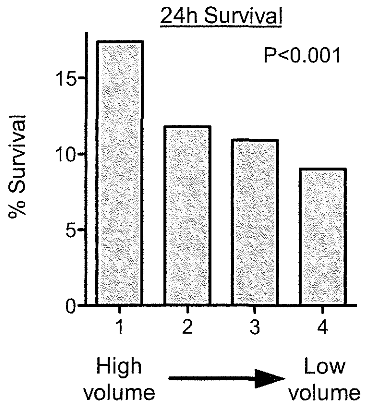
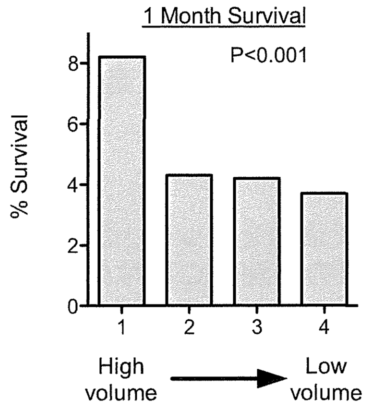
# Survival Outcomes by Center volume

24時間生存

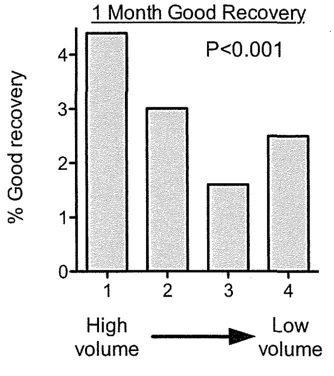



1ヶ月生存




# Neurological Outcome by Center Volume

1ヶ月神経学的転帰良好




**Center volume for 1m good recovery (per quartile)**

Adjusted OR 1.27 95% CI 1.04-1.54 *P*=0.017

Adjusted:
age, gender, cardiac ethiology, witness, bystander CPR, VF/VT, EMS airway device, EMS adrenaline, prehospital time, ECPR, CAG, hypothermia

# 考察

- Center volumeの増加は心原性心肺停止症例の神経学的転帰の改善と関連しない(n=4125, 155施設, 2005-2009, 米国).
  *Resuscitation 2012; 83: 862-868*

- 年間心肺停止40症例以上受け入れている施設での生存退院率は40症例未満に比して高い(37% vs. 30%, n=4087, 254施設, 2005-2007,米国).
  *Resuscitation 2010; 81: 524-529*

- ICUで治療を行っている心肺停止症例数が多い施設(年間20例以上)での病院死亡率は低い(n=4674, 39施設, 2002-2005, 米国).
  *Resuscitation 2009; 80: 30-34*

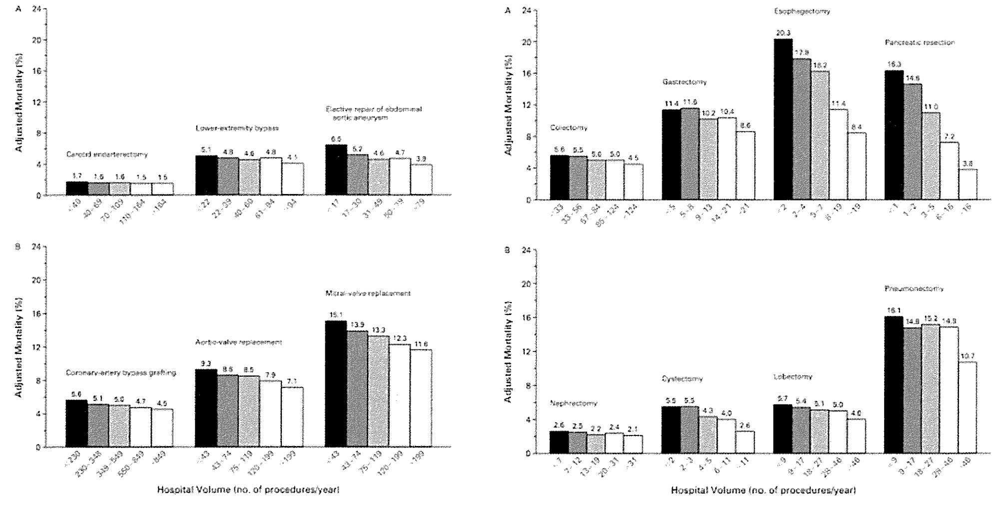
- 病床数の増加は心肺停止症例の病院死亡率の改善と関連を認めた(adjusted OR 0.55, P<0.001, n=109739, 1000施設, 2000-2004, 米国).
  *Intensive Care Medicine 2009; 35: 505-511*

The New England Journal of Medicine

Special Article

文献① N Engl J Med 2002;346:1128-37.

HOSPITAL VOLUME AND SURGICAL MORTALITY IN THE UNITED STATES



SPECIAL ARTICLE

文献② N Engl J Med 2003;349:2117-27.

## Surgeon Volume and Operative Mortality in the United States

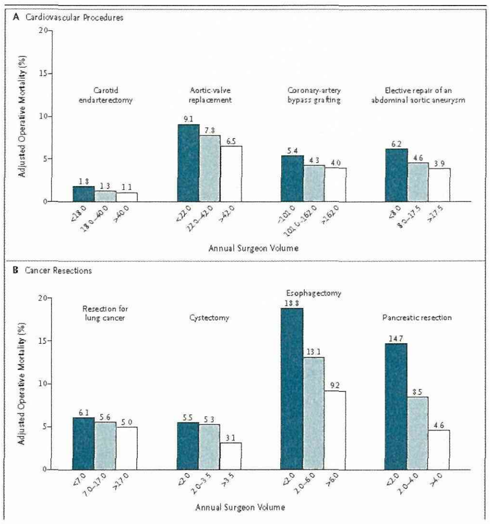



Table 2. Adjusted Odds Ratio for Operative Death, According to Surgeon Volume and Hospital Volume.*

| Procedure | Odds of Operative Death with Low Volume as Compared with High Volume | | | | | |
|---|---|---|---|---|---|---|
| | Surgeon Volume | Surgeon Volume, Adjusted for Hospital Volume | Proportion of Effect of Surgeon Volume Attributable to Hospital Volume | Hospital Volume | Hospital Volume, Adjusted for Surgeon Volume | Proportion of Effect of Hospital Volume Attributable to Surgeon Volume |
| | adjusted odds ratio (95% CI) | | % | adjusted odds ratio (95% CI) | | % |
| **Cardiovascular procedures** | | | | | | |
| Carotid endarterectomy | 1.64 (1.47–1.84) | 1.70 (1.51–1.91) | 0 | 1.04 (0.92–1.17) | 0.89 (0.79–1.01) | —† |
| Aortic-valve replacement | 1.44 (1.29–1.59) | 1.45 (1.30–1.63) | 0 | 1.13 (1.00–1.28) | 0.97 (0.86–1.10) | 100 |
| Coronary-artery bypass grafting | 1.36 (1.28–1.45) | 1.33 (1.25–1.42) | 8 | 1.26 (1.15–1.37) | 1.13 (1.03–1.24) | 49 |
| Elective repair of an abdominal aortic aneurysm | 1.65 (1.46–1.86) | 1.55 (1.36–1.77) | 15 | 1.40 (1.23–1.59) | 1.17 (1.02–1.35) | 57 |
| **Cancer resections** | | | | | | |
| Resection for lung cancer | 1.24 (1.08–1.44) | 1.16 (0.99–1.36) | 34 | 1.29 (1.11–1.51) | 1.22 (1.04–1.44) | 24 |
| Cystectomy of the bladder | 1.83 (1.37–2.45) | 1.45 (1.03–2.04) | 46 | 2.06 (1.50–2.83) | 1.65 (1.14–2.39) | 39 |
| Esophagectomy | 2.30 (1.54–3.42) | 1.80 (1.13–2.87) | 38 | 2.23 (1.47–3.39) | 1.67 (1.02–2.73) | 46 |
| Pancreatic resection | 3.61 (2.44–5.33) | 2.31 (1.43–3.72) | 50 | 3.95 (2.55–6.11) | 2.34 (1.38–3.99) | 54 |

Table 3. Adjusted Operative Mortality Rates among Medicare Patients in 1998 and 1999, According to Total Hospital Volume, Relative to the Leapfrog Group Volume Criteria and Surgeon Volume.*

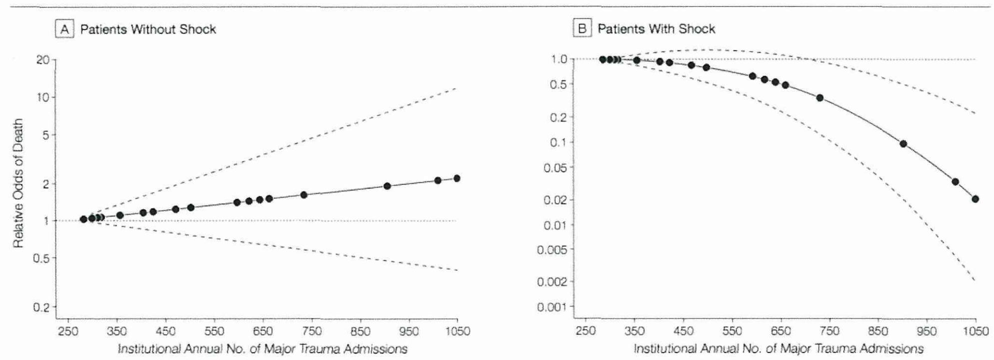
| Procedure | Cutoff | Hospital Volume <Cutoff | | | Hospital Volume ≥Cutoff | | |
|---|---|---|---|---|---|---|---|
| | | Low-Volume Surgeons | High-Volume Surgeons | Overall Hospital Mean | Low-Volume Surgeons | High-Volume Surgeons | Overall Hospital Mean |
| | no./yr | percent | | | | | |
| Coronary-artery bypass grafting | 450 | | | | | | |
| Proportion of patients | | 47.3 | 20.1 | | 19.3 | 46.8 | |
| Mortality | | 5.4 | 4.6 | 5.0 | 5.4 | 3.7 | 4.2 |
| Elective repair of an abdominal aortic aneurysm | 50 | | | | | | |
| Proportion of patients | | 45.3 | 18.1 | | 17.8 | 52.5 | |
| Mortality | | 6.4 | 4.3 | 5.4 | 5.8 | 3.6 | 4.3 |
| Esophagectomy | 13 | | | | | | |
| Proportion of patients | | 36.0 | 14.4 | | 9.2 | 70.0 | |
| Mortality | | 19.2 | 11.1 | 15.3 | 17.5 | 8.1 | 9.5 |
| Pancreatic resection | 11 | | | | | | |
| Proportion of patients | | 50.5 | 9.4 | | 6.9 | 80.5 | |
| Mortality | | 15.7 | 6.9 | 11.9 | 6.1 | 3.7 | 4.5 |

ORIGINAL CONTRIBUTION

文献③ JAMA 2001;285:1164-1171.

