Is Volume Related to Outcome in Health Care? A Systematic Review and Methodologic Critique of the Literature

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Purpose: **To systematically review the methodologic rigor of the research on volume and outcomes and to summarize the magnitude and significance of the association between them.**

Data Sources: **The authors searched MEDLINE from January 1980 to December 2000 for English-language, population-based studies examining the independent relationship between hospital or physician volume and clinical outcomes. Bibliographies were reviewed to identify other articles of interest, and experts were contacted about missing or unpublished studies.**

Study Selection: **Of 272 studies reviewed, 135 met inclusion criteria and covered 27 procedures and clinical conditions.**

Data Extraction: **Two investigators independently reviewed each article, using a standard form to abstract information on key study characteristics and results.**

Data Synthesis: **The methodologic rigor of the primary studies varied. Few studies used clinical data for risk adjustment or examined effects of hospital and physician volume simultaneously. Overall, 71% of all studies of hospital volume and 69% of studies of physician volume reported statistically significant associations between higher volume and better outcomes. The strongest associations were found for AIDS treatment and for surgery on pancreatic cancer, esophageal cancer, abdominal aortic aneurysms, and pediatric cardiac problems (a median of 3.3 to 13 excess deaths per 100 cases were attributed to low volume). Although statistically significant, the volume–outcome relationship for coronary artery bypass surgery, coronary angioplasty, carotid endarterectomy, other cancer surgery, and orthopedic procedures was of much smaller magnitude. Hospital volume–outcome studies that performed risk adjustment by using clinical data were less likely to report significant associations than were studies that adjusted for risk by using administrative data.**

Conclusions: **High volume is associated with better outcomes across a wide range of procedures and conditions, but the magnitude of the association varies greatly. The clinical and policy significance of these findings is complicated by the methodologic shortcomings of many studies. Differences in case mix and processes of care between high- and low-volume providers may explain part of the observed relationship between volume and outcome.**

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Measuring and understanding the association between volume and outcome in the delivery of health services has been the focus of much research since the 1980s (1, 2). Recently, purchasers and consumer groups have taken an interest in the wider public dissemination of data on hospital volume for specific surgical procedures and medical conditions (3–5). Because high volume has been associated with better health outcomes for a variety of procedures and conditions, these groups recommend that consumers or health plans use data on volume to choose high-quality hospitals and physicians. Because reliable, valid, and timely information about health outcomes is lacking, data on volume are even more attractive. The wisdom of this policy, however, depends critically on the strength, magnitude, and meaning of the association between volume and outcome in health care.

During the past 20 years, a large body of research has focused on measuring and explaining the association between patient outcomes and the volume of health services provided by hospitals and physicians (1, 2, 6–11). Many (but not all) studies have documented that higher volume is associated with better outcomes. Two principal hypotheses have been advanced to explain these relationships: 1) Physicians (and hospitals) develop more effective skills if they treat more patients ("practice makes perfect") or 2) physicians (and hospitals) achieving better outcomes receive more referrals and thus accrue larger volumes ("selective referral") (2, 6, 9, 10).

Past reviews of this subject have focused only on specific procedures or conditions (12–14) or on effects of hospital volume (12, 15), have included non–population-based studies (14–16), or were done before many recent primary studies (12, 16). In addition, to our knowledge, no comprehensive review has systematically analyzed and described the methodologic rigor of this literature. This project was undertaken to address some of these limitations as part of a 2000 joint workshop of the U.S. Institute of Medicine and the National Cancer Policy Board (17). We set out to conduct a systematic review of the research evidence linking volume and outcome in health care, to summarize and describe the methodologic rigor of the existing literature, and to highlight the research and policy implications of these findings.

Methods

Study Identification and Selection

We searched MEDLINE for English-language articles published between 1 January 1980 and 31 December 2000 that assessed the relationship between volume and outcome in health care. Our search algorithms combined the Medical Subject Headings (MeSH terms) and text words *outcome, outcome assessment, outcome and process assessment, volume, utilization, frequency, statistics,* and *regionalization* with names of clinical conditions and procedures (Appendix). Bibliographies were reviewed to identify other articles of interest, and experts were contacted about missed or unpublished studies. We also searched the Cochrane Collaboration database.

