume surgeons had better results than other surgeons in performing abdominal aortic aneurysm surgery.

The purpose of this study is to extend, in several respects, the previous volume-mortality research pertaining to abdominal aortic aneurysm surgery. First, a three-year 1985–1987 data base is used to explore in more depth the effect of surgeon volume and hospital volume on in-hospital mortality rate. A previous study in New York State (Hannan, O'Donnell, Kilburn, et al. 1989) examined mortality rates for patients of high- and low-volume surgeons and hospitals after standardizing by age, number of secondary diagnoses, admission status, and disease condition/stage. However, because of the limited amount of data (1986 only), mortality rates were compared for only two surgeon volume ranges by splitting the data at the median surgeon volume for all cases (four procedures per year). This study examines standardized mortality rates for multiple ranges of surgeon volumes and hospital volumes in an attempt to target more accurately the volume level that best discriminates among providers' performances. In addition, ruptured and unruptured aneurysms are analyzed separately.

Second, the causal direction of the volume-mortality relationship is investigated. That is, does "practice make perfect" in that when hospitals or surgeons perform more operations, their skill levels increase? Or, can the relationship be explained by the "selective referral hypothesis," whereby primary care physicians or patients gravitate to surgeons or hospitals that have better outcomes (and better reputations) or away from providers with worse outcomes? The answers to these questions are important because they have a bearing on whether or not low-volume providers can be transformed into high-volume providers with superior performances.

Some studies (Hughes, Hunt, and Luft 1987; Luft, Hunt, and Maerki 1987; Luft 1980) have used simultaneous equation models with a single year of data to examine causal direction between volume and mortality. In general, the findings of these studies suggest that causal paths in both directions are supported, but that the relative importance of each path is dependent on the procedure studied. This study uses a longitudinal data base to explore the effect of performance on volume by first identifying groups of surgeons and hospitals with low and high patient mortality rates for an initial time period and then tracking the change in the volume of aneurysm operations they perform during a subsequent time period. The effect of volume on performance is also investigated by contrasting the patient mortality rates of surgeons and hospitals before and after substantial increases occurred in their surgical volumes.

Third, the amount of specialization of the high-volume aneurysm surgeons is contrasted with the amount of specialization for low-volume aneurysm surgeons. Degree of specialization is measured in three ways: the percentage of all nondiagnostic primary procedures (1) that are abdominal aortic aneurysm operations, (2) that are aorta operations, and (3) that are vascular surgical operations.

METHODS

The primary source of data for the study was the set of patient discharge data abstracts for all New York State patients discharged in 1985–1987 who had abdominal aortic aneurysm surgery as a primary procedure (ICD-9-CM code 38.44) and had a principal diagnosis of an abdominal aortic aneurysm (ICD-9-CM 441.3 or 441.4). Analyses of "practice makes perfect" and "selective referral" hypotheses were based on the six-year period 1982–1987 in order to track changes in volumes and mortality rates over a reasonably long period of time. These data were available from the Statewide Planning and Research Cooperative System (SPARCS) that is maintained by the New York State Department of Health. Information in the discharge data abstracts includes patient-specific data relating to age, sex, race, admission status (scheduled or unscheduled), principal diagnosis, secondary diagnoses (up to four), primary procedure, secondary procedures (up to four), payer, whether or not the patient had been transferred from another acute care facility, and the license number of the surgeon performing the operation. Unscheduled admissions are urgent or emergency patients. There is no significant difference in the percentage of unscheduled admissions by sponsorship.

Other information used in the study was derived from the discharge data abstracts. The hospital volume assigned to each case was computed as the number of times abdominal aortic aneurysm surgery was performed in the hospital in the 12 months previous to the date of surgery; similarly, surgeon volume was measured as the number of times the surgeon performed abdominal aortic aneurysm surgery in the 12 months previous to the date of surgery. For example, January 1985 cases use data from February 1984 through January 1985 to compute volumes. Both linear and logarithmic functions of the volume measures were examined to determine which function showed the strongest relationship to the mortality rate data. Disease stage was determined by applying a software package (Disease Staging) developed by SysteMetrics, Inc. to SPARCS discharge data (Gonnella, Hornbrook, and Louis 1984). The stages for the disease condition "abdominal aortic aneurysm" are presented in Table 1. In this study, patient death was not considered in determining the stage so that the effect of the highest predeath stage of illness on the probability of dying in the hospital could be examined. Disease stage was not used for ruptured aneurysms because all patients were in Stage 3. For unruptured aneurysms, two stages were used (Stage 1.0 and Stage 3). Disease stage was included in the model as a dummy variable with Stage 1 as the reference group.

Selected secondary diagnoses were also tested to see if they were related to in-hospital mortality. Diagnoses were selected on the basis of their likelihood of being a comorbidity rather than a complication, the frequency with which they occurred, and their bivariate relationship to mortality rate. Cancer (ICD-9-CM 140.0–239.9), coronary heart disease (ICD-9-CM 412–414), diabetes (ICD-9-CM 250), and cardiac dysrhythmias (ICD-9-CM 427) were all examined for both ruptured aneurysms and for unruptured aneurysms. Cardiac dysrhythmia was the only one used in the multivariate analyses because none of the other diagnoses had a significant bivariate relationship to mortality rate at the .40 level of significance.

Other data were obtained from the New York State Department of Health's Health Facility Master File. These data included hospital size,

Table 1: Description of Stages for Abdominal Aortic Aneurysms

Stage	*Description*
1.0	Abdominal aortic aneurysm, asymptomatic
2.0*	Abdominal aortic aneurysm, symptomatic
3.1	Abdominal aortic aneurysm with rupture or aortoenteric fistula or aortocaval fistula
3.2	Shock
4.0	Death

*Patients cannot be classified in this stage using discharge abstract data because the data are not detailed enough.

hospital sponsorship status (voluntary, public, or private), and teaching status (teaching or nonteaching).