## Relationship Between Trauma Center Volume and Outcomes

**Figure 2.** Association Between Adjusted Relative Odds of Death and Trauma Center Volume in Patients With PAI

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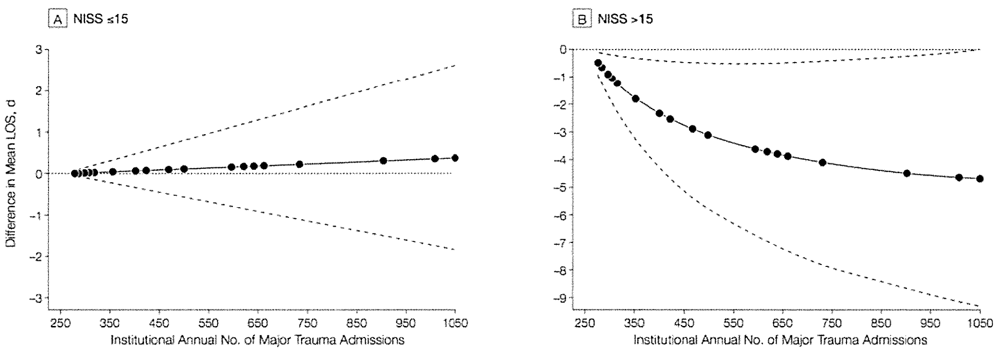
ORIGINAL CONTRIBUTION

文献③ JAMA 2001;285:1164-1171.

## Relationship Between Trauma Center Volume and Outcomes

**Figure 3.** Differences in Mean LOS for Patients Admitted With PAI as a Function of Trauma Center Volume

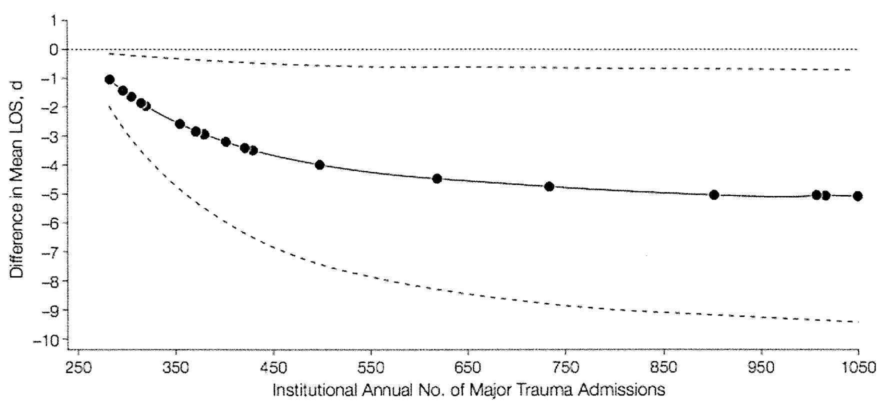



ORIGINAL CONTRIBUTION

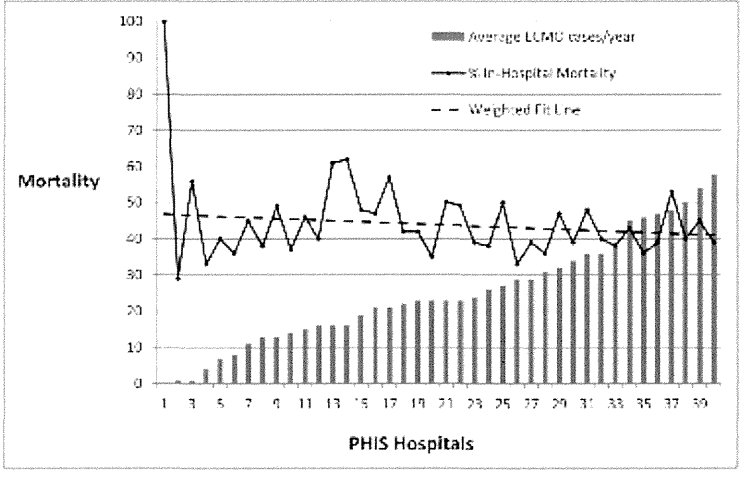
文献③ JAMA 2001;285:1164-1171.

## Relationship Between Trauma Center Volume and Outcomes

**Figure 6.** Differences in Mean LOS for Patients Admitted With Multisystem Blunt Trauma as a Function of Trauma Center Volume



**Pediatric and Neonatal Extracorporeal Membrane Oxygenation: Does Center Volume Impact Mortality?*** 文献④ Crit Care Med 2014; 42:512–519



Special Article

# HOSPITAL VOLUME AND SURGICAL MORTALITY IN THE UNITED STATES

JOHN D. BIRKMEYER, M.D., ANDREA E. SIEWERS, M.P.H., EMILY V.A. FINLAYSON, M.D., THERESE A. STUKEL, PH.D., F. LEE LUCAS, PH.D., IDA BATISTA, B.A., H. GILBERT WELCH, M.D., M.P.H., AND DAVID E. WENNBERG, M.D., M.P.H.

## ABSTRACT

*Background* Although numerous studies suggest that there is an inverse relation between hospital volume of surgical procedures and surgical mortality, the relative importance of hospital volume in various surgical procedures is disputed.

*Methods* Using information from the national Medicare claims data base and the Nationwide Inpatient Sample, we examined the mortality associated with six different types of cardiovascular procedures and eight types of major cancer resections between 1994 and 1999 (total number of procedures, 2.5 million). Regression techniques were used to describe relations between hospital volume (total number of procedures performed per year) and mortality (in-hospital or within 30 days), with adjustment for characteristics of the patients.

*Results* Mortality decreased as volume increased for all 14 types of procedures, but the relative importance of volume varied markedly according to the type of procedure. Absolute differences in adjusted mortality rates between very-low-volume hospitals and very-high-volume hospitals ranged from over 12 percent (for pancreatic resection, 16.3 percent vs. 3.8 percent) to only 0.2 percent (for carotid endarterectomy, 1.7 percent vs. 1.5 percent). The absolute differences in adjusted mortality rates between very-low-volume hospitals and very-high-volume hospitals were greater than 5 percent for esophagectomy and pneumonectomy, 2 to 5 percent for gastrectomy, cystectomy, repair of a nonruptured abdominal aneurysm, and replacement of an aortic or mitral valve, and less than 2 percent for coronary-artery bypass grafting, lower-extremity bypass, colectomy, lobectomy, and nephrectomy.

*Conclusions* In the absence of other information about the quality of surgery at the hospitals near them, Medicare patients undergoing selected cardiovascular or cancer procedures can significantly reduce their risk of operative death by selecting a high-volume hospital. (N Engl J Med 2002;346:1128-37.)



OVER the past three decades, numerous studies have described higher rates of operative mortality with selected surgical procedures at hospitals where few such procedures are performed (low-volume hospitals).[1-4] Several recent reviews suggest that thousands of preventable surgical deaths occur each year in the United States because elective but high-risk surgery is performed in hospitals that have inadequate experience with the surgical procedures involved.[5-7] As part of a broader initiative aimed at improving hospital safety, a large coalition of private and public purchasers of health insurance — the Leapfrog Group — is encouraging patients undergoing one of five high-risk procedures to seek care at high-volume hospitals.[8] In the lay media, there has been an emphasis on the importance of experience with particular procedures,[9,10] and several consumer-oriented Web sites (e.g., http://www.healthscope.org) have begun providing patients with information about volume at hospitals near them.

Despite the recent interest in surgical volume, many question the applicability of previous research on volume and outcome to current practice.[11,12] First, many studies of volume and outcome are outdated. Given that the surgical mortality associated with many procedures has fallen considerably since these studies were conducted,[13,14] the relative importance of the volume of procedures performed may be declining. Second, most published studies on volume and outcome have used state-level data bases or regional populations that are served by a small number of high-volume centers.[6] Whether their results are broadly generalizable is uncertain. And finally, although some procedures (e.g., cardiac surgery) have been studied extensively, the relative importance of hospital volume to mortality with

From the Veterans Affairs Outcomes Group, Department of Veterans Affairs Medical Center, White River Junction, Vt. (J.D.B., E.V.A.F., H.G.W.); the Department of Surgery, Dartmouth–Hitchcock Medical Center, Lebanon, N.H. (J.D.B.); the Center for the Evaluative Clinical Sciences, Dartmouth Medical School, Hanover, N.H. (J.D.B., T.A.S., H.G.W., D.E.W.); the Center for Outcomes Research and Evaluation, Maine Medical Center, Portland (A.E.S., F.L.L., I.B., D.E.W.); and the Department of Surgery, University of California, San Francisco (E.V.A.F.). Address reprint requests to Dr. Birkmeyer at the Veterans Affairs Outcomes Group (111B), Veterans Affairs Medical Center, White River Junction, VT 05009, or at john.birkmeyer@dartmouth.edu.





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many other high-risk procedures either has not been explored or has been studied in samples that were too small to permit assessment of performance at all meaningful levels of hospital volume.

To address many of these limitations, we studied surgical mortality in the Medicare population, which accounts for the majority of all patients in the United States who undergo high-risk surgery and an even larger majority of those who die after surgery.[15] Using current national data (from 1994 through 1999), we studied the importance of hospital volume to the operative mortality associated with six types of cardiovascular procedures and eight types of major cancer resections.

