SPECIAL ARTICLE

Variation in Hospital Mortality Associated with Inpatient Surgery

Amir A. Ghaferi, M.D., John D. Birkmeyer, M.D., and Justin B. Dimick, M.D., M.P.H.

ABSTRACT

BACKGROUND

Hospital mortality that is associated with inpatient surgery varies widely. Reducing rates of postoperative complications, the current focus of payers and regulators, may be one approach to reducing mortality. However, effective management of complications once they have occurred may be equally important.

METHODS

We studied 84,730 patients who had undergone inpatient general and vascular surgery from 2005 through 2007, using data from the American College of Surgeons National Surgical Quality Improvement Program. We first ranked hospitals according to their risk-adjusted overall rate of death and divided them into five groups. For hospitals in each overall mortality quintile, we then assessed the incidence of overall and major complications and the rate of death among patients with major complications.

RESULTS

Rates of death varied widely across hospital quintiles, from 3.5% in very-low-mortality hospitals to 6.9% in very-high-mortality hospitals. Hospitals with either very high mortality or very low mortality had similar rates of overall complications (24.6% and 26.9%, respectively) and of major complications (18.2% and 16.2%, respectively). Rates of individual complications did not vary significantly across hospital mortality quintiles. In contrast, mortality in patients with major complications was almost twice as high in hospitals with very high overall mortality as in those with very low overall mortality (21.4% vs. 12.5%, $P<0.001$). Differences in rates of death among patients with major complications were also the primary determinant of variation in overall mortality with individual operations.

CONCLUSIONS

In addition to efforts aimed at avoiding complications in the first place, reducing mortality associated with inpatient surgery will require greater attention to the timely recognition and management of complications once they occur.

From the Michigan Surgical Collaborative for Outcomes Research and Evaluation, the Department of Surgery, University of Michigan, Ann Arbor. Address reprint requests to Dr. Ghaferi at Michigan Surgical Collaborative for Outcomes Research and Evaluation, 211 N. Fourth Ave., Suite 201, Ann Arbor, MI 48104, or at aghaferi@umich.edu.

N Engl J Med 2009;361:1368-75.

Surgical rates of death vary widely across hospitals in the United States. Payers and regulators are currently focused on ways of reducing postoperative complications, which may be one approach to reducing the observed variations in mortality. Among the most prominent efforts are pay-for-performance plans aimed at creating incentives for greater compliance with evidence-based practices for perioperative care. For example, the Surgical Care Improvement Project of the Centers for Medicare and Medicaid Services (CMS) is focusing on process compliance for three surgical complications: surgical-site infection, venous thromboembolism, and cardiac ischemia. More recently, the CMS began withholding payment for certain preventable complications.[1]

Whether these efforts will ultimately be successful in reducing variation in hospital mortality is unclear, however. Instead, variation in how well hospitals recognize and rescue patients from major complications once they have occurred may also be important in explaining rates of death. Previous studies have suggested that the "failure to rescue" — mortality among patients with major complications — may be an important mechanism underlying hospital mortality associated with surgery.[2] However, since these studies were largely based on administrative data, the relationships between complications, failure to rescue, and mortality have not been clearly elucidated.

A better understanding of such relationships would have obvious implications for the types of policies that are likely to reduce surgical mortality. In this context, we used data from the American College of Surgeons National Surgical Quality Improvement Program to explore variations in hospital death rates associated with inpatient surgery. In particular, we focused on the extent to which rates of complications and death after the development of a major complication explain variations in mortality across hospitals.

METHODS

DATA SOURCE AND STUDY POPULATION

We used data from the American College of Surgeons National Surgical Quality Improvement Program from 2005 through 2007. The program is a prospective, multicenter clinical registry that was created to provide feedback on risk-adjusted outcomes to hospitals for quality-improvement purposes. It began in 1991 as a Veterans Health Administration quality initiative to improve surgical outcomes in veterans hospitals.[3] In 2004, the program began to collect data from non-veterans hospitals and now includes 186 participating centers. More than 130 patient and operative variables are recorded, including patient demographics, preoperative risk factors, laboratory values, intraoperative variables, and postoperative 30-day morbidity and mortality. All information in the database is deidentified, and informed consent is obtained from patients before data collection.

The data-collection process relies on a sampling strategy aimed at collecting a diverse set of surgical procedures. Nurses who are trained in surgical and clinical review record the data with the use of standardized definitions. The reliability of the data is ensured through intensive training mechanisms for the nurse reviewers and by conducting interrater reliability audits of participating sites.[4] Although the American College of Surgeons National Surgical Quality Improvement Program administers the database, the authors are solely responsible for the analyses and conclusions presented here.

The most recent database includes information on 363,897 patients who underwent surgery at the participating hospitals from 2005 to 2007. For this study, we identified a subgroup of 215,526 patients who underwent general or vascular surgery, using current-procedural-terminology codes.[5] Since outpatient surgery is associated with a very low rate of mortality, we then restricted our analysis to 170,403 patients who underwent inpatient surgery. Finally, given our primary interest in understanding surgical mortality, we further limited the study population to patients who underwent procedures that have rates of death of more than 1%. With these exclusions, our study was based on 84,730 patients who underwent 1 of 42 general and vascular operations. Although our study cohort included only 23% of all patients who were enrolled in the database, it captured 68% of deaths.

PRIMARY OUTCOMES

We focused on two primary outcomes: the rate of complications and the rate of death among patients who had major complications. Postoperative complications included superficial, deep, and organ-space infections, acute renal failure, postoperative bleeding requiring transfusion, myocardial infarction, pneumonia, pulmonary embolism, stroke, unplanned intubation, fascial dehiscence, prolonged mechanical ventilation (>48 hr), deep venous thrombosis, urinary tract infection, septic shock, vascular graft loss, and renal insufficiency. In assessing the relationship between hospital mortality and complications, we examined all complications and a subgroup of major complications. To define the latter, we excluded patients with urinary tract infection, deep venous thrombosis (in the absence of pulmonary embolism), superficial infections, and renal insufficiency (in the absence of a need for dialysis). We then assessed mortality after major complications (i.e., the proportion of deaths among patients with at least one major complication).

STATISTICAL ANALYSIS

The main purpose