Logistic regression analysis was employed to analyze the data on a patient-specific basis. Separate models were fit for ruptured and unruptured aneurysm surgery performed during the three-year period. The binary dependent variable indicated whether or not the patient had died in the hospital during or after the surgery. Independent variables included the data elements in both the discharge data abstracts and the forementioned Health Facility Master File. Thus, hospital volume, surgeon volume, and a number of control variables relating to patient and hospital characteristics were used. The object was to determine if hospital volume or surgeon volume, or both, had a significant marginal relationship with the in-hospital mortality rate while controlling for the effects of other variables.

The logistic regression analysis was supplemented by a comparison of indirectly standardized mortality rates for unruptured aneurysm surgery from 1985–1987 for different hospital volume–surgeon volume combinations. This was done so that the magnitude of adjusted mortality rate differences among low- and high-volume providers could be identified. The analysis was limited to unruptured aneurysms because the vascular surgeons used as consultants to the study reasoned that some clinical data elements that were not contained in the discharge data abstracts were required to capture accurately the severity-of-illness differences in patients with ruptured aneurysms. The first step consisted of aggregating hospitals and physicians into volume ranges so that each of the intersecting hospital volume–surgeon volume combinations had a reasonable number of cases, and so that the crude mortality rates were as homogeneous as possible within groups and as heterogeneous as possible among groups. Four surgeon volume ranges and five hospital volume ranges were used.

As the next step, the crude mortality rate for each surgeon volume–hospital volume range was indirectly standardized using the coefficients of the patient-related variables that were significant in the logistic regression models. Standardizations were restricted to patient-related variables in order to identify differences in patient severity of illness rather than differences resulting from hospital organizational characteristics. Neither hospital volume nor surgeon volume was included in the standardizations.

Once standardized mortality rates were obtained for each of the surgeon volume–hospital volume combinations, the volume ranges were analyzed to determine whether surgeon volume or hospital volume, or both, were significantly related to standardized mortality rate.

The next phase of the analysis was directed toward an investigation of the "selective referral hypothesis," that is, the hypothesis that the relationship between provider volume and in-hospital mortality rate can be explained, at least in part, by the tendency of primary care physicians or patients to seek out surgeons or hospitals having the lowest mortality rates.

This hypothesis was investigated by identifying groups of hospitals with the lowest and highest mortality rates for unruptured aneurysm surgery for some initial period. Then, the changes in volumes of aneurysm surgery performed by the two groups between the initial period and some subsequent period were compared. Separate analyses were conducted using crude mortality rates and standardized rates. In addition, the available six-year data base (1982–1987) was split into all possible initial and subsequent periods of at least two years. Some analyses were limited to hospitals that had performed a minimum number of procedures during the six-year period. Also, the definition of "lowest" and "highest" mortality groups was varied from the upper and lower thirds to above and below the median mortality rate. The analysis was then repeated using high- and low-mortality-rate surgeons rather than hospitals. Although hospital volume was the volume measure that was significant in the logistic regression model for unruptured aneurysm surgery, surgeon volume was also tested for selective referrals, because referrals are generally made to surgeons rather than hospitals.

The practice makes perfect hypothesis was then investigated by identifying aneurysm surgeons who were low-volume providers in some initial time period, but became high-volume providers in a subsequent period. The purpose was to determine whether the adjusted mortality rates for these surgeons improved or not when their volumes increased. Although the same type of investigation was repeated using hospitals rather than surgeons, not enough hospitals had increased their volumes substantially enough to allow for examination.

In the final phase of the analysis, the 1985–1987 percentages of all nondiagnostic primary procedures that were (1) abdominal aortic aneurysm operations, (2) operations on the aorta, and (3) vascular surgical operations were contrasted for high-volume surgeons and the group of all other surgeons performing at least one aneurysm operation during the three-year period. "Operations on the aorta" were defined as ICD-9-CM codes 38.04, 38.14, 38.34, 38.44, 39.24, 39.25, and 39.26.

"Vascular surgery" was defined as any operation with an ICD-9-CM code in the range 38.00–39.99.

RESULTS

Table 2 presents data on resections of abdominal aortic aneurysms performed as primary procedures in New York State hospitals from 1982 through 1987. For each year, the table contains the number of surgeries, number of deaths, mortality rate, and the number of hospitals and surgeons performing this type of surgery. Also, only those cases with principal diagnoses of ruptured and unruptured abdominal aortic aneurysms are included in order to increase the likelihood that similar patients are being analyzed. Table 2 subdivides the data further by principal diagnosis code because of the large differences in mortality rates between patients with ruptured and unruptured aneurysms.

As indicated in Table 2, the number of patients undergoing abdominal aortic aneurysm surgery rose dramatically, from 942 in 1982 to 1,769 in 1987, an increase of 87.8 percent. Surgeries for ruptured aneurysms rose from 221 to 372 (an increase of 68.3 percent) and unruptured aneurysm surgeries increased from 721 to 1,397 (an increase of 93.8 percent). One possible reason for the increase in unruptured aneurysms is that surgeons are operating on patients with smaller aneurysms. Ruptured aneurysm surgery may be increasing because emergency medical services have reduced the mortality rate during transport to the hospital. Both types of surgery may be increasing because of an increase in the incidence of the condition or a willingness by surgeons to operate on progressively older patients. However, in-hospital mortality rates have remained fairly stable over time. Two exceptions are the 2 percent decrease in the overall rate between 1982 and 1983, and the 9 percent increase between 1986 and 1987 for patients with ruptured aneurysms. The 9 percent increase was accompanied by a 21 percent volume increase in ruptured aneurysms between 1986 and 1987. One possible explanation for these two increases is that patients who would have died before reaching the hospital in 1986 were kept alive long enough to reach the hospital in 1987 (as a result of improved emergency medical services) but died in the hospital as a result of their especially serious ruptures.