## METHODS

### Subjects and Data Bases

We obtained the Medicare Provider Analysis and Review (MEDPAR) files and the denominator files from the Center for Medicare and Medicaid Services for the years 1994 through 1999. These files contain hospital-discharge abstracts for the acute care hospitalizations of all Medicare recipients covered by the hospital care program (Part A). Only patients covered by fee-for-service arrangements are included in the MEDPAR file; thus, our sample excludes the approximately 10 percent of Medicare patients who were enrolled in risk-bearing health maintenance organizations during this period. We excluded patients who were under 65 years of age or over 99 years of age. The study protocol was approved by the institutional review board of Dartmouth Medical School.

### Hospital Volume

Patients undergoing each of the 14 procedures examined in our analysis were identified with the use of appropriate procedure codes from the *International Classification of Diseases, 9th Revision, Clinical Modification* (ICD-9-CM).[16] These procedures were selected because they are relatively complex, are associated with a nontrivial risk of operative mortality, and are most often performed on an elective basis.

We focused on the total number of each type of procedure performed at a given hospital (hospital volume), not the total number of procedures involving Medicare recipients (Medicare volume), in order to place our results in the context of the volume standards suggested by the Leapfrog Group[8] and others. To estimate total volumes, we examined data from the all-payer 1997 Nationwide Inpatient Sample. We determined the proportion of all patients undergoing each procedure who were covered by Medicare; the proportion ranged from 43 percent (for nephrectomy) to 75 percent (for carotid endarterectomy). To estimate the total volume at individual hospitals, we divided the observed Medicare volume (the total number of each type of procedure performed on Medicare patients during the six-year study period) by these procedure-specific proportions.

Hospital volume, expressed as the average number of procedures per year, was first evaluated as a continuous variable. To simplify the presentation of our results, however, we also created categorical variables, defining five categories of hospital volume: very low, low, medium, high, and very high. For each procedure, the hospitals were ranked in order of increasing total hospital volume, and then five volume groups were defined by the selection of whole-number cutoff points for annual volume that most closely sorted the patients into five groups of equal size (quintiles). The cutoff points were established before mortality was examined in order to avoid selecting cutoff points that could maximize the associations between volume and outcome.[17] To reflect most accurately the overall institutional experience with each type of operation, we combined the replacement of aortic and mitral valves (into the single category of heart-valve replacement) and lobectomy and pneumonectomy (into the category of lung resection) in determining hospital volume. However, the outcomes of these procedures were assessed separately.

### Assessment of Outcomes

In creating cohorts for the analysis of outcomes, we applied several restrictions in order to increase the homogeneity of the study samples and thus minimize the potential for confounding by case mix. For the eight types of major cancer resections, we excluded patients without an accompanying cancer-diagnosis code (related to the index procedure). Patients undergoing repair of an abdominal aortic aneurysm were excluded if they had a diagnosis or procedure code suggesting rupture of the aneurysm, thoracoabdominal aneurysm, or both. Patients undergoing coronary-artery bypass grafting were excluded if they simultaneously underwent valve replacement.

Our primary outcome measure was operative mortality, defined as the rate of death before hospital discharge or within 30 days after the index procedure. Because a large proportion of surgical deaths before discharge occurred more than 30 days after surgery, we decided that 30-day mortality alone would not adequately reflect true operative mortality. Because the length of stay did not vary systematically according to hospital volume, the inclusion of late, in-hospital deaths would not be expected to bias our results. Moreover, associations between volume and outcome were largely unchanged when we repeated our analyses using 30-day mortality alone.

### Statistical Analysis

We used multiple logistic regression to examine relations between hospital volume and operative mortality, with adjustment for characteristics of the patients.[18] We used the patient as the unit of analysis, with volume measured at the hospital level. We first fitted separate models for each procedure against the logarithm of volume to establish the general form of the relation. We then fitted models against the quintiles of volume for each procedure.

We adjusted for age group (65 to 69 years, 70 to 74 years, 75 to 79 years, 80 to 84 years, or 85 to 99 years), sex, race (black or nonblack), and their interactions, as well as the year of the procedure, the relative urgency of the index admission (elective, urgent, or emergency), the presence of coexisting conditions, and mean income from Social Security.[18] This last measure was assessed at the ZIP Code level (on the basis of the 1990 Census file) because patient-level information on socioeconomic status is not available.

Coexisting conditions were identified with the use of information from the index admission and any other admissions that had occurred within the preceding six months. Relative to low-volume hospitals, high-volume hospitals treat a larger number of patients who have been transferred or referred from other centers. To minimize the possibility of bias due to the identification of more previous admissions (and thus more coexisting conditions) at high-volume centers, we excluded information on coexisting conditions identified at previous admissions that occurred within two weeks before the index hospitalization. For the purposes of risk adjustment, coexisting conditions (identified by their appropriate ICD-9-CM codes) were compiled into a Charlson score (the number of coexisting conditions, weighted according to their relative effects on mortality),[19,20] which was modified to exclude conditions that were likely to reflect either the primary indication for surgery or postoperative complications.[21,22] We also explored two alternative approaches to incorporating coexisting conditions into our risk-adjustment models: including Charlson scores with weights derived empirically for each procedure and including coexisting conditions individually by inserting into each model each condition that was present in at least 2 percent of the patients. Because all three approaches yielded virtually identical results, we report only those from the model that used the Charlson score with published weights.[19]





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We used overdispersed binary logistic models to adjust for clustering of deaths within hospitals.[23] The net effect was to increase the width of the confidence intervals between 2 percent (cystectomy) and 44 percent (lobectomy), with a mean increase of 25 percent. We computed adjusted mortality rates on the basis of the average values of the characteristics of the patients by back-transforming predicted mortality from the logistic model. Our final risk-adjustment models had intermediate discriminative ability, with C statistics ranging from 0.60 (for pneumonectomy) to 0.71 (for nephrectomy). All P values are two-tailed.

Because the Medicare files used for this analysis reflect the use of procedures among patients with fee-for-service arrangements for health care, we may have underestimated hospital volume in regions of the country that had a high penetration of Medicare managed care during the study period (mainly southern California and the Southwest). For this reason, we repeated our analyses after restricting our data set to hospital-referral regions with a penetration of Medicare managed care of less than 10 percent. Because the adjusted odds ratios for death associated with hospital volume changed negligibly as a result of this restriction, these data are not presented.

## RESULTS

Between 1994 and 1999, approximately 2.5 million Medicare patients underwent 1 of the 14 cardiovascular or cancer-related procedures that we studied. The criteria used to define the five strata of hospital volume varied markedly according to procedure, reflecting the relative frequency with which each is performed (Table 1). Medicare volume and total volume for the 14 procedures were highly correlated at the hospital level (overall correlation coefficient, 0.97).

The age and sex of the patients did not vary consistently among strata of hospital volume (Table 2). However, for most of the 14 procedures, black patients were more likely to undergo surgery at a lower-volume hospital. For most procedures, Charlson scores tended to be slightly higher at higher-volume hospitals. However, patients were more likely to be admitted nonelectively at lower-volume hospitals. This trend was more apparent with respect to several cancer-related resections (e.g., esophagectomy) than with respect to cardiovascular procedures.

When it was assessed as a continuous (logarithmic) variable, hospital volume was related to both observed and adjusted operative mortality rates for all 14 procedures ($P<0.001$ for all trends). In terms of odds ratios for death, adjustment for characteristics of the patients attenuated the associations between volume and outcome moderately for carotid endarterectomy, colectomy, gastrectomy, esophagectomy, and pulmonary lobectomy (Table 3). Risk adjustment had negligible effect with respect to the other procedures.

In terms of absolute differences in adjusted mortality rates, the importance of hospital volume varied markedly according to the type of procedure (Fig. 1 and 2). For example, for pancreatic resection, adjusted mortality rates at very-low-volume hospitals were 12.5 percent higher than at very-high-volume hospitals (16.3 percent vs. 3.8 percent) (Fig. 2A). Relatively large differences in risk were also observed for esophagectomy (11.9 percent) and pneumonectomy (5.4 percent). Absolute differences in adjusted mortality rates between very-low-volume and very-high-volume hospitals were between 2 percent and 5 percent for gastrectomy, cystectomy, repair of a nonruptured abdominal aortic aneurysm, and aortic- and mitral-valve replacement, and the differences were less than 2 percent for coronary-artery bypass grafting, lower-extremity bypass, colectomy, lobectomy, and nephrectomy. The absolute difference in mortality between very-low-volume and very-high-volume hospitals was smallest for carotid endarterectomy (1.7 percent vs. 1.5 percent).

Relations between volume and outcome in the intermediate strata of hospital volume also varied widely according to the type of procedure (Fig. 1 and 2). For several types of procedure (including coronary-artery bypass grafting, valve replacement, and pancreatic resection), mortality declined monotonically with each stratum of increasing hospital volume. For others (including elective repair of an abdominal aortic aneurysm, gastrectomy, and pneumonectomy), differences in mortality were most apparent at the extremes of volume, whereas hospitals in the intermediate-volume strata had similar mortality rates.

## DISCUSSION

In this large, national study, higher-volume hospitals had lower operative mortality rates for six types of cardiovascular procedures and eight types of major cancer resections. However, the absolute magnitude of the relation between volume and outcome varied markedly among the types of procedures. Dramatic differences in mortality between very-low-volume and very-high-volume hospitals were observed for pancreatic resection and esophagectomy (more than 12 percent, in absolute terms), whereas relatively small differences in mortality (1 percent or less) were found for 3 of the 14 procedures examined in our analysis. These findings suggest the relative importance of hospital volume for individual patients who are considering where to undergo various procedures. From the public health perspective, however, one must also consider the total number of patients who undergo each procedure. For example, in the case of coronary-artery bypass grafting (for which volume had a moderate effect but which is very common), 314 deaths would be averted in the United States each year if the mortality rate at very-low-volume hospitals were reduced to the rate at very-high-volume centers. Conversely, in the case of pancreatic resection (for which volume had a very large effect but which is performed infrequently), lowering the mortality rate at very-low-volume centers to that observed at very-high-volume centers would avert only 32 deaths annually.