For our systematic review, we selected English-language articles in which hospital or physician volume was an independent variable, health outcomes (for example, death, stroke, or clinical complications) were the dependent variable, samples were community- or population-based, and patients had primarily been treated since 1980. When multiple articles used the same data, we included the most recent or complete article. We excluded studies published before 1980 because clinical and surgical care and outcomes have changed considerably since then for nearly all of the topics we reviewed. We excluded studies from single institutions, voluntary registries, or other convenience samples because of concerns about reporting bias and generalizability.

Our initial search also identified articles about volume and outcome in trauma, newborn intensive care, and organ transplantation. We did not include these topics in our review because these services have already been extensively regionalized or are otherwise highly regulated by government or other administrative bodies.

Review Methods

Two of the authors reviewed each article independently, using a standardized abstraction form to record study characteristics, methodologic attributes, and research results. Reviewers were not blinded to journal, authors, or findings. The degree of initial agreement between reviewers was very high ($\kappa = 0.82$ to 1.0). Any discrepancies were resolved by discussion. A third reviewer was used in rare instances when the original two reviewers did not reach full agreement. We critically read each study with an eye toward assessing its methodologic rigor as well as describing its results.

Our methodologic review focused on key design attributes that influence the validity and generalizability of systematic reviews and the studies on which they are based (18, 19). Some preexisting patient factors, such as disease severity and burden of comorbid illness, are clear determinants of outcome independent of volume. Because it is necessary to account for differences in such factors to make valid comparisons between high- and low-volume providers, we assessed the quality of risk-adjustment techniques (12, 14, 20). We considered four levels of risk adjustment (none, models based on administrative data alone, models that included some clinical data, and clinical models with good calibration [Hosmer–Lemeshow test]) and discrimination (c-statistic $\geq$ 0.75) (20). In addition, we noted whether the investigators controlled for any specific processes of care (medical therapies, surgical techniques, or adjunctive procedures) that are known to result in better outcomes. Increasing evidence shows that high-volume providers may more consistently use proven effective therapies, such as aspirin or β-blockers in myocardial infarction (21) or adjuvant therapy in breast cancer (22). We also noted whether the investigators had explicitly measured the appropriateness of patient selection for procedural conditions. Although there has been little investigation of this issue, one study of carotid endarterectomy found that high-volume surgeons had a higher proportion of operations for inappropriate indications compared with low-volume surgeons (23).

We ascertained four other analytic attributes: the type of outcomes assessed, the number of hospitals and physicians in each study (an indicator of the potential for variation at the two provider levels of interest), the number of volume strata examined, and the unit of analysis (whether effects of hospital and physician volume were assessed). Finally, samples that included all patients undergoing a specific procedure were considered more generalizable to the overall population than studies restricted to patients with one type of insurance.

Statistical Analysis

Studies that found a statistically significant mortality advantage for high-volume providers ($P < 0.05$) were considered positive. For each study, we recorded the definition of high and low volume (cases per year) and the overall mortality rate of the sample. All summary death rates reflect in-hospital mortality unless otherwise specified. We calculated the absolute difference in mortality rate between the highest and lowest volume strata reported and expressed this as the number of excess deaths per 100 cases attributable to low volume. We report medians and ranges for high- and low-volume thresholds, mean mortality rates, and absolute differences in mortality rates. A few studies assessed volume as a continuous variable, making it impossible to calculate a mortality difference between high- and low-volume providers. We included data on whether these studies demonstrated statistically significant associations in our summary. We used chi-square tests to assess associations between positive findings and methodologic attributes. All analyses were done by using SAS software, version 6.12 (SAS Institute, Inc., Cary, North Carolina).