Concomitant with the rise in the number of surgeries performed was a smaller increase in the number of hospitals and surgeons performing abdominal aortic aneurysm surgery. The number of surgeons rose in the five-year period from 363 to 477 (a 31.4 percent increase),

Table 2: Resections of Abdominal Aortic Aneurysms Performed as Primary Procedures in New York State Hospitals 1982–1987

	Ruptured					*Non-ruptured*					*Total*				
Year	*No. Operations*	*No. Deaths*	*Mortality Rate*	*No. Physicians*	*No. Hospitals*	*No. Operations*	*No. Deaths*	*Mortality Rate*	*No. Physicians*	*No. Hospitals*	*No. Operations*	*No. Deaths*	*Mortality Rate*	*No. Physicians*	*No. Hospitals*
1982	221	118	.534	154	92	721	68	.094	296	135	942	186	.197	363	155
1983	244	122	.500	173	109	861	74	.086	301	141	1105	196	.177	370	162
1984	240	130	.542	169	107	890	64	.072	309	138	1130	194	.172	382	158
1985	274	146	.533	191	116	1038	84	.081	342	142	1312	230	.175	415	161
1986	308	157	.510	215	133	1135	89	.078	367	150	1443	246	.171	440	169
1987	372	223	.600	236	134	1397	100	.072	391	152	1769	323	.183	477	169

and the number of hospitals increased from 155 to 169 (up 9.0 percent).

Although the average annual number of abdominal aortic aneurysm operations per hospital and per surgeon rose somewhat in the five-year period, the numbers in 1987 were still very low. The 1,769 operations in 1987 were performed by 169 hospitals (an average of 10.5 operations per hospital) and 477 surgeons (an average of 3.7 operations per surgeon).

LOGISTIC REGRESSION RESULTS

Table 3 presents means and standard deviations for hospital and surgeon characteristics used in subsequent analyses. Table 4 presents the results of two logistic regression models for the years 1985–1987: ruptured aneurysm surgery only and unruptured aneurysm surgery only.

As indicated in Table 4, surgeon volume (but not hospital volume) was significantly inversely related to in-hospital mortality rate for ruptured aneurysm surgery, and hospital volume (but not surgeon volume) was significantly inversely related to mortality rate for unruptured aneurysm surgery. One possible explanation for surgeon volume being more important in ruptured aneurysm outcomes is that ruptured aneurysms are more difficult cases and require more individual expertise.

Patient age was significant in both models, with older patients having higher mortality rates. Although the number of secondary diagnoses was significant in both models, it was directly related to mortality rate for unruptured aneurysms and inversely related to mortality rate for ruptured aneurysms. A possible explanation for the latter finding is (1) that the secondary diagnoses are complications occurring after surgery rather than presurgical risk factors, and (2) that many patients with ruptured aneurysms die in surgery before experiencing postsurgical complications. Because the number of secondary diagnoses may be a measure of complications, this variable was removed from the logistic regression models and new results were obtained. The volume measures that were significant in the previous models remained significant.

Admission status was significant in the unruptured aneurysm model, with unscheduled admissions having higher mortality rates. Clearly, there are clinical differences between patients who require prompt or immediate surgery and patients who do not. These differences are likely to include factors such as aneurysm size and location,

Table 3: Abdominal Aortic Aneurysms in New York State—Descriptive Statistics for Patient and Hospital Characteristics, 1985–1987

	All Cases (N = 4524)		*Ruptured Cases (N = 954)*		*Nonruptured Cases (N = 3570)*	
Categorical Variables	*Proportion of Cases*		*Proportion of Cases*		*Proportion of Cases*	
Admission status						
Scheduled*	.625		.077		.771	
Sex						
Female	.216		.210		.218	
Dysrythmia	.153		.221		.135	
Hospital size						
≤ 275	.303		.387		.280	
276–900	.636		.587		.650	
Race						
White	.953		.954		.953	
Transfer from acute hospital or long-term care	.086		.109		.079	
Hospital sponsorship						
Voluntary	.918		.887		.927	
Public	.056		.083		.049	
Hospital teaching general surgery	.553		.479		.573	
Payer						
Medicare	.764		.779		.760	
Blue Cross	.147		.112		.156	
Year						
1986	.319		.323		.318	
1987	.391		.390		.391	
Other Variables	*Mean*	*(s.d.)*	*Mean*	*(s.d.)*	*Mean*	*(s.d.)*
Age	70.8	(8.33)	73.0	(8.99)	70.3	(8.05)
Number of secondary diagnoses	2.9	(1.34)	3.0	(1.30)	2.9	(1.35)
Number of Annual Procedures						
Per hospital	9.1	(11.20)	2.5	(2.01)	8.0	(10.11)
Per physician	3.4	(4.25)	1.5	(0.96)	3.3	(4.01)

*The reference groups for categorical variables are: Admission status = unscheduled; Sex = male; Dysrythmia = no dysrythmia; Hospital size = hospitals with more than 900 beds; Race = nonwhite; Transfer status = patients who have not been transferred from acute or long-term care facilities; Hospital sponsorship = proprietary; Hospital teaching status = nonteaching; Payer = Medicaid; Stage = nonruptured; Year = 1985.

Table 4: Abdominal Aortic Aneurysms in New York State—Regression Analysis Coefficients

	1985–1987			
Variable	*Ruptured Cases*	*Std. Error*	*Unruptured Cases*	*Std. Error*
Admission status†	-0.35	.27	-0.53***	.15
Age	0.06***	.01	0.08***	.01
Sex	-0.23	.18	0.14	.16
Hospital size				
>275	-0.25	.19	-0.07	.20
Race	0.20	.35	0.18	.32
Transfer from acute hospital or long-term care	-0.13	.23	0.11	.25
Hospital sponsorship				
Public	0.67*	.30	-0.03	.29
Hospital teaching general surgery	0.16	.18	0.30	.18
Number of secondary diagnoses	-0.18**	.06	0.76***	.09
Cardiac dysrhythmia (sec. diag.)	1.02***	.19	0.75***	.16
Payer				
Medicare	0.57*	.26	-0.41	.31
Blue Cross	0.59	.32	-0.09	.38
Disease stage‡	NA§		3.28***	.56
Year				
1986	-0.07	.18	-0.29	.17
1987	0.33	.18	-0.35*	.17
Log volumes				
Hospital	0.03	.10	-0.28**	.10
Surgeon	-0.33***	.09	-0.08	.09

*$p < .05$.