We believe that our results reflect real differences

**TABLE 1.** DISTRIBUTION OF PATIENTS AND HOSPITALS AMONG QUINTILES OF VOLUME FOR THE 14 PROCEDURES.*

| PROCEDURE | HOSPITAL VOLUME | | | | |
|---|---|---|---|---|---|
| | VERY LOW | LOW | MEDIUM | HIGH | VERY HIGH |
| Coronary-artery bypass grafting | | | | | |
| No. of Medicare patients | 188,176 | 157,060 | 197,322 | 181,427 | 177,682 |
| No. of hospitals | 595 | 181 | 149 | 91 | 52 |
| Average no. of procedures/yr (57% Medicare) | <230 | 230–348 | 349–549 | 550–849 | >849 |
| Heart-valve replacement | | | | | |
| Aortic | | | | | |
| No. of Medicare patients | 30,377 | 30,329 | 31,590 | 29,607 | 29,707 |
| No. of hospitals | 639 | 198 | 123 | 70 | 39 |
| Mitral | | | | | |
| No. of Medicare patients | 12,526 | 13,010 | 13,560 | 12,603 | 13,236 |
| No. of hospitals | 620 | 198 | 123 | 70 | 39 |
| Average no. of procedures/yr (62% Medicare) | <43 | 43–74 | 75–119 | 120–199 | >199 |
| Carotid endarterectomy | | | | | |
| No. of Medicare patients | 101,319 | 85,009 | 102,038 | 95,587 | 95,336 |
| No. of hospitals | 2,013 | 404 | 291 | 180 | 102 |
| Average no. of procedures/yr (75% Medicare) | <40 | 40–69 | 70–109 | 110–164 | >164 |
| Lower-extremity bypass | | | | | |
| No. of Medicare patients | 53,974 | 53,080 | 53,221 | 52,958 | 50,347 |
| No. of hospitals | 2,068 | 502 | 305 | 204 | 105 |
| Average no. of procedures/yr (70% Medicare) | <22 | 22–39 | 40–60 | 61–94 | >94 |
| Elective repair of abdominal aortic aneurysm | | | | | |
| No. of Medicare patients | 27,970 | 27,273 | 29,029 | 28,884 | 27,421 |
| No. of hospitals | 1,900 | 426 | 257 | 156 | 80 |
| Average no. of procedures/yr (70% Medicare) | <17 | 17–30 | 31–49 | 50–79 | >79 |
| Colectomy | | | | | |
| No. of Medicare patients | 63,386 | 58,720 | 62,789 | 59,398 | 59,992 |
| No. of hospitals | 2,856 | 727 | 486 | 319 | 199 |
| Average no. of procedures/yr (59% Medicare) | <33 | 33–56 | 57–84 | 85–124 | >124 |
| Gastrectomy | | | | | |
| No. of Medicare patients | 6,324 | 6,287 | 6,871 | 6,194 | 6,268 |
| No. of hospitals | 2,010 | 636 | 419 | 239 | 119 |
| Average no. of procedures/yr (54% Medicare) | <5 | 5–8 | 9–13 | 14–21 | >21 |
| Esophagectomy | | | | | |
| No. of Medicare patients | 861 | 1,817 | 1,091 | 1,393 | 1,175 |
| No. of hospitals | 618 | 620 | 187 | 119 | 31 |
| Average no. of procedures/yr (49% Medicare) | <2 | 2–4 | 5–7 | 8–19 | >19 |
| Pancreatic resection | | | | | |
| No. of Medicare patients | 1,563 | 2,757 | 1,885 | 2,166 | 2,159 |
| No. of hospitals | 1,028 | 555 | 168 | 90 | 27 |
| Average no. of procedures/yr (50% Medicare) | <1 | 1–2 | 3–5 | 6–16 | >16 |
| Nephrectomy | | | | | |
| No. of Medicare patients | 10,732 | 11,724 | 11,899 | 12,385 | 12,250 |
| No. of hospitals | 1,916 | 606 | 380 | 253 | 137 |
| Average no. of procedures/yr (43% Medicare) | <7 | 7–12 | 13–19 | 20–31 | >31 |
| Cystectomy | | | | | |
| No. of Medicare patients | 4,262 | 5,380 | 3,149 | 4,833 | 4,725 |
| No. of hospitals | 1,438 | 550 | 190 | 180 | 64 |
| Average no. of procedures/yr (63% Medicare) | <2 | 2–3 | 4–5 | 6–11 | >11 |
| Pulmonary resection | | | | | |
| Lobectomy | | | | | |
| No. of Medicare patients | 14,816 | 15,731 | 14,759 | 15,469 | 14,788 |
| No. of hospitals | 1,806 | 456 | 248 | 164 | 79 |
| Pneumonectomy | | | | | |
| No. of Medicare patients | 1,969 | 2,098 | 2,072 | 2,088 | 2,183 |
| No. of hospitals | 944 | 445 | 246 | 163 | 79 |
| Average no. of procedures/yr (56% Medicare) | <9 | 9–17 | 18–27 | 28–46 | >46 |

*To estimate the average total hospital volume, we divided the observed Medicare volume (per year) by the proportion of Medicare patients undergoing each procedure (as determined on the basis of the Nationwide Inpatient Sample).

**TABLE 2.** CHARACTERISTICS OF THE PATIENTS ACCORDING TO HOSPITAL VOLUME.*

| PROCEDURE | HOSPITAL VOLUME | | | | |
|---|---|---|---|---|---|
| | VERY LOW | LOW | MEDIUM | HIGH | VERY HIGH |
| | percent | | | | |
| Coronary-artery bypass grafting | | | | | |
| Age >75 yr | 35.8 | 36.2 | 36.1 | 36.6 | 36.8 |
| Female sex | 35.2 | 34.7 | 35.1 | 35.3 | 35.0 |
| Black race | 4.7 | 3.5 | 3.5 | 3.6 | 3.4 |
| Nonelective admission | 60.8 | 60.4 | 59.8 | 60.9 | 60.8 |
| Charlson score ⩾3 | 9.2 | 9.0 | 9.1 | 9.5 | 10.1 |
| Aortic-valve replacement | | | | | |
| Age >75 yr | 49.6 | 50.3 | 51.0 | 53.1 | 52.3 |
| Female sex | 43.9 | 42.6 | 43.1 | 44.9 | 42.5 |
| Black race | 4.4 | 4.0 | 3.2 | 3.5 | 2.0 |
| Nonelective admission | 44.5 | 43.8 | 43.8 | 43.9 | 40.8 |
| Charlson score ⩾3 | 8.5 | 8.7 | 8.7 | 10.0 | 9.4 |
| Mitral-valve replacement | | | | | |
| Age >75 yr | 39.6 | 41.1 | 40.9 | 43.3 | 42.4 |
| Female sex | 59.0 | 58.2 | 57.7 | 59.4 | 58.1 |
| Black race | 4.7 | 4.2 | 3.4 | 3.8 | 2.6 |
| Nonelective admission | 49.4 | 49.4 | 49.7 | 48.1 | 45.6 |
| Charlson score ⩾3 | 9.4 | 9.5 | 10.1 | 10.7 | 10.9 |
| Carotid endarterectomy | | | | | |
| Age >75 yr | 49.0 | 48.8 | 47.3 | 46.4 | 46.3 |
| Female sex | 45.8 | 44.2 | 43.4 | 43.5 | 42.2 |
| Black race | 4.0 | 2.6 | 2.6 | 2.6 | 2.4 |
| Nonelective admission | 36.0 | 32.1 | 33.5 | 31.1 | 30.3 |
| Charlson score ⩾3 | 10.0 | 10.1 | 9.8 | 9.8 | 10.2 |
| Lower-extremity bypass | | | | | |
| Age >75 yr | 49.5 | 50.6 | 50.4 | 50.4 | 50.8 |
| Female sex | 46.6 | 46.8 | 46.1 | 45.5 | 46.1 |
| Black race | 12.4 | 10.5 | 12.6 | 10.5 | 12.6 |
| Nonelective admission | 44.6 | 42.2 | 41.1 | 37.2 | 38.4 |
| Charlson score ⩾3 | 20.1 | 20.0 | 19.6 | 20.8 | 21.0 |
| Elective repair of abdominal aortic aneurysm | | | | | |
| Age >75 yr | 44.4 | 43.8 | 42.5 | 42.6 | 42.2 |
| Female sex | 25.1 | 23.3 | 23.0 | 22.2 | 22.3 |
| Black race | 4.2 | 2.5 | 2.4 | 2.5 | 2.4 |
| Nonelective admission | 31.8 | 26.3 | 27.3 | 25.3 | 25.5 |
| Charlson score ⩾3 | 9.1 | 9.2 | 9.5 | 9.7 | 10.1 |
| Colectomy | | | | | |
| Age >75 yr | 60.9 | 60.5 | 59.9 | 59.7 | 59.3 |
| Female sex | 56.2 | 56.1 | 55.9 | 56.0 | 54.6 |
| Black race | 8.8 | 7.3 | 7.6 | 6.9 | 7.2 |
| Nonelective admission | 55.7 | 47.4 | 48.5 | 44.4 | 43.0 |
| Charlson score ⩾3 | 41.1 | 44.3 | 45.3 | 45.1 | 45.9 |
| Gastrectomy | | | | | |
| Age >75 yr | 56.8 | 54.9 | 54.0 | 53.3 | 48.9 |
| Female sex | 44.0 | 41.3 | 41.9 | 39.7 | 37.4 |
| Black race | 13.7 | 12.9 | 13.2 | 11.3 | 11.3 |
| Nonelective admission | 51.4 | 44.7 | 41.9 | 41.0 | 29.7 |
| Charlson score ⩾3 | 56.2 | 58.8 | 59.3 | 60.3 | 62.3 |
| Esophagectomy | | | | | |
| Age >75 yr | 31.9 | 31.7 | 31.3 | 28.6 | 28.1 |
| Female sex | 22.8 | 24.0 | 24.6 | 23.4 | 25.8 |
| Black race | 12.0 | 7.6 | 6.7 | 6.5 | 5.5 |
| Nonelective admission | 37.4 | 26.9 | 20.5 | 20.5 | 7.6 |
| Charlson score ⩾3 | 43.3 | 43.3 | 45.4 | 41.6 | 43.0 |
| Pancreatic resection | | | | | |
| Age >75 yr | 37.7 | 36.3 | 35.3 | 36.8 | 35.2 |
| Female sex | 48.0 | 51.3 | 49.0 | 48.9 | 47.4 |
| Black race | 8.1 | 8.0 | 6.8 | 6.0 | 5.0 |
| Nonelective admission | 50.6 | 43.7 | 43.9 | 35.4 | 18.6 |
| Charlson score ⩾3 | 46.4 | 51.7 | 53.4 | 55.6 | 64.5 |
| Nephrectomy | | | | | |
| Age >75 yr | 46.1 | 45.8 | 44.3 | 43.2 | 41.6 |
| Female sex | 44.9 | 44.0 | 42.8 | 42.9 | 41.4 |
| Black race | 7.7 | 5.2 | 5.5 | 6.0 | 6.5 |
| Nonelective admission | 35.4 | 28.5 | 24.7 | 23.4 | 20.2 |
| Charlson score ⩾3 | 19.2 | 19.9 | 20.2 | 21.1 | 23.1 |