RESULTS

Methodologic Characteristics of Included Studies

Our systematic review identified 254 articles. Eighteen articles reported on more than one procedure or condition. Because we summarized the literature by topic, we evaluated each article that studied more than one procedure as more than one study. We reviewed a total of 272 studies, of which 135 (53%) met all inclusion criteria. These 135 studies covered 27 clinical topics. Studies were most commonly excluded because volume was not an independent variable ($n = 43$), the sample was not population based ($n = 40$), or the study data were obtained before 1980 ($n = 29$). Studies were also excluded if no primary health outcomes were assessed, if mixed outcomes were assessed (for example, death plus long length of stay), or if data were duplicative.

We found the literature to be extremely heterogeneous, even for a given procedure, making formal meta-analysis impossible. The methodologic characteristics of the 135 studies we reviewed are described in **Table 1**. Overall, 124 studies were from the United States, 6 were from Canada, 3 were from Europe, and 2 were from the United Kingdom. Half of all the studies we identified were published since 1998, underscoring the growing interest in this topic. The vast majority of reports were based on state or national hospital-discharge databases and had sample sizes that exceeded 1000 and included 20 or more hospitals and 50 or more physicians. For 79% of studies, the primary outcome was death, usually inpatient death. Many studies, however, reported 30-day mortality rates, and several articles on cancer reported long-term survival. Twenty-one percent of studies measured more than just death. For example, all 12 studies of coronary angioplasty also reported rates of emergency coronary artery bypass surgery, and half of the investigations of carotid endarterectomy reported stroke or other neurologic outcomes. Ninety percent of studies analyzed at least three categories of volume, usually tertiles or quartiles, and a few analyzed volume (or the logarithm of volume) as a continuous variable.

Among the 135 studies we reviewed, 124 attempted to detect the effects of hospital volume on outcome and 45 compared the influence of physician volume. Most individual studies were one-dimensional, examining hospital volume only (67%) or physician volume only (8%). Nine percent of studies examined both hospital and physician volume but failed to explore joint effects. Only 16% of studies performed multivariate analyses designed to separate the independent or synergistic effects of hospital and physician volume on outcomes.

We were particularly interested in the type of risk-adjustment techniques used, if any. Failure to account for imbalances in patient case mix among providers can seriously confound the relationship between volume and outcome. Twelve percent of studies performed no risk adjustment. Most studies (60%) used administrative data to adjust for some combination of age, sex, and discharge diagnoses. Approximately one in four studies (28%) used clinical data in their risk-adjustment models. Among this group, only 10 studies (7%) reported risk-adjustment models that were robustly discriminating and well calibrated.

Two other, higher-level methodologic issues were rarely addressed. Only two studies (23, 24) measured the appropriateness of patient selection. Ten investigators tried to account for differential use of key processes of care between high- and low-volume providers. Five studies of cancer (22, 25–28) adjusted for use of adjuvant therapy or type of surgical resection. Three studies of coronary angioplasty controlled for use of key pharmacologic therapies (heparin, aspirin, or β-blockers) (29, 30) or adjunctive procedures (intra-aortic balloon pump or stents) (29, 31). In a study of myocardial infarction, Thiemann and colleagues (21) adjusted for use of aspirin, β-blockers, and revascularization. Espehaug and colleagues (32), who studied total hip replacement, adjusted for prosthesis type and use of perioperative antibiotics.

Table 1. **Methodologic Characteristics of Reviewed Studies (n = 135)**

Characteristic	Value, %
Sample size ≥ 1000 persons	82
Sample representative of overall population	64
Number of hospitals or physicians studied	
<20 hospitals and <50 physicians	6
≥20 hospitals or ≥50 physicians	7
≥20 hospitals and ≥50 physicians	87
Type of primary outcome	
Death	79
Other clinical outcomes with or without death	21
Volume analyzed by >2 categories	90
Unit of analysis	
Hospital or physician volume	75
Hospital and physician volume analyzed separately	9
Hospital and physician volume analyzed simultaneously	16
Type of risk adjustment	
None	13
Administrative data	60
Clinical data	20
Clinical data with robust prediction model	7
Appropriateness of patient selection measured	2
Clinical processes of care measured	7

Summary Findings of Included Studies

Of the 135 studies we reviewed, 90 examined hospital volume only, 11 focused on physician volume only, and 34 assessed both. Overall, there were 169 assessments of the relationship between hospital or physician volume and outcomes. One hundred and eighteen comparisons (70% of the total) indicated a statistically significant association between higher hospital or physician volume and better health outcomes. No study documented a statistically significant association between higher volume and poorer outcomes. Overall, the same proportion of studies reported significant associations between outcomes and hospital volume (71%) and between outcomes and physician volume (69%). Of the 21 studies that examined the independent effects of both physician and hospital volume, 12 found significant independent effects for both, 4 found significant independent effects for hospital volume only, 4 found significant independent effects for physician volume only, and one found such effects for neither.