**$p < .01$.

***$p < .001$.

†Omitted categories of categorical variables: unscheduled admission; male; no secondary diagnosis; hospital with fewer than 275 beds; nonwhite; no transfer from acute or long-term care facility; nonpublic sponsorship; nonteaching hospital; Medicaid; nonruptured; 1985.

‡Aortoenteric fistula, or aortocaval fistula or shock.

§Not applicable.

blood pressure, and renal artery involvement. Unfortunately, these variables are not available in an administrative data base such as SPARCS. In their absence, admission status serves as a surrogate for differences in severity of illness resulting from these factors.

For unruptured cases, patients in Disease Stage 3 (patients with fistulas or in shock) had significantly higher mortality rates than patients in Stage 1. Because a very small number of unruptured cases (26) were in Stage 3, the unruptured model was refit without disease stage as an independent variable. The significance of hospital volume remained unchanged. As mentioned earlier, disease stage was used only for unruptured cases because all ruptured cases were classified in Stage 3.

The year in which the surgery was performed was a significant variable for unruptured aneurysms: patients receiving surgery for unruptured aneurysms in 1987 had significantly lower mortality rates than patients receiving surgery in 1985. Patients undergoing surgery in 1986 also had lower (although not significantly lower) rates than the 1985 patients. Thus, there has been an overall improvement in mortality for aneurysm surgery apart from the volume-mortality relationship. The reader is referred to a recent study (Cromwell, Mitchell, and Stason 1990) for other methods of testing this phenomenon.

In the ruptured aneurysm model, payer status, hospital sponsorship, and cardiac dysrhythmia were significant. Medicare patients had significantly higher mortality rates than Medicaid patients and public hospitals had higher rates than nonpublic hospitals. Further, patients with cardiac dysrhythmia had higher rates than patients without that secondary diagnosis. Cardiac dysrhythmia was also significant in the unruptured aneurysm model.

It should be noted that another set of logistic regression models was formulated in which the hospital and surgeon volumes were defined more broadly. The new volume definitions were the number of operations on the aorta rather than just aortic aneurysm resections. The set of cases investigated was again limited to aneurysms, however. The results for the new set of regression models were virtually identical to results from the other set with respect to the significant volume measures, significant control variables, and the overall fit of the models. Thus, it would appear that the volume measures can be more broadly defined for this particular low-volume procedure.

STANDARDIZED MORTALITY RATE ANALYSIS

The significant patient-related variables in the logistic regression analysis for unruptured abdominal aortic aneurysm patients in 1985–1987 were admission status (scheduled, unscheduled), age, number of secondary diagnoses, disease stage (ruptured or shock, or both, and other), and year.

Each operation performed in the 1985–1987 time period was assigned a surgeon volume based on the number of abdominal aortic aneurysms that the operating surgeon had performed in the previous 12 months. Similarly, a hospital volume was assigned for each operation based on the number of abdominal aortic aneurysms performed by the hospital in the previous 12 months. Table 5 presents the number of cases, crude mortality rates, and indirectly standardized mortality rates for various intersections of surgeon and hospital volume ranges. Surgeon volume was split into the ranges 0–2, 3–9, and 10 or more; hospital volume was represented by the ranges 0–9, 10–26, and 27 or more. The numbers of surgeons and hospitals in each volume range are also contained in the table. Note that these numbers sum to more than the totals in Table 2 because the number of operations performed

Table 5: Number of Cases, Crude Mortality Rates, and Indirectly Standardized Mortality Rates for Unruptured Abdominal Aortic Aneurysm Procedures Performed in New York State, by Annual Hospital and Surgeon Volume

		1985–1987 Hospital Volume in Previous 12 Months				
		0–9	*10–26*	*27–88*	*Total*	*No. Surgeons*[§]
Surgeon Volume in Previous 12 Months	0–2	570[*]	328	121	1,019	533
		12.3[†]	8.2	9.1	10.6	
		10.4[‡]	8.2	7.5	9.4	
	3–9	386	605	328	1,319	238
		10.9	6.1	5.2	7.3	
		10.3	6.6	5.2	7.4	
	10–43	44	240	948	1,232	69
		6.8	6.7	5.3	5.6	
		11.5	6.8	5.8	6.2	
	Total:	1,000	1,173	1,397	3,570	
		11.5	6.8	5.6	7.6	
		10.4	7.1	5.9		
No. Hospitals[§]		159	71	28		

[*] Number of cases.

[†] Crude mortality rate (percent).

[‡] Indirectly standardized mortality rate (percent).

[§] The numbers of hospitals and surgeons sum to more than the total number in the state because providers can be in different volume groups at different points in time.

by a given provider in the previous 12 months changes during the course of the three-year period.

The data in Table 5 demonstrate that crude mortality rates decrease monotonically from 11.5 percent for patients in hospitals with annual aneurysm surgery volumes of fewer than ten to 5.6 percent for patients in hospitals performing 27 or more aneurysm operations. Corresponding standardized mortality rates decrease monotonically from 10.4 percent for patients in hospitals with volumes of fewer than ten to 5.9 percent for patients in hospitals with volumes of 27 or more.

With regard to the relationship between surgeon volume and mortality rate, crude rates decrease monotonically from 10.6 percent for patients of surgeons performing fewer than three aneurysm operations annually to 5.6 percent for patients of surgeons performing ten or more operations a year. The corresponding standardized rates decrease from 9.4 percent to 6.2 percent.

Because of the correlation between hospital volume and surgeon volume, it is difficult to determine which of the two factors is more strongly associated with mortality rate by inspecting Table 5. However, when mortality rates were indirectly standardized using hospital volume in addition to the patient-related variables, there were no statistically significant differences among the surgeon volume groups. Significant differences did remain when surgeon volume was used in addition to the patient-related variables in calculating indirectly standardized mortality rates for different hospital volume groups. Thus, hospital volume was the more significant volume measure for unruptured aneurysms, which is consistent with the logistic regression results.