**TABLE 2.** CONTINUED.

| PROCEDURE | HOSPITAL VOLUME | | | | |
|---|---|---|---|---|---|
| | VERY LOW | LOW | MEDIUM | HIGH | VERY HIGH |
| | percent | | | | |
| Cystectomy | | | | | |
| Age >75 yr | 41.1 | 42.7 | 44.0 | 43.3 | 39.2 |
| Female sex | 23.3 | 22.5 | 20.8 | 20.8 | 18.3 |
| Black race | 6.6 | 3.5 | 3.1 | 3.3 | 3.8 |
| Nonelective admission | 27.4 | 22.9 | 18.4 | 17.0 | 14.9 |
| Charlson score ≥3 | 34.0 | 33.8 | 35.6 | 36.6 | 43.1 |
| Pulmonary lobectomy | | | | | |
| Age >75 yr | 33.8 | 34.7 | 33.1 | 33.7 | 32.0 |
| Female sex | 43.1 | 44.3 | 43.0 | 43.6 | 44.2 |
| Black race | 7.3 | 4.2 | 4.3 | 4.5 | 4.7 |
| Nonelective admission | 26.1 | 21.6 | 19.3 | 14.3 | 12.7 |
| Charlson score ≥3 | 31.1 | 32.0 | 32.1 | 34.1 | 37.0 |
| Pneumonectomy | | | | | |
| Age >75 yr | 25.9 | 26.0 | 24.5 | 24.5 | 20.8 |
| Female sex | 28.2 | 27.0 | 28.1 | 27.5 | 27.3 |
| Black race | 8.1 | 3.9 | 4.0 | 4.8 | 5.0 |
| Nonelective admission | 28.2 | 24.0 | 24.6 | 17.6 | 15.8 |
| Charlson score ≥3 | 52.4 | 54.3 | 56.8 | 57.5 | 59.9 |

*The Charlson score is a measure of the number of coexisting conditions, weighted according to their relative effects on mortality.

in the quality of surgery between high-volume and low-volume hospitals. First, the effect is large. For some procedures, mortality at low-volume centers was several times as high as at high-volume hospitals — a difference that is too great to be attributed to chance or unmeasured confounding. Second, relations between volume and outcome are remarkably consistent over time and across studies. According to one recent structured review of the literature, 123 of 128 analyses involving 40 different procedures (96 percent) found lower mortality at high-volume hospitals (differences were statistically significant in 80 percent of these analyses).[5] Only 4 of the 128 (3 percent) found higher mortality rates at high-volume hospitals, but none of these findings were statistically significant. And finally, the link between surgical volume and mortality is clinically plausible. Although the mechanisms underlying the relations between volume and outcome have not been fully characterized, high-volume hospitals may have more surgeons who specialize in specific procedures, more consistent processes for postoperative care, better-staffed intensive care units, and greater resources, in general, for dealing with postoperative complications.

Our analysis has several limitations. First, because we studied only Medicare patients, our results may not be generalizable to patients under 65 years of age. However, there is no evidence that age affects the relations between volume and outcome. Second, our measure of volume was imperfect. We estimated total hospital volume by extrapolating from Medicare volume, not by direct measurement. Although Medicare and total volumes are highly correlated at the hospital level, there probably remains some degree of misclassification of hospital-volume status, which would tend to bias our analysis toward the null hypothesis (no effect of volume on outcome). Third, because our primary goal was to estimate the potential effect of referral policies that focus exclusively on volume, we did not attempt to adjust for characteristics of the provider that are likely to be highly correlated with volume. Analyses that aimed to assess the independent effect of hospital volume would need to account for other variables that may influence mortality, including hospital size and teaching status, the volume of procedures performed by a particular surgeon, and staffing patterns in the intensive care unit.[24-27]

Finally, because we relied on administrative data, we may not have accounted adequately for differences in case mix among strata of hospital volume. Administrative data are limited in their ability to differentiate patients according to the severity of illness.[21,22,28,29] Age and the prevalence of coexisting conditions did not vary substantially according to hospital volume in our data set. However, even for conditions for which the procedure itself is almost always elective, patients at lower-volume hospitals were more likely to have been admitted nonelectively. Conversely, patients at higher-volume hospitals were more likely to have had recent nonelective admissions elsewhere. Although these find-





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**TABLE 3.** OPERATIVE MORTALITY RATES AND THEIR ASSOCIATION WITH HOSPITAL VOLUME.*

| PROCEDURE | HOSPITAL VOLUME | | | | |
|---|---|---|---|---|---|
| | VERY LOW | LOW | MEDIUM | HIGH | VERY HIGH |
| Coronary-artery bypass grafting | | | | | |
| Observed mortality rate (%) | 6.1 | 5.5 | 5.3 | 5.1 | 4.8 |
| Unadjusted odds ratio (95% CI) | 1.0 | 0.91 (0.86–0.97) | 0.88 (0.82–0.93) | 0.84 (0.79–0.90) | 0.79 (0.73–0.86) |
| Adjusted odds ratio (95% CI) | 1.0 | 0.92 (0.86–0.98) | 0.89 (0.83–0.95) | 0.84 (0.78–0.90) | 0.79 (0.73–0.86) |
| Aortic-valve replacement | | | | | |
| Observed mortality rate (%) | 9.9 | 9.2 | 9.1 | 8.7 | 7.6 |
| Unadjusted odds ratio (95% CI) | 1.0 | 0.91 (0.84–0.99) | 0.91 (0.84–0.99) | 0.87 (0.80–0.95) | 0.75 (0.65–0.85) |
| Adjusted odds ratio (95% CI) | 1.0 | 0.92 (0.85–0.99) | 0.91 (0.84–0.99) | 0.84 (0.77–0.92) | 0.75 (0.66–0.86) |
| Mitral-valve replacement | | | | | |
| Observed mortality rate (%) | 16.1 | 15.0 | 14.4 | 13.4 | 12.5 |
| Unadjusted odds ratio (95% CI) | 1.0 | 0.92 (0.84–1.01) | 0.87 (0.79–0.97) | 0.81 (0.73–0.90) | 0.74 (0.66–0.84) |
| Adjusted odds ratio (95% CI) | 1.0 | 0.91 (0.83–1.00) | 0.86 (0.78–0.96) | 0.79 (0.71–0.88) | 0.74 (0.65–0.84) |
| Carotid endarterectomy | | | | | |
| Observed mortality rate (%) | 2.0 | 1.9 | 1.8 | 1.7 | 1.7 |
| Unadjusted odds ratio (95% CI) | 1.0 | 0.91 (0.85–0.98) | 0.88 (0.81–0.95) | 0.82 (0.76–0.89) | 0.82 (0.75–0.90) |
| Adjusted odds ratio (95% CI) | 1.0 | 0.95 (0.88–1.02) | 0.91 (0.84–0.99) | 0.88 (0.81–0.95) | 0.88 (0.80–0.96) |
| Lower-extremity bypass | | | | | |
| Observed mortality rate (%) | 6.1 | 5.8 | 5.5 | 5.5 | 4.9 |
| Unadjusted odds ratio (95% CI) | 1.0 | 0.94 (0.88–0.99) | 0.89 (0.83–0.94) | 0.90 (0.84–0.96) | 0.78 (0.72–0.85) |
| Adjusted odds ratio (95% CI) | 1.0 | 0.94 (0.89–1.00) | 0.90 (0.85–0.97) | 0.94 (0.87–1.01) | 0.81 (0.74–0.88) |
| Elective repair of abdominal aortic aneurysm | | | | | |
| Observed mortality rate (%) | 7.8 | 5.9 | 5.2 | 5.3 | 4.4 |
| Unadjusted odds ratio (95% CI) | 1.0 | 0.75 (0.69–0.81) | 0.66 (0.60–0.72) | 0.66 (0.61–0.73) | 0.54 (0.49–0.60) |
| Adjusted odds ratio (95% CI) | 1.0 | 0.79 (0.73–0.86) | 0.70 (0.64–0.76) | 0.71 (0.65–0.78) | 0.58 (0.53–0.65) |
| Colectomy | | | | | |
| Observed mortality rate (%) | 7.4 | 6.9 | 6.4 | 6.1 | 5.4 |
| Unadjusted odds ratio (95% CI) | 1.0 | 0.93 (0.88–0.98) | 0.86 (0.81–0.90) | 0.81 (0.77–0.86) | 0.73 (0.68–0.77) |
| Adjusted odds ratio (95% CI) | 1.0 | 0.98 (0.93–1.03) | 0.89 (0.84–0.94) | 0.89 (0.84–0.93) | 0.80 (0.76–0.85) |
| Gastrectomy | | | | | |
| Observed mortality rate (%) | 13.0 | 12.7 | 11.1 | 11.3 | 8.7 |
| Unadjusted odds ratio (95% CI) | 1.0 | 0.98 (0.88–1.10) | 0.84 (0.75–0.93) | 0.85 (0.76–0.96) | 0.64 (0.55–0.74) |
| Adjusted odds ratio (95% CI) | 1.0 | 1.01 (0.90–1.13) | 0.88 (0.79–0.99) | 0.90 (0.80–1.01) | 0.72 (0.63–0.83) |
| Esophagectomy | | | | | |
| Observed mortality rate (%) | 23.1 | 18.9 | 16.9 | 11.7 | 8.1 |
| Unadjusted odds ratio (95% CI) | 1.0 | 0.78 (0.63–0.95) | 0.68 (0.54–0.86) | 0.44 (0.35–0.55) | 0.29 (0.21–0.40) |
| Adjusted odds ratio (95% CI) | 1.0 | 0.85 (0.69–1.05) | 0.76 (0.60–0.97) | 0.51 (0.40–0.64) | 0.36 (0.26–0.50) |
| Pancreatic resection | | | | | |
| Observed mortality rate (%) | 17.6 | 15.4 | 11.6 | 7.5 | 3.8 |
| Unadjusted odds ratio (95% CI) | 1.0 | 0.85 (0.72–1.01) | 0.62 (0.50–0.76) | 0.38 (0.31–0.47) | 0.18 (0.13–0.26) |
| Adjusted odds ratio (95% CI) | 1.0 | 0.88 (0.74–1.05) | 0.64 (0.51–0.79) | 0.40 (0.32–0.50) | 0.20 (0.14–0.29) |
| Nephrectomy | | | | | |
| Observed mortality rate (%) | 3.6 | 3.2 | 2.7 | 2.9 | 2.6 |
| Unadjusted odds ratio (95% CI) | 1.0 | 0.88 (0.76–1.02) | 0.75 (0.64–0.87) | 0.80 (0.69–0.93) | 0.70 (0.59–0.82) |
| Adjusted odds ratio (95% CI) | 1.0 | 0.94 (0.81–1.09) | 0.83 (0.71–0.97) | 0.90 (0.77–1.05) | 0.80 (0.68–0.95) |
| Cystectomy | | | | | |
| Observed mortality rate (%) | 6.4 | 6.3 | 4.9 | 4.5 | 2.9 |
| Unadjusted odds ratio (95% CI) | 1.0 | 0.99 (0.84–1.17) | 0.76 (0.62–0.93) | 0.69 (0.57–0.84) | 0.44 (0.35–0.54) |
| Adjusted odds ratio (95% CI) | 1.0 | 1.00 (0.84–1.18) | 0.78 (0.64–0.96) | 0.71 (0.58–0.86) | 0.46 (0.37–0.58) |
| Pulmonary lobectomy | | | | | |
| Observed mortality rate (%) | 6.4 | 5.9 | 5.5 | 5.3 | 4.2 |
| Unadjusted odds ratio (95% CI) | 1.0 | 0.91 (0.83–1.01) | 0.85 (0.76–0.94) | 0.81 (0.73–0.90) | 0.64 (0.55–0.75) |
| Adjusted odds ratio (95% CI) | 1.0 | 0.94 (0.85–1.04) | 0.89 (0.80–0.99) | 0.87 (0.78–0.97) | 0.70 (0.60–0.81) |
| Pneumonectomy | | | | | |
| Observed mortality rate (%) | 17.0 | 15.4 | 15.7 | 15.0 | 10.6 |
| Unadjusted odds ratio (95% CI) | 1.0 | 0.89 (0.75–1.06) | 0.91 (0.77–1.08) | 0.86 (0.73–1.02) | 0.58 (0.47–0.73) |
| Adjusted odds ratio (95% CI) | 1.0 | 0.91 (0.76–1.08) | 0.93 (0.78–1.11) | 0.91 (0.76–1.08) | 0.62 (0.50–0.77) |