We did not find a simple relationship between the quality of risk adjustment and research results. A positive relationship between hospital volume and outcome was reported in 44% of articles with no risk adjustment, 82% of those with risk adjustment based on administrative data, and 50% of those with risk adjustment based on clinical data ($P < 0.001$). We found a positive association between physician volume and outcome in 62% of studies with no risk adjustment, 68% of those with risk adjustment using administrative data, and 73% of investigations using clinical risk-adjustment models ($P > 0.2$). Reports published in general medical or medical journals were more likely to support a relationship between hospital volume and outcome than were those published in surgical journals (86% vs. 52%, respectively; $P < 0.001$). No such relationship with publication type was found for studies of physician volume and outcome. We found no associations between research findings and other methodologic characteristics, such as sample size, number of providers, representativeness, type of outcome, number of volume strata, measurement of processes of care, or year of publication.

Although the evidence supported the general proposition that higher volume is associated with better outcomes, the consistency and magnitude of the relationships varied greatly. **Tables 2** and **3** summarize by topic the characteristics and findings of the effects of hospital and physician volume. We found the most consistent and striking absolute differences in mortality rates between high- and low-volume hospitals for pancreatic cancer surgery (median difference, 13 deaths per 100 cases), esophageal cancer surgery (12 deaths per 100 cases), pediatric cardiac surgery (11 deaths per 100 cases), treatment of AIDS (9.3 deaths per 100 cases), and surgery for unruptured abdominal aortic aneurysm (3.3 deaths per 100 cases). Evidence to support a relationship between hospital volume and outcome was much more limited and inconsistent for many other common surgical procedures and conditions. For procedures such as coronary artery bypass grafting (CABG) and coronary angioplasty, the median difference in mortality rates between high- and low-volume centers was 1.6 and 0.2 per 100 cases, respectively. **Tables 2** and **3** report the absolute mortality rates for each condition so that the magnitude of the volume effect can be compared with the underlying adverse event rate.

Among the smaller subset of investigations of relationships between physician volume and outcome, the most striking differences in mortality rates between high- and low-volume surgeons were seen for pancreatic cancer, ruptured abdominal aortic aneurysm, and pediatric cardiac surgery (median differences of 3 to 14 deaths per 100 cases for the three procedures). Surgeon volume seemed to be a more important determinant of outcomes than hospital volume in the case of CABG, carotid endarterectomy, surgery for ruptured abdominal aortic aneurysm, and surgery for colorectal cancer.

DISCUSSION

Our systematic review of the past 20 years of research on the relationship between volume and outcome evaluated 135 population-based studies involving 27 procedures and clinical conditions. The methodologic rigor of published studies was very heterogeneous and was modest overall. Most articles examined effects of hospital volume or physician volume only. Very few sought to identify the simultaneous contribution of hospital and physician volume to outcomes. The quality of risk-adjustment techniques also varied; only one in four studies used clinical data for risk adjustment, and fewer reported robust risk models. The limitations of using administrative information for risk adjustment are beyond the scope of our discussion but have been reviewed extensively elsewhere (20).

We found that 71% of all studies of hospital volume and 69% of studies of physician volume reported a statistically significant association between higher volume and better health outcomes. No study documented a statistically significant association between higher volume and worse outcomes. We are confident that the overall association between hospital volume and outcome is robust. However, studies that performed more methodologically sophisticated risk adjustment using clinical data were less likely to report a positive effect of hospital volume on outcome than were studies that did not adjust for risk or used administrative data to do so. It is therefore possible that subtle differences in disease severity or comorbidity may partly explain the association between hospital volume and outcome. We found no pattern of less impressive results in higher-quality studies in the less extensive literature examining the relationship between physician volume and outcomes.