TESTING THE SELECTIVE REFERRAL HYPOTHESIS

As described in the Methods section, surgeons with high and low patient mortality rates in some initial period were identified. Then their aneurysm surgery volumes were tracked over a subsequent period to determine if the surgeons with better outcomes experienced larger volume increases. To check for stability of the results, we varied the definition of mortality rate (crude and standardized), the initial and subsequent periods (each at least two years, with the union of the two periods comprising all of 1982–1987), the definition of high- and low-mortality-rate surgeons (upper and lower quartiles, thirds, and halves), and the minimum number of procedures performed in the initial period and in the entire six-year period.

Table 6 presents the results for one of these combinations. The period 1982–1984 was used as the initial period, and aneurysm surgeons performing at least nine procedures in this period and at least one per year in 1985–1987 were split into thirds on the basis of the standardized mortality rates of their patients in 1982–1984.

As Table 6 indicates, both groups had substantial increases in the number of aneurysm operations performed per year, but the low-mortality surgeons had a significant increase in the percentage of all aneurysm operations that they performed between 1982–1984 and 1985–1987 (from 51.8 percent to 56.8 percent). Therefore, some evidence of a selective referral effect for surgeons does exist. Whereas high-mortality surgeons experienced a slight increase in the number of operations per surgeon per year (from 5.57 to 6.34), the low-mortality surgeons experienced much more pronounced increases (from 5.81 to 8.34 operations per surgeon per year).

Thus, low-mortality aneurysm surgeons experienced an aneurysm volume increase of 43.6 percent (from 523 to 751) between 1982–1984 and 1985–1987 in comparison with an aneurysm volume increase of 14.0 percent (from 501 to 571) for high-mortality surgeons.

Table 6: Changes in Volumes of Aneurysm Surgery for Surgeons with High and Low Patient Mortality Rates for Unruptured Aneurysm Surgery in Some Initial Time Period

Initial Period = 1982–1984

Subsequent Period = 1985–1987

Minimum Number of Procedures = nine in 1982–1984 and at least one per year in the 1985–1987 period

	Aneurysm Operations in 1982–1984	*Aneurysm Operations in 1985–1987*	*Total*
Low-mortality† surgeons (1982–1984)	523, (51.8%)	751, (56.8%)	1,274
High-mortality† surgeons (1982–1984)	501, (48.9%)	571, (43.2%)	1,072
Total	1,024	1,322	2,346
$\chi^2 = 7.67^*$			

*$p < .01$.

†Low mortality = patient standardized mortality rate < .045 (lowest third); High mortality rate = patient standardized mortality rate ≥ .105 (highest third). Number of surgeons in each group = 30.

For other nondiagnostic procedures within the same time periods, low-mortality aneurysm surgeons experienced a decrease of 10.0 percent (from 18,553 procedures to 16,688) between 1982–1984 and 1985–1987. High-mortality aneurysm surgeons also experienced a decrease of 10.0 percent during this period (from 21,508 to 19,350).

It should be noted that the results in Table 6 were somewhat sensitive to changes in the definition of initial and subsequent time period, the definition of high- and low-volume surgeons, and the type of mortality rate (crude or standardized). Occasionally, definitional combinations resulted in increases in the same direction as Table 6 that did not prove to be statistically significant. However, both groups always had increases in the number of operations per surgeon per year.

Table 7 presents one variation of parameters in the investigation of a selective referral process with regard to hospitals. Low-mortality and high-mortality hospitals are defined as hospitals with standardized mortality rates for unruptured aneurysm surgery in 1982–1983 in the lower and upper quartiles, respectively, of all hospitals that performed at least 20 aneurysm operations in that period and 60 operations between 1982 and 1987.

The table reflects the change in total aneurysm surgical volume

Table 7: Changes in Volumes of Aneurysm Surgery for Hospitals with High and Low Patient Mortality Rates for Unruptured Aneurysm Surgery in Some Initial Time Period

Initial Period = 1982–1983

Subsequent Period = 1984–1987

Minimum Number of Procedures = 60 over 1982–1987 period and at least 20 in 1982–1983 period

	Aneurysm Operations in 1982–1983	*Aneurysm Operations in 1984–1987*	*Total*
Low-mortality† hospitals (1982–1983)	436, (56.5%)	1,249, (57.9%)	1,685
High-mortality† hospitals (1982–1983)	335, (43.5%)	909, (42.1%)	1,244
Total	771	2,158	2,929
χ^2 = .41*			

*Not significant.

†Low mortality = patient standardized mortality rate < .05 (lowest third); High mortality rate = patient standardized mortality rate ≥ .10 (highest third). There are 11 hospitals in each group.

from the initial 1982–1983 period to the subsequent 1984–1987 period for each group of hospitals. The data indicate that the percentage of cases that were performed by the low-mortality group increased from 56.5 percent in 1982–1983 to 57.9 percent in 1984–1987, but that the increase was not statistically significant. Also, both groups of hospitals performed substantially more operations per year in the latter period than in the initial period. For the low-mortality hospitals, the operations per hospital per year rose from 19.8 to 28.3; for the high-mortality hospitals, the increase was from 15.2 to 20.6.

Also, the results were stable in that when the examined time periods and the definitions of low- and high-mortality hospitals were varied, there were always nonsignificant increases in the percentage of all operations performed by the low-mortality hospitals. The same results occurred when the restriction of at least 60 procedures during the six-year period was removed (X^2 = .11 n.s.).

One possible reason why selective referral effects were not significant may be the large increase in total aneurysm operations performed with virtually no change in the number of hospitals. This may have washed out "selective" referrals to hospitals.