*Odds ratios for death (according to quintile of volume) were adjusted for age, sex, race, year of procedure, Social Security income, urgency of admission, and Charlson score, a measure of coexisting conditions. CI denotes confidence interval.

ings raise the possibility of unmeasured differences in case mix among hospitals, we do not believe that confounding is a likely explanation for our main findings.

Although relations between volume and outcome have long been recognized, large-scale efforts to reduce surgical mortality by concentrating selected procedures in high-volume hospitals are only now beginning to gain momentum. The most visible of these efforts is being directed by the nonprofit Leapfrog Group, a coalition of more than 80 large public and

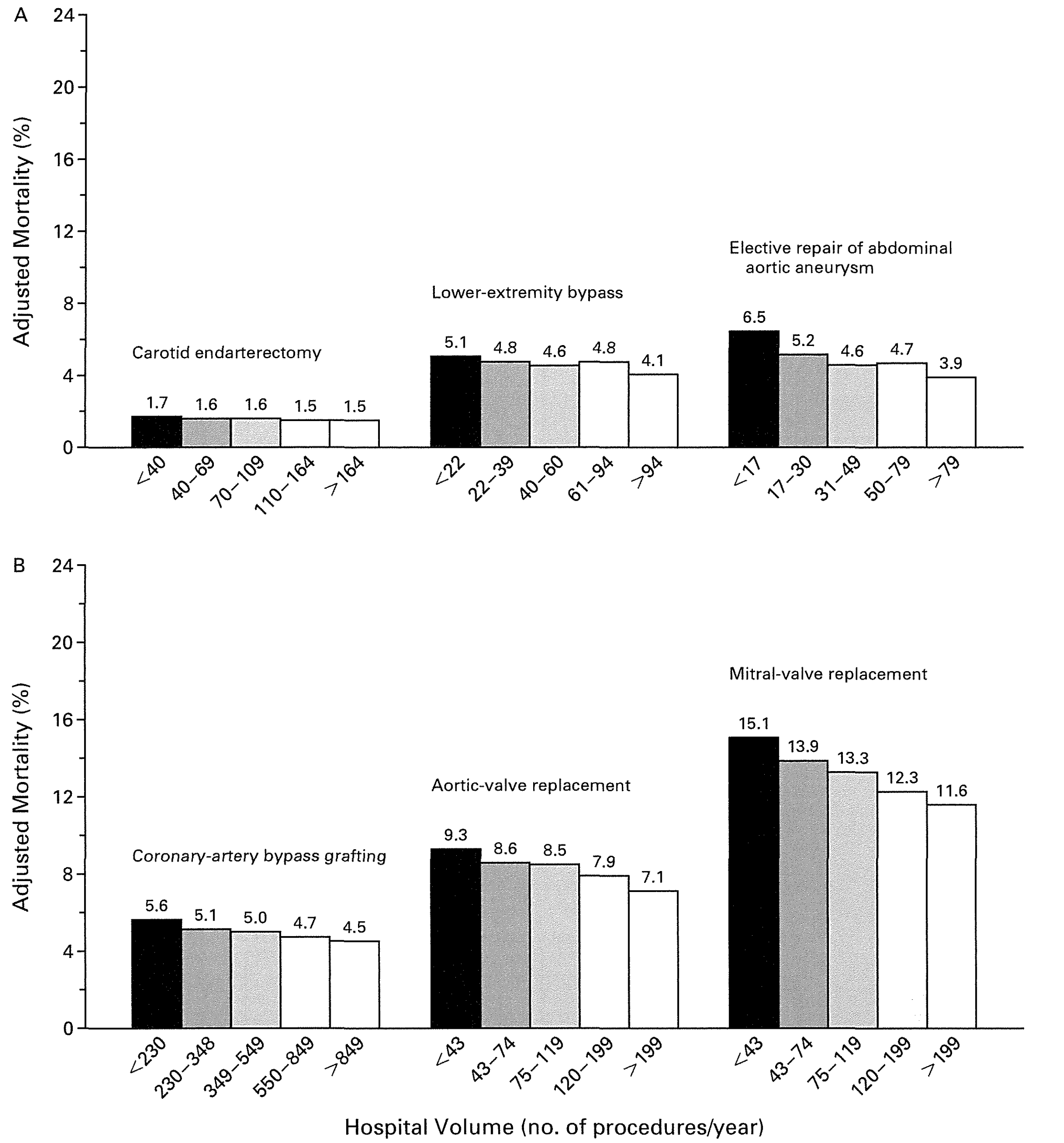


**Figure 1.** Adjusted In-Hospital or 30-Day Mortality among Medicare Patients (1994 through 1999), According to Quintile of Total Hospital Volume for Peripheral Vascular Procedures (Panel A) and Cardiac Procedures (Panel B).

P<0.001 for all procedures. The outcomes for aortic-valve and mitral-valve replacement were stratified according to the total volume of heart-valve replacements. Values above the bars are the percent mortality.

private purchasers that insure more than 25 million persons. The coalition is encouraging both patients and payers to select hospitals that meet minimal volume standards for coronary-artery bypass surgery (500 procedures per year), coronary angioplasty (400 per year), carotid endarterectomy (100 per year), repair of abdominal aortic aneurysm (30 per year), and esophagectomy for cancer (6 per year). Although our analysis does not indicate that these specific volume thresholds are better than other alternatives, it does confirm that the proposed standards could reduce the surgical mortality associated with several of these procedures.