The magnitude of the volume–outcome association varied greatly by topic. We found the most consistent and striking differences in mortality rates between high- and low-volume providers for several high-risk procedures and conditions, including pancreatic cancer, esophageal cancer, abdominal aortic aneurysms, pediatric cardiac problems, and treatment of AIDS. The magnitude of volume–outcome relationships for more common procedures, such as CABG, coronary angioplasty, and carotid endarterectomy, for which selective referral and regionalization policies have been proposed, was much more modest. This was true even after we took the lower average mortality rates for these procedures into account.

This systematic review confirms and extends the findings of earlier work. Previous reviews have also found that the associations between procedure volume and surgery outcomes are strongest for pancreatic and esophageal cancer and are more modest or heterogeneous for most other conditions (12, 13, 15, 16). Our approach to research synthesis differed because we sought to comprehensively review the methodologic rigor and findings of a large number of procedures and conditions, focus on population-based studies (to increase generalizability), and estimate a summary effect of hospital and physician volume across studies for each topic.

Although the literature generally supports the notion that high volume is often associated with better outcomes, many questions remain about the clinical and policy significance of these relationships. The relative contribution of hospital versus physician volume is largely unknown because very few studies have examined both types of volume

Table 2. **Summary of Articles Examining Associations between Hospital Volume and Death***

Procedure or Condition (Reference)	Studies Included	Studies with Significant Volume–Outcome Association	Range of Time Periods Studied	Median Cases per Year Defining Low Volume (Range)†	Median Cases per Year Defining High Volume (Range)†	Median Average Mortality Rate (Range)	Median Absolute Difference in Mortality Rate for High vs. Low Volume (Range)
	n				*n*		%
AIDS (38–43)	6	6	1984 to 1994	1 (1 to 160)	100 (5 to 161)	17.3 (9.0 to 25.2)	9.3 (3.7 to 20.1)
Myocardial infarction (21, 37)	2	2	1980 to 1995	73‡	238‡	13.8 and 15.2§	2.3§‖
Coronary angioplasty (31, 34, 44–50)¶	9	5	1989 to 1997	200 (46 to 200)	400 (160 to 1000)	1.4 (0.9 to 2.9)	0.2 (0.0 to 1.4)
Coronary artery bypass surgery (33, 37, 51–56)	8	6	1980 to 1995	100 (35 to 224)	500 (96 to 1421)	4.1 (2.8 to 6.5)	1.6 (0 to 4.4)
Pediatric cardiac surgery (56–58)	3	3	1988 to 1995	19 (10 to 100)	300 (100 to 400)	7.3 (6.8 to 7.7)	11.0 (2.3 to 15.5)
Carotid endarterectomy (24, 35, 59–71)§	15	7	1980 to 1997	10 (5 to 50)	50 (21 to 100)	1.8 (0.9 to 2.3)	0.4 (−0.5 to 1.8)**
Surgery for unruptured abdominal aortic aneurysm (56, 65, 67, 72–76)	8	7	1980 to 1997	12 (3 to 31)	36 (12 to 433)	7.5 (3.8 to 7.6)	3.3 (1.1 to 11.6)
Surgery to repair ruptured abdominal aortic aneurysm (67, 72–78)	8	2	1980 to 1995	9 (2 to 10)	20 (5 to 50)	49.8 (40.0 to 63.2)	7.9 (1.5 to 18.7)
Lower-extremity arterial bypass surgery (65, 67)	2	1	1982 to 1997	13 and 20	32 and 100	3.1 and 3.8	1.1 and 1.4
Pancreatic cancer surgery (79–88)	10	9	1984 to 1997	5 (1 to 22)	20 (3 to 200)	9.7 (5.8 to 12.9)	13.0 (3.0 to 17.9)
Esophageal cancer surgery (79, 89, 90)	3	3	1984 to 1997	5 (5 to 10)	30 (11 to 200)	13.9 (8.9 to 14.0)	12.0 (11.0 to 13.9)
Breast cancer surgery (25)	1	1	1984 to 1989	10	151	NA	††
Colorectal cancer surgery (26–28, 52, 54, 65, 89, 91–93)	10	4	1983 to 1997	18 (10 to 84)	115 (18 to 253)	6.0 (3.5 to 12.3)	1.9 (−1.2 to 9.7)**
Lung cancer surgery (65, 79, 93, 94)	4	2	1983 to 1997	7 (5 to 37)	19 (11 to 170)	5.5 (1.9 to 12.9)	1.9 (1.6 to 3.9)
Gastric cancer surgery (52, 89, 93)	3	1	1986 to 1997	10 (5 to 15)	63 (15 to 201)	10.9 (6.2 to 12.2)	6.5 (4.0 to 7.1)
Total hip replacement (32, 37, 54, 65, 95–98)	8	3	1980 to 1997	16 (6 to 42)	100 (15 to 213)	0.8 (0.3 to 3.4)	0.7 (0.0 to 1.4)
Total knee replacement (95)	1	1	1993 to 1994	25	200	0.2	0.1
Hip fracture repair (36, 95)	2	2	1990 to 1994	25 and 32	73 and 200	3.0 and 7.8	0.7‡‡
Open prostatectomy (99, 100)	2	2	1989 to 1995	25 and 38	54 and 141	0.2 and 0.5§	0.1 and 0.2§
Transurethral prostatectomy (54, 101)	2	2	1980 to 1991	9 and 10	22 and 101	0.9§ and 2.9§§	1.2§ and 0.5§§
Surgery for ruptured cerebral aneurysm (102, 103)	2	2	1984 to 1993	1 and 6	5 and 100	15.0 and 19.2	5.8 and 9.0
Surgery for unruptured cerebral aneurysm (103)	1	1	1987 to 1993	6	100	8.0	9.0