TESTING THE PRACTICE MAKES PERFECT HYPOTHESIS

Table 8 examines the changes in standardized mortality rate for unruptured aneurysm surgery for surgeons with low volumes of surgery in an initial period (1982–1984) and relatively high volumes in a subsequent period (1985–1987). Under the practice makes perfect hypothesis, one would expect to see a significant decrease in standardized mortality rates in the latter period as a result of the experience gained by the surgeons.

In Table 8A, standardized mortality rates for the 22 surgeons in New York with 1–6 operations in 1982–1984, and 14 or more operations between 1985 and 1987 were compared. No significant change was found between the initial and subsequent periods.

Similarly, in Table 8B, 1–6 operations was used as the volume in 1982–1984, and 22 or more operations as the volume in the subsequent period. In this table, there was a substantial decrease, from 5.8 percent to 2.5 percent, but it was not statistically significant because of the small volumes of cases.

Thus, evidence of a practice makes perfect effect is limited. However, the case for practice makes perfect becomes stronger by taking

Table 8: Differences in Standardized Mortality Rates in Unruptured Aneurysm Surgery for Surgeons Performing Low Volumes of Surgery in an Initial Period and High Volumes in a Subsequent Period

8A: Surgeons with 1–6 Aneurysm Operations in 1982–1984 and 14 or More Operations in 1985–1987 (22 Surgeons)

	1982–1984	*1985–1987*
Total volume	90	455
Crude mortality rate	6.7%	5.1%
Standardized mortality rate	6.8%*	6.2%*

8B: Surgeons with 1–6 Aneurysm Operations in 1982–1984 and 22 or More Operations in 1985–1987 (6 Surgeons)

	1982–1984	*1985–1987*
Total Volume	24	177
Crude mortality rate	4.2%	1.7%
Standardized mortality rate	5.8%**	2.5%**

*No significant difference in these rates.

**No significant difference in these rates.

into account the fact that the movement of surgeons from "low" to "high" volumes does not occur over the full range of volume. In Table 8A, 22 surgeons averaged two operations annually in the initial period and at least 4.7 operations a year in the later period. When more pronounced volume increases were sought in Table 8B, only six of the surgeons who averaged two operations a year in the initial period averaged at least 7.3 operations a year in the later period. Thus, few surgeons moved from very low to very high volumes.

In addition to the 22 surgeons in Table 8A, nine other surgeons performed one to six aneurysm operations in the 1982–1984 period. These surgeons had a standardized mortality rate of 7.2 percent in 1982–1984, which was somewhat higher than the 6.8 percent rate of the surgeons in Table 8A. Similarly, 38 surgeons other than the ones in Table 8A performed 14 or more aneurysm operations in the 1985–1987 period, with a standardized mortality rate of 6.4 percent (as compared with the 6.3 percent standardized rate for the surgeons in Table 8A). Hence, surgeons who moved from low to high volumes had patient mortality rates that were lower in the initial period than surgeons with similar volumes, and achieved results that were slightly better than the results of surgeons with similar volumes in the later period. Thus, some evidence of practice makes perfect is there, because the standardized mortality rates of these surgeons decreased; but there is also some evidence of selective referrals because the surgeons experiencing volume increases were ones with lower mortality rates. It is also noteworthy that the growth in volume was due to "less risky patients," as indicated by higher standardized mortality rates (relative to the crude rates) in the later period.

As mentioned earlier, no results are presented for the practice makes perfect hypothesis in hospitals because virtually no hospitals experienced significant volume increases between 1982 and 1987.

DEGREE OF SPECIALIZATION OF HIGH-VOLUME AND LOW-VOLUME SURGEONS

Table 9 identifies two groups of surgeons who performed abdominal aortic aneurysm surgery in New York State in 1985–1987. The first column is the group of all surgeons who performed at least one aneurysm operation as a primary procedure in the three-year period, but did not perform 24 or more of these operations as primary procedures in the three-year period. A total of 678 of these surgeons performed 2,843 aneurysm operations with a crude mortality rate of 22.0 percent and a standardized mortality rate of 18.9 percent in a total of 196 hospitals.

The second column pertains to the subset of surgeons who performed at least 24 such surgeries from 1985–1987 in New York State.

Table 9: Specialization of Surgeons Performing Abdominal Aortic Aneurysms in New York State, 1985–1987

	*Low-Volume Surgeons**	*High-Volume Surgeons†*
Number of surgeons	678	43
Number of nondiagnostic operations per surgeon	438	683
Percent of nondiagnostic procedures that are abdominal aortic aneurysms	1.1	6.1
Percent of nondiagnositic procedures that are aorta operations	2.1	10.5
Percent of nondiagnostic procedures that are vascular operations	18.5	51.5

*Surgeons who did not perform 24 or more abdominal aortic aneurysm operations in 1985–1987 but did perform at least one of those operations in the three-year period.

†Surgeons performing at least 24 abdominal aortic aneurysm operations in 1985–1987.

This definition was considered to be consistent with the optimal split of ten operations in a one-year period from Table 5. An average of eight in the three-year period was used rather than ten because three-year averages tend to be lower in general.

The amount of specialization for each volume group is measured in three different ways: the percentage of all nondiagnostic primary procedures performed by a surgeon that were abdominal aortic aneurysm resections, the percentage that were operations on the aorta, and the percentage that were vascular surgical operations.

Table 9 indicates that the group of high-volume surgeons had specialization percentages that were far different than those of the set of low-volume aneurysm surgeons.

As expected, the low-volume aneurysm surgeons had a lower percentage of all nondiagnostic operations that were aneurysm operations (1.1 percent) than did the group of high-volume aneurysm surgeons (6.1 percent). Also, whereas the low-volume aneurysm surgeons performed operations on the aorta in only 2.1 percent of their nondiagnostic operations, the comparable percentage for high-volume aneurysm surgeons was 10.5 percent. When all vascular surgical operations were used as a numerator, the specialization percentages were 18.5 percent for low-volume surgeons and 51.5 percent for high-volume surgeons.