Many may object to such initiatives aimed at concentrating selected surgical procedures in high-volume

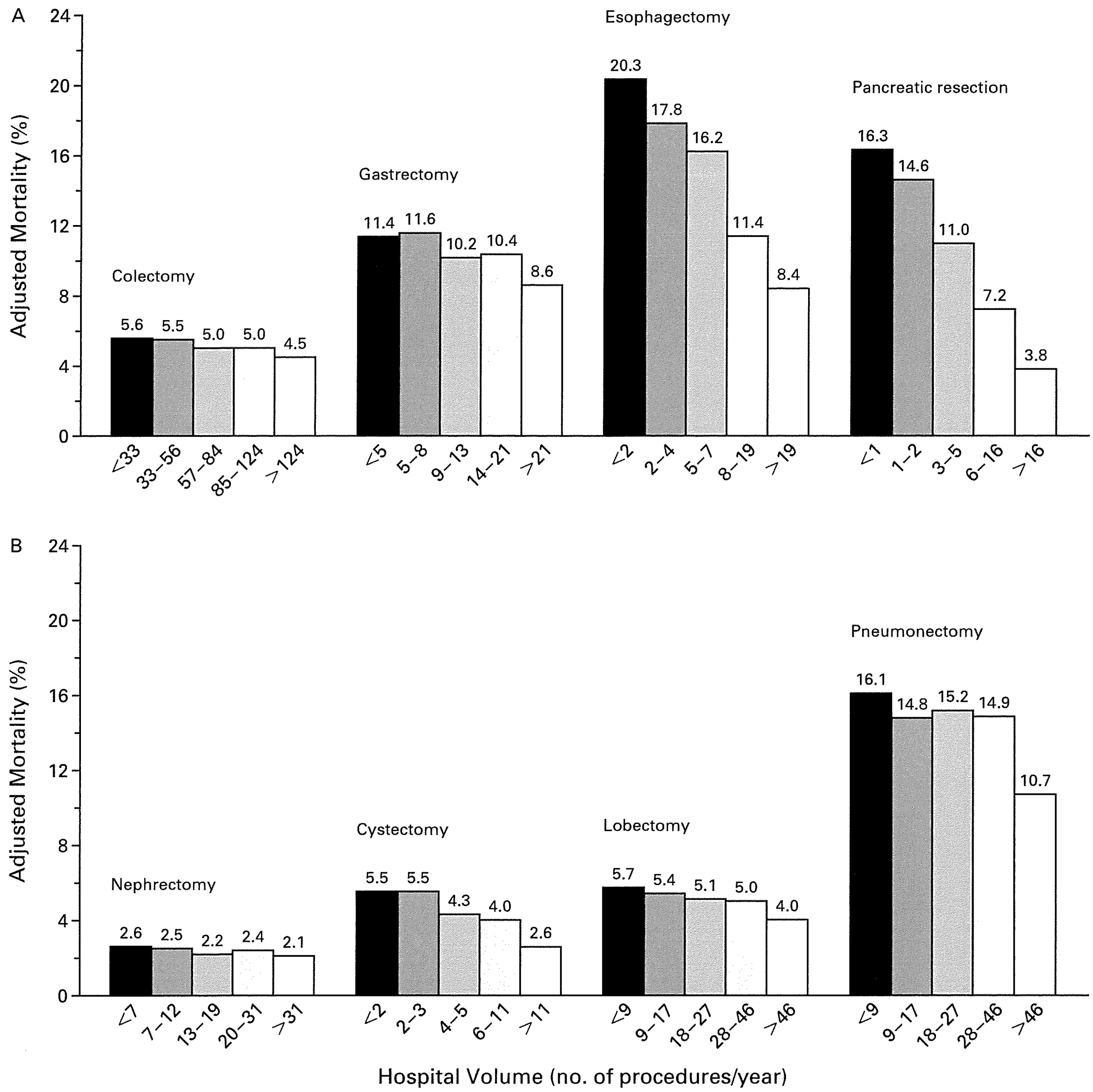


**Figure 2.** Adjusted In-Hospital or 30-Day Mortality among Medicare Patients (1994 through 1999), According to Quintile of Total Hospital Volume for Resections of Gastrointestinal Cancer (Panel A) and Resections of Other Cancers (Panel B).

P<0.001 for all procedures. The outcomes for lobectomy and pneumonectomy were stratified according to the total volume of lung resections. Values above the bars are the percent mortality.

hospitals. They may rightly point out that procedure volume is an imperfect proxy for quality — that some low-volume hospitals have excellent outcomes, whereas some high-volume hospitals have poor outcomes. Unfortunately, most patients facing high-risk surgery have no way of knowing the relative quality of the hospitals near them. Although several states currently have public reporting systems in place,[30,31] these efforts are largely restricted to reporting on cardiac surgery. Most other procedures are not performed frequently enough to allow assessment of procedure-specific mortality at the level of the individual hospital. Thus, in the absence of better information about surgical quality, patients undergoing many types of procedures can substantially improve their odds of survival by selecting a high-volume hospital near them.

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SPECIAL ARTICLE

# Surgeon Volume and Operative Mortality in the United States

John D. Birkmeyer, M.D., Therese A. Stukel, Ph.D., Andrea E. Siewers, M.P.H., Philip P. Goodney, M.D., David E. Wennberg, M.D., M.P.H., and F. Lee Lucas, Ph.D.


## ABSTRACT

### BACKGROUND

Although the relation between hospital volume and surgical mortality is well established, for most procedures, the relative importance of the experience of the operating surgeon is uncertain.

### METHODS

Using information from the national Medicare claims data base for 1998 through 1999, we examined mortality among all 474,108 patients who underwent one of eight cardiovascular procedures or cancer resections. Using nested regression models, we examined the relations between operative mortality and surgeon volume and hospital volume (each in terms of total procedures performed per year), with adjustment for characteristics of the patients and other characteristics of the providers.

### RESULTS

Surgeon volume was inversely related to operative mortality for all eight procedures ($P=0.003$ for lung resection, $P<0.001$ for all other procedures). The adjusted odds ratio for operative death (for patients with a low-volume surgeon vs. those with a high-volume surgeon) varied widely according to the procedure — from 1.24 for lung resection to 3.61 for pancreatic resection. Surgeon volume accounted for a large proportion of the apparent effect of the hospital volume, to an extent that varied according to the procedure: it accounted for 100 percent of the effect for aortic-valve replacement, 57 percent for elective repair of an abdominal aortic aneurysm, 55 percent for pancreatic resection, 49 percent for coronary-artery bypass grafting, 46 percent for esophagectomy, 39 percent for cystectomy, and 24 percent for lung resection. For most procedures, the mortality rate was higher among patients of low-volume surgeons than among those of high-volume surgeons, regardless of the surgical volume of the hospital in which they practiced.

### CONCLUSIONS

For many procedures, the observed associations between hospital volume and operative mortality are largely mediated by surgeon volume. Patients can often improve their chances of survival substantially, even at high-volume hospitals, by selecting surgeons who perform the operations frequently.


From the Department of Surgery, Dartmouth–Hitchcock Medical Center, Lebanon, N.H. (J.D.B., P.P.G.); the Veterans Affairs Outcomes Group, Veterans Affairs Medical Center, White River Junction, Vt. (J.D.B., P.P.G.); the Institute for Clinical Evaluative Sciences, Toronto (T.A.S.); and the Center for Outcomes Research and Evaluation, Maine Medical Center, Portland (A.E.S., D.E.W., F.L.L.). Address reprint requests to Dr. Birkmeyer at the Section of General Surgery, Dartmouth–Hitchcock Medical Center, Lebanon, NH 03756, or at john.birkmeyer@hitchcock.org.

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For many surgical procedures, patients at hospitals where a high number of such procedures are performed (high-volume hospitals) have lower mortality rates than those at hospitals that are less experienced with the procedures.[1-4] In one recent study of the national population of Medicare recipients, we found strong relations between hospital volume and operative mortality associated with 14 high-risk cancer resections and cardiovascular procedures.[5] Despite the considerable body of research in this area, little is known about the mechanisms underlying the observed associations between volume and outcome. Because they tend to be much larger facilities, high-volume hospitals have a broader range of specialist and technology-based services, better-staffed intensive care units, and other resources that are not available at smaller centers. By virtue of these resources, high-volume hospitals may be better equipped to deliver the complex perioperative care required by patients who are undergoing high-risk surgery.

On the other hand, the outcome of a surgical procedure may depend as much on how well the operation itself is performed as on the resources available at the hospital. If so, another explanation for the observed relation between the hospital volume and the outcome may be that high-volume hospitals tend to have surgeons who are more experienced with specific procedures. Numerous studies have explored the associations between surgeon volume (the number of procedures performed by the surgeon) and mortality for some procedures.[1,6-12] However, relatively few of these analyses have simultaneously accounted for hospital volume and other potential confounding characteristics of the hospital that may be strongly correlated with surgeon volume. Moreover, few have been large enough to characterize the relative influence of these two measures of volume with sufficient precision.

To address these issues, we undertook a comprehensive evaluation of the operative risk associated with eight different cardiovascular procedures and cancer resections using data from the national population of Medicare recipients. We had two primary aims: to assess the association between surgeon volume and operative mortality for various procedures and to achieve a better understanding of the extent to which the observed effects of hospital volume can be explained by the experience of the operating surgeon.

## METHODS

### PATIENTS AND DATA BASES

We obtained 100 percent of the national analytic files from the Center for Medicare and Medicaid Services for 1998 and 1999. The Medicare Provider Analysis and Review (MEDPAR) and inpatient files, which contain hospital-discharge abstracts for the fee-for-service, acute care hospitalizations of all Medicare recipients, were used to create our main data sets for analysis; the Medicare denominator file was used to determine the vital status of the patients. The institutional review board of Dartmouth Medical School approved the study protocol.

As in our previous work,[5,13,14] we used the appropriate procedure codes from the *International Classification of Diseases, Ninth Revision* (ICD-9), to identify all patients between 65 and 99 years of age who underwent 1 of 14 cardiovascular procedures or cancer resections. To simplify the presentation of our results, however, we present here the analyses for only four cardiovascular procedures and four cancer resections. These procedures, which were selected prospectively, included two that are frequently the focus of debate concerning the regionalization of health care services (coronary-artery bypass grafting and carotid endarterectomy). Six other procedures (aortic-valve replacement, elective repair of an abdominal aortic aneurysm, pancreatic resection, esophagectomy, lung resection, and cystectomy) for which we have previously found a relatively strong association between hospital volume and operative mortality were selected to represent diverse surgical subspecialties.

In examining the data related to the cancer resections, we excluded from the analysis of outcomes (but not from the tallies of volume) patients who did not have an accompanying diagnosis code for cancer. This restriction was intended to exclude small subgroups of patients who had a much higher level of risk at base line (e.g., patients who underwent pancreatic resection because of infection) and thus to minimize confounding. Similarly, patients who underwent repair of an abdominal aortic aneurysm were excluded if they had diagnosis or procedure codes suggesting the rupture of an aneurysm, the presence of a thoracoabdominal aneurysm, or both. We excluded from the analysis of the cohort that underwent coronary-artery bypass grafting patients who had a valve replaced simultaneously.