* For each study, we calculated (if possible) the absolute difference in mortality rate between the highest- and lowest-volume strata reported. All mortality rates reflect in-hospital death unless otherwise specified. Two reviewed studies of surgery for abdominal aortic aneurysm (52, 104) are not classified here because they analyzed ruptured and unruptured cases together. Values reported with "and" are values from individual studies rather than medians. NA = not available.

† Definitions indicate the thresholds below or above which a hospital was considered low or high volume.

‡ Volume was primarily analyzed as a continuous variable with no high- or low-volume threshold specified.

§ 30-day mortality rate.

‖ Farley and Ozminkowski (37) reported a 2.2% decrease in the in-hospital mortality rate per each 10% increase in volume.

¶ One study of primary coronary angioplasty for acute myocardial infarction (30) is not included here but is included in the overall findings.

** Negative numbers indicate that high-volume hospitals had higher mortality rates than low-volume hospitals.

†† Roohan and coworkers (25) published data for 5-year survival, not short-term mortality. Patients receiving care at the lowest-volume hospitals had a 60% higher risk for death within 5 years than those undergoing surgery at high-volume hospitals.

‡‡ Value given is for one study only. Data from the other study were not available.

§§ 60-day mortality rate.

Table 3. **Summary of Articles Examining Associations between Physician Volume and Death***