Thus, the group of surgeons who perform higher volumes of surgery on aneurysms had a much greater tendency to specialize in operations on the aorta and in vascular surgical operations than did the low-volume aneurysm surgeons. This is also evidenced by the .81 correlation coefficient between the number of aneurysm resections performed by a surgeon and the number of aorta operations (excluding aneurysms) performed. The correlation coefficient between the number of aneurysms performed and the number of vascular surgical operations performed (excluding aneurysms) was .67.

DISCUSSION

This study has demonstrated that hospital volume has a strong inverse relationship with in-hospital mortality rates for patients receiving resections of unruptured abdominal aortic aneurysms in New York State in 1985–1987. For patients receiving resections of ruptured aneurysms, surgeon volume was inversely related to mortality rate, although these results are less definitive because the discharge data elements used in the study may not adequately capture severity-of-illness differences for patients with ruptured aneurysms.

A possible limitation of the study is that in-hospital mortality rate was used as the measure of mortality as opposed to a 30-day mortality rate (where the patient dies within 30 days of admission, whether he or she is still hospitalized or not), which is favored by many researchers. This could yield a potential bias if high-volume providers are discharging some patients prematurely and these patients are dying shortly after discharge, or if high-volume providers are transferring more patients to other hospitals to die. However, when provider volume groups were defined as in Table 5, it was determined that the higher-volume surgeons and hospitals had lower percentages of transfers to other hospitals and postoperative lengths of stay that were shorter, but not significantly shorter, than the lower-volume providers. Consequently, it is unlikely that the volume measures would no longer have been significant if 30-day mortality had been used in lieu of in-hospital mortality.

A major focus of this study was the investigation of the causal relationship between volume and mortality rate. Other studies (Hughes, Garnick, Luft, et al. 1988; Luft, Hunt, and Maerki 1987; Luft 1980; Luft, Garnick, Mark, et al. 1987) have characterized the two causal directions as either practice makes perfect, whereby surgeons who perform high volumes of a particular operation become more skilled at it and achieve superior outcomes, or selective referrals, whereby referring physicians and/or patients recognize the best surgeons and send more patients to them. Excellent discussions of these competing hypotheses are provided by Luft, Hunt, and Maerki (1987) and by Luft, Garnick, Mark, et al. (1987).

These authors emphasize that the value of policies such as the regionalization of particular operations is not diminished by the comparative correctness of either of the two hypotheses. However, they point out that if the selective referral hypothesis is the stronger causal link, future high-volume providers must be selected carefully to achieve superior outcomes. For example, if preferred provider organizations were to agree to send more surgical patients to certain hospitals with the best prices, these hospitals' surgical volumes would increase substantially. Unless practice does make perfect, however, current low-volume hospitals with poor outcomes may be transformed into high-volume hospitals with poor outcomes.

Another point these authors make is that both the selective referral and practice makes perfect effects have a time dimension and are measured best using longitudinal data. Without access to longitudinal data bases, previous research was forced to apply simultaneous equation methods to a single year of data.

This study used a longitudinal data base to test the relative merits of the two hypotheses. The practice makes perfect hypothesis was tested by identifying providers with low surgical volumes in an initial time period and higher volumes in a subsequent period to determine if the volume increases contributed to lower risk-adjusted patient mortality rates. Unfortunately, the analysis was limited by necessity to surgeons because hospital volume was extremely stable over the six-year period. Although the decreases in surgeons' adjusted mortality rates that occurred in the subsequent period were not statistically significant, the volume increases in the latter period were not large enough to foretell any more improvement. Also, very few surgeons experienced even modest volume increases, and these surgeons had lower patient mortality rates in the initial period than would have been expected given their low surgical volumes. However, when their volumes increased, they had patient mortality rates as low as those of consistently high-volume surgeons.

It should be noted that, despite the fact that surgeon volume was significantly related to mortality rate for ruptured aneurysms and not for unruptured aneurysms, the practice makes perfect test was conducted using the unruptured cases. Thus, it is not surprising that no significant changes occurred in either section of Table 8. The reason for this is that very few surgeons changed from low volumes of ruptured aneurysm cases in some initial period to relatively higher volumes in a subsequent period (the results, although not presented here, evidenced no significant changes). It is possible that if more data had been available on volume changes for ruptured aneurysms, a significant reduction in standardized mortality rate might have occurred.

Perhaps the most interesting finding is that aneurysm surgeons very rarely change from low to high volumes. Even the new surgeon who becomes a high-volume aneurysm surgeon rises to a "high" level quickly without experiencing a protracted period as a low-volume surgeon.

The selective-referral hypothesis was tested by examining relative changes in surgical volume for providers with high and low risk-adjusted patient mortality rates in some initial period. The results demonstrate that low mortality rate providers have larger increases in volume per year between the two time periods than providers with high patient mortality rates. For surgeons, these differences were usually statistically significant, but for hospitals they were not.

Thus, there appears to be some evidence of a selective referral effect. This is consistent with the results of studies that have used simultaneous equations to examine selective referrals for aneurysms

(Luft, Hunt, and Maerki 1987; Luft 1980). However, one possible alternative explanation is that the low-mortality surgeons accepted a higher percentage of aneurysm referrals in the later period than the high-mortality surgeons although they received no more referrals.

Regardless of the interpretation, Table 6 demonstrates that many high-mortality surgeons did perform more aneurysm operations per year in the later period than in the initial period. However, since Table 6 was limited to surgeons who performed at least one operation in the later period, high-mortality surgeons who discontinued aneurysm surgery are not included. Thus, the increase in procedures performed by high-volume surgeons is not surprising. Nevertheless, it is unlikely that the selective referral effect identified here will substantially remedy the wide variations in risk-adjusted mortality rates among hospitals without new means of improving the referral process. The results of Table 9 demonstrate that high-volume aneurysm surgeons tended to specialize more in other operations on the aorta, and generally in other vascular operations, than did the low-volume aneurysm surgeons.