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#### IDENTIFICATION OF SURGEONS

For all procedures, we identified the operating surgeon with the use of the unique provider identification number listed in the "primary operator" field of the inpatient file. Previous work has suggested the reliability of this approach in identifying operating surgeons.[15] Records containing invalid provider identification numbers (6 percent) were excluded from further analysis. For some procedures, the number of unique, valid identification numbers exceeded the number of surgeons in the relevant specialties in the United States. This problem was most apparent in the analysis of the two cardiac procedures, for which cardiologists were often identified in the primary-operator field. For this reason, we used information from the 1998 Medicare provider files to restrict our analysis to physicians who had designated themselves as surgeons. For coronary-artery bypass grafting and valve-replacement procedures, we included only self-designated cardiothoracic surgeons. Because the specialists who perform the other procedures are more diverse, we included any self-designated surgeon. These restrictions removed a large proportion of potentially eligible surgeons from our analysis (ranging from 6 percent for cystectomy to 72 percent for coronary-artery bypass grafting). However, because the physicians who were excluded tended to be associated with relatively few patients (most often only one each), the restrictions resulted in the exclusion of a relatively low proportion of patients from our analysis of outcomes (ranging from 4 percent for cystectomy to 13 percent for coronary-artery bypass grafting).

#### STATISTICAL ANALYSIS

Our primary analyses focused on the relations between surgeon volume and hospital volume (the main variables measuring exposure) and operative mortality, defined as death before hospital discharge or within 30 days after the index procedure. Because, for some procedures, a large proportion of operative deaths before discharge occurred more than 30 days after surgery, 30-day mortality alone would not adequately reflect the true operative mortality.

To characterize volume, we first determined the average number of procedures that each hospital and each surgeon performed on Medicare patients during each of the two years. To make our estimates of volume more easily interpretable, we then estimated the total (all-payer) volumes, using data from the 1997 Nationwide Inpatient Sample. As in our previous research,[5] we determined the proportion of patients undergoing each procedure who were covered by Medicare — which ranged from 49 percent for esophagectomy to 75 percent for carotid endarterectomy — and divided each provider's observed Medicare volume (the total number of each type of procedure performed on Medicare patients) by these procedure-specific proportions. Although volume was evaluated as a continuous (log-transformed) variable in the assessment of statistical significance, we also created categorical variables for volume by ranking providers in order of increasing estimated total volume and selecting cutoff points that most closely sorted patients into three evenly sized groups with low, medium, and high volume. In sensitivity analyses, we recategorized hospital volume as a binary variable according to the criteria established by the Leapfrog Group for four procedures: coronary-artery bypass grafting (450 or more procedures per year vs. fewer than 450), repair of abdominal aortic aneurysm (50 or more per year vs. fewer than 50), esophagectomy (13 or more per year vs. fewer than 13), and pancreatic resection (11 or more per year vs. fewer than 11).

We used multiple logistic-regression analyses to examine the relation between surgeon volume and operative mortality, with adjustment for characteristics of the patients.[16] We used the patient as the unit of analysis, with volume measured at the level of the surgeon and at the level of the hospital. All models were analyzed separately for each procedure. Separate models were used to investigate the relation between operative mortality and surgeon volume, with and without consideration of hospital volume, and the relation between operative mortality and hospital volume, with and without consideration of surgeon volume. To establish the general form of the relation, we first modeled the relations between operative mortality and the logarithms of surgeon volume and hospital volume considered separately. We then fitted the models to the three volume strata. We adjusted for the effect of clustering of patients within surgeons and clustering of surgeons within hospitals by using binary mixed-effects models incorporating the two levels of nesting.[17] Surgeons who operated in more than one hospital were assumed to be in different clusters and contributed a random effect for each hospital in which they worked. We used the statistical software package MLwiN (Centre for Multilevel Modeling) to perform all modeling.[18]

We adjusted the analyses for characteristics of both the patients and the hospitals. The characteristics of the patients for which we adjusted included age group (in five-year intervals), sex, race (black or nonblack), year of procedure (1998 or 1999), whether the procedure was performed electively or not, and the mean income from Social Security in the ZIP Code of the patient's residence. Coexisting conditions were identified by their appropriate ICD-9 codes, with the exclusion of conditions that were likely to reflect either the primary indication for surgery or postoperative complications.[5] We explored three alternative approaches to the incorporation of data on coexisting conditions into our models for risk adjustment, including the use of Charlson scores with published weights,[19] the use of Charlson scores with weights derived empirically for each procedure, and adjustment for all pertinent coexisting conditions as individual variables. Because all three approaches yielded virtually identical results, we report only those from the models derived according to the first approach. We used 1998 and 1999 files from the American Hospital Association to ascertain the characteristics of the hospitals specific to the year in which the event occurred. The characteristics of the hospitals for which we adjusted included the type of ownership (not-for-profit, for-profit, or government), location (urban or nonurban), and teaching status (as defined by Taylor et al.[20]).

We computed adjusted mortality rates on the basis of the average values of the characteristics of the patients and the hospitals by back-transforming predicted mortality from the logistic-regression

Table 1. Characteristics of the Patients, According to Surgeon Volume.

| Characteristic | Low-Volume Surgeons | Medium-Volume Surgeons | High-Volume Surgeons |
|---|---|---|---|
| | | *percentage of patients* | |
| **Cardiovascular procedures** | | | |
| Carotid endarterectomy | | | |
| Age >75 yr | 49.4 | 50.1 | 50.4 |
| Female sex | 43.6 | 43.1 | 44.4 |
| Black race | 3.8 | 2.6 | 2.3 |
| Charlson score ≥3 | 10.7 | 10.2 | 9.9 |
| Nonelective admission | 32.2 | 27.4 | 26.3 |
| Coronary-artery bypass grafting | | | |
| Age >75 yr | 39.4 | 39.3 | 40.3 |
| Female sex | 35.0 | 35.4 | 34.9 |
| Black race | 4.6 | 3.7 | 2.9 |
| Charlson score ≥3 | 10.0 | 9.5 | 9.7 |
| Nonelective admission | 57.0 | 58.5 | 55.4 |
| Aortic-valve replacement | | | |
| Age >75 yr | 53.7 | 54.5 | 55.5 |
| Female sex | 43.8 | 43.4 | 44.3 |
| Black race | 4.7 | 2.8 | 2.0 |
| Charlson score ≥3 | 9.4 | 8.7 | 10.2 |
| Nonelective admission | 43.1 | 38.9 | 36.4 |
| Elective repair of an abdominal aortic aneurysm | | | |
| Age >75 yr | 46.3 | 45.4 | 47.0 |
| Female sex | 23.3 | 23.8 | 23.0 |
| Black race | 3.7 | 2.6 | 2.2 |
| Charlson score ≥3 | 9.3 | 9.9 | 10.2 |
| Nonelective admission | 26.5 | 23.9 | 22.5 |




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models. To assess the relative contribution of surgeon volume to the observed associations between hospital volume and outcome, we used models that estimated the relation between the operative mortality and hospital volume, first excluding and then including a variable for surgeon volume. The relative attenuation of the odds ratio was computed as $[OR_H - OR_{HS}] \div [OR_H - 1]$, where $OR_H$ is the odds ratio for operative death with a given hospital volume without consideration of surgeon volume and $OR_{HS}$ is the odds ratio for operative death with a given hospital volume after adjustment for surgeon volume; both odds ratios were adjusted for patient characteristics and other characteristics of the hospital. A P value of less than 5 percent was considered to indicate statistical significance, and all tests were two-sided.

## RESULTS

A total of 474,108 Medicare patients underwent one of the eight cardiac procedures or cancer resections during 1998 or 1999. Overall, approximately 25 percent of the surgeons who were included in the study operated at more than one hospital. Patients were much more likely to undergo surgery performed by a low-volume surgeon if they went to a low-volume hospital (range, 51 percent for carotid endarterectomy to 70 percent for pancreatic resection) than if they went to a high-volume hospital (range, 6 percent for pancreatic resection to 21 percent for carotid endarterectomy). The numbers of Medicare patients treated by low-volume, medium-volume, and high-volume surgeons in different hospital-volume strata are given in Supplemen-

**Table 1. (Continued.)**

| Characteristic | Low-Volume Surgeons | Medium-Volume Surgeons | High-Volume Surgeons |
|---|---|---|---|
| | | *percentage of patients* | |
| **Cancer resections** | | | |
| Resection for lung cancer | | | |
| Age >75 yr | 35.6 | 35.3 | 35.7 |
| Female sex | 42.6 | 43.2 | 43.5 |
| Black race | 5.9 | 4.5 | 4.1 |
| Charlson score ≥3 | 32.2 | 36.7 | 38.1 |
| Nonelective admission | 20.8 | 16.6 | 11.1 |
| Cystectomy of the bladder | | | |
| Age >75 yr | 44.3 | 47.0 | 43.8 |
| Female sex | 22.1 | 19.8 | 19.7 |
| Black race | 4.7 | 3.4 | 2.3 |
| Charlson score ≥3 | 34.2 | 34.1 | 41.4 |
| Nonelective admission | 20.4 | 19.4 | 15.6 |
| Esophagectomy | | | |
| Age >75 yr | 31.2 | 31.6 | 31.0 |
| Female sex | 24.4 | 25.1 | 21.5 |
| Black race | 8.7 | 6.8 | 4.3 |
| Charlson score ≥3 | 42.2 | 41.8 | 42.4 |
| Nonelective admission | 24.7 | 14.9 | 15.5 |
| Pancreatic resection | | | |
| Age >75 yr | 41.6 | 38.6 | 39.2 |
| Female sex | 49.1 | 51.9 | 48.8 |
| Black race | 8.0 | 7.2 | 4.2 |
| Charlson score ≥3 | 52.4 | 53.8 | 64.9 |
| Nonelective admission | 40.0 | 37.6 | 18.3 |




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