Procedure or Condition (Reference)	Studies Included	Studies with a Significant Volume–Outcome Association	Range of Time Periods Studied	Median Cases per Year Defining Low Volume (Range)†	Median Cases per Year Defining High Volume (Range)†	Median Average Mortality Rate (Range)	Median Absolute Difference in Mortality Rate for High vs. Low Volume (Range)
	n			n		%	
AIDS (105)	1	1	1984 to 1994	1	35	NA	NA‡
Myocardial infarction (106)	1	1	1993	12	13	NA	NA§
Coronary angioplasty (29, 31, 47, 49, 107)	5	1	1990 to 1997	75 (25 to 85)	138 (50 to 250)	1.0 (0.7 to 2.5)	0.06 (−0.3 to 0.7)‖
Coronary artery bypass (33, 52, 111)	3	3	1986 to 1992	55 (51 to 116)	150 (116 to 259)	3.7 (2.4 to 4.4)	2.2 (0.8 to 5.7)
Pediatric cardiac surgery (57)	1	1	1992 to 1995	74	75	6.8	2.9
Carotid endarterectomy (23, 59, 60, 62–64, 66, 69, 70, 108, 109, 112)¶	12	7	1980 to 1995	8 (1 to 30)	30 (5 to 50)	2.0 (0.7 to 2.8)‡	1.4 (1.2 to 5.8)
Surgery for unruptured abdominal aortic aneurysm (73)	1	0	1985 to 1987	2	10	7.6	3.2
Surgery for ruptured abdominal aortic aneurysm (73, 77, 78)	3	3	1985 to 1997	4**	10**	53.6 (46.3 to 54.9)	14.5**
Pancreatic cancer surgery (85, 86)	2	1	1984 to 1995	1 and 9	10 and 42	8.0 and 12.9	7.0 and 10.2
Breast cancer surgery (22)	1	1	1980 to 1988	10	50	NA	NA††
Colorectal cancer surgery (52, 91–93, 110)	5	4	1983 to 1997	12 (5 to 21)	22 (9 to 40)	3.0 (2.0 to 6.0)	1.9 (1.4 to 1.9)
Lung cancer surgery (93)	1	0	1994 to 1997	22	132	1.9	1.1‡‡
Gastric cancer surgery (52, 93)	2	2	1986 to 1997	1 and 2	2 and 12	6.2 and 12.2	4.0 and 5.7
Total hip replacement (96–98)	3	2	1988 to 1992	9 (2 to 10)	27 (10 to 100)	0.4 (0.3 to 1.3)	0.0 and 1.7

* For each study, we calculated (if possible) the absolute difference in mortality rate between the highest- and lowest-volume strata reported. All mortality rates reflect in-hospital death unless otherwise specified. Values reported with "and" are values from individual studies rather than medians. NA = not available.
† Definitions indicate the thresholds below or above which a physician was considered low or high volume.
‡ Adjusted relative risk for death was 0.69 for patients of high-volume physicians compared with lowest-volume physicians.
§ Patients of high-volume physicians had lower in-hospital mortality rates (odds ratio, 0.89).
‖ Negative numbers indicate that high-volume physicians had higher mortality rates than low-volume physicians.
¶ 30-day mortality rate.
** Value given for one study only. Data from other studies were not available.
†† Patients with high-volume surgeons had better 5-year survival (odds ratio, 0.85).
‡‡ Difference in mortality rates between high- and low-volume surgeons was of borderline statistical significance ($P = 0.08$).

simultaneously. For some procedures, effects of only hospital or only physician volume seemed to be significant. Therefore, policies advocating selective referral to high-volume providers based solely on hospital (or physician) volume may not achieve their intended effect; a low-volume surgeon at a high-volume hospital may have significantly poorer results than a moderate-volume surgeon at a moderate-volume hospital (33). Other important synergistic relationships between effects of hospital and physician volume probably exist as well.

Even when a compelling volume–outcome relationship existed, our review revealed wide variations in the definitions of high and low volume for a given topic. This made it difficult to specify evidence-based recommendations about which institutions or physicians are truly high-volume providers suitable for "selective referral." For almost every condition or procedure for which at least three studies were identified, the thresholds used to define high and low volume overlapped substantially, that is, the definition of high volume in one study was the number used to indicate low volume in another. In many studies, the providers with the lowest volume (often ≤1 case per year) seemed to have markedly worse results than providers in the other volume categories, although formal statistical analysis of these comparisons was often lacking. More detailed research will be needed to determine the conditions or procedures for which a policy of "selective avoidance" of very-low-volume providers might be more appropriate than selective referral to high-volume (or very-high-volume) providers.