In summary, the safest means for increasing New York's statewide percentage of unruptured aneurysm resections performed by high-volume providers is to increase the number of patients operated on by providers who already do a high volume of cases. One reviewer has suggested that this could be accomplished for relatively uncommon procedures such as aneurysm surgery by establishing centers of excellence on the basis of high volumes and low risk-adjusted mortality rates. Medicare reimbursement and licensing could then be used to create regional referrals to centers. This is currently the process used by some preferred provider organizations to identify preferred referral hospitals.

Clearly, one concern with this approach would be whether centers could be reached in time by emergency patients with ruptured aneurysms. However, a recent study in New York (Cohen et al. 1991) found that if patients with suspected ruptured aneurysms are transferred to centers experienced in these procedures within six hours, patient mortality rates are not significantly compromised.

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REFERENCES

Cohen, J. R., E. Birnbaum, M. Kassan, and L. Wise. "Experience in Managing 70 Patients with Ruptured Abdominal Aortic Aneurysms." *New York State Journal of Medicine* 91, no. 3 (1991): 97–100.

Cromwell, J., J. B. Mitchell, and W. B. Stason. "Learning by Doing in CABG Surgery." *Medical Care* 28, no. 1 (1990): 6–18.

Farber, B. F., D. L. Kaiser, and R. P. Wenzel. "Relation Between Surgical Volume and Incidence of Postoperative Wound Infection." *New England Journal of Medicine* 305, no. 4 (1981): 200–204.

Flood, A. B., W. R. Scott, and W. Ewy. "Does Practice Make Perfect? Part I: The Relation between Hospital Volume and Outcomes for Selected Diagnostic Categories." *Medical Care* 22, no. 2 (1984a): 98–114.

———. "Does Practice Make Perfect? Part II: The Relation between Volume and Outcomes and Other Hospital Characteristics." *Medical Care* 22, no. 2 (1984b): 115–25.

Fowles, J., J. P. Bunker, M. Oda, D. J. Schurman, P. N. Osborn, and M. Loftus. "Relation of Surgical Volume to Outcomes and Charges: Pilot Study of Total Hip Replacement Using Northern California Medicare Data." *Business Health* 4, no. 8 (1987): 44–46.

Freeland, M. S., S. S. Hunt, and H. S. Luft. "Selective Contracting for Hospital Care Based on Volume, Quality and Price: Prospects, Problems and Unanswered Questions." *Journal of Health Politics, Policy and Law* 12, no. 3 (1987): 409–26.

Gonnella, J. S., M. C. Hornbrook, and D. Z. Louis. "Staging of Disease: A Case-Mix Measurement." *Journal of American Medical Association* 251, no. 5 (1984): 637–44.

Hannan, E. L., J. F. O'Donnell, H. Kilburn, H. Bernard, and A. Yazici. "Investigation of the Relationship between Volume and Mortality for Surgical Procedures Performed in New York State." *Journal of American Medical Association* 262, no. 4 (1989): 503–10.

Hughes, R. G., D. W. Garnick, H. S. Luft, S. J. McPhee, and S. S. Hunt. "Hospital Volume and Patient Outcomes: The Case of Hip Fracture Patients." *Medical Care* 26, no. 11 (1988): 1057–67.

Hughes, R. G., S. S. Hunt, and H. S. Luft. "Effects of Surgeon Volume and Hospital Volume on Quality of Care in Hospitals." *Medical Care* 25, no. 6 (1987): 489–503.

Kelly, J. V., and F. J. Hellinger. "Heart Disease and Hospital Deaths: An Empirical Study." *Health Services Research* 22, no. 3 (August 1987): 369–95.

———. "Physician and Hospital Factors Associated with Mortality of Surgical Patients." *Medical Care* 24, no. 9 (1986): 785–800.

Luft, H. S. "The Relations between Surgical Volume and Mortality: An Exploration of Causal Factors and Alternative Models." *Medical Care* 18, no. 9 (1980): 940–59.

Luft, H. S., J. P. Bunker, and A. C. Enthoven. "Should Operations Be Regionalized: The Empirical Relation between Surgical Volume and Mortality." *New England Journal of Medicine* 301, no. 25 (1979): 1364–69.

Luft, H. S., D. W. Garnick, D. Mark, S. J. McPhee, and J. Tetrault.

Evaluating Research on the Use of Volume of Services Performed in Hospitals as an Indicator of Quality. Washington, DC: Office of Technology Assessment, U.S. Congress, 1987.

Luft, H. S., S. S. Hunt, and S. C. Maerki. "The Volume-Outcome Relationship: Practice Makes Perfect or Selective Referral Patterns?" *Health Services Research* 22, no. 2 (June 1987): 157–82.

Maerki, S. C., H. S. Luft, and S. S. Hunt. "Selecting Categories of Patients for Regionalization: Implications of the Relationship between Volume and Outcome." *Medical Care* 24, no. 2 (1986): 148–58.

Pilcher, D. B., J. H. Davis, and T. Ashikaga. "Treatment of Abdominal Aortic Aneurysm in an Entire State over 7.5 Years." *American Journal of Surgery* 139, no. 4 (1980): 487–94.

Roos, L. L., S. M. Cageorge, N. P. Roos, and R. Danzinger. "Centralization, Certification and Monitoring: Readmissions and Complications after Surgery." *Medical Care* 24, no. 11 (1986): 1044–66.

Shortell, S. M., and J. P. LoGerfo. "Hospital Medical Staff Organization and Quality of Care: Results for Myocardial Infarction and Appendectomy." *Medical Care* 19, no. 10 (1981): 1041–55.

Showstack, J. A., K. E. Rosenfeld, D. W. Garnick, H. S. Luft, R. E. Schaffarzick, and J. Fowles. "Association of Volume with Outcome of Coronary Artery Bypass Graft Surgery." *Journal of American Medical Association* 257, no. 6 (1987): 785–89.

Sloan, F. A., J. M. Perrin, and F. Valvona. "In-Hospital Mortality of Surgical Patients: Is There an Empiric Basis for Standard Setting?" *Surgery* 99, no. 4 (1986): 446–53.