Most of the studies we reviewed examined the volume of services at one period in time; very few explored changes in volume and performance over time. This is important because complication rates and caseload numbers change over time. Over the past 20 years, mortality rates for almost all major procedures have decreased because of major advancements in surgical technique, anesthesia practice, and perioperative management (34, 35, 111). Conversely, the annual volume of some operations, such as carotid endarterectomy, has doubled in less than a decade, so that providers who were low volume through the early to mid-1990s may have much higher annual caseloads a few years later (35, 113). Because most of the studies we reviewed were based on data from the 1980s to mid-1990s, the extent to which their findings reflect current practice and volume is unclear.

The few studies that analyzed longitudinal trends in volume–outcome relationships found that the relative and absolute differences in performance between high- and low-volume providers narrowed over time (12, 34, 111). In addition, articles that tracked changes in individual hospital volume over time found that fluctuating numbers of cases within the same institution had no or minimal effects on outcomes (36, 37, 114). This suggests that volume–outcome relationships may reflect fixed differences in the overall quality between high- and low-volume providers, rather than the principle of "practice makes perfect."

Missing from most of the research we reviewed was an exploration of the mechanism through which volume influences outcomes. Volume is clearly a proxy measure of other things because it cannot directly produce good or bad results. Specific processes of care, correlated with volume, are the most likely explanatory factors. High-volume hospitals or physicians may use effective treatments more often than their low-volume counterparts. In one study of myocardial infarction, differential use of therapies proven to be effective (thrombolytics, aspirin, β-blockers, angiotensin-converting enzyme inhibitors, and revascularization) explained one third of the survival advantage attributed to high-volume hospitals (21). Future investigations of volume–outcome relationships may be able to make important contributions by identifying specific differences in clinical management or procedural techniques between high-volume providers with good outcomes and low-volume provider with poor ones. Such studies would not only help uncover the mechanism through which caseload influences health but may also discover ways to achieve better outcomes in many procedures for which randomized, controlled trials are not feasible.

It is important to emphasize that any relationship between volume and outcome is true only on average. Outcomes vary widely among individual hospitals and physicians. Some low-volume providers have good outcomes, and some high-volume providers have poor outcomes. In New York State's 2000 report on cardiac surgery, almost half (47%) of high-volume CABG hospitals ($\geq$500 procedures per year) and one third of high-volume cardiac surgeons ($\geq$150 procedures per year) had risk-adjusted mortality rates that were greater than the statewide average (115).

Our study has some limitations. First, we cannot be sure that we identified all relevant studies because MEDLINE does not uniformly catalog this topic. However, we used a broad electronic search strategy, examined bibliographies by hand, and contacted experts in the field. Second, we cannot exclude a negative publication bias that might have diminished the number of studies failing to report the expected association. Third, the literature was too heterogeneous to permit formal quantitative meta-analysis. Nonetheless, we believe the medians and ranges of the volume–outcome effects we report will provide important and generalizable data by which to assess the magnitude and meaning of these relationships.

Conclusion

Twenty years of research have established that, for some procedures and conditions, higher volume among hospitals and physicians is associated with better outcomes. However, the magnitude of the relationship varies greatly among individual procedures and conditions. The clinical and policy significance of this finding is complicated by methodologic shortcomings of many studies. Even when a significant association exists, volume does not predict outcome well for individual hospitals or physicians. Investigating precisely what physicians and hospitals with high volumes and good outcomes do differently from those with low volume and poor outcomes is likely to contribute substantially to our knowledge and our ability to improve care for all patients.

Appendix: MEDLINE Search Algorithm

Our search algorithm was as follows: AIDS[mesh] OR liver diseases/surgery[mesh] OR lung diseases/surgery[MESH] OR coronary artery bypass[mesh] OR endarterectomy,carotid[mesh] OR neoplasms/surgery[mesh]OR angioplasty[mesh] OR myocardial infarction[mesh] OR vascular surgical procedures[mesh]OR peripheral vascular diseases/surgery[mesh]OR arthroplasty,replacement,knee[mesh]OR arthroplasty,replacement,hip[mesh]) AND utilization[subheading] AND (volume[Text word] OR frequency[Text word] OR frequent [Text word] OR statistics[subheading]) AND (outcome assessment[mesh] OR outcome and process assessment[mesh] OR outcome[Text word] OR regionalization [text word]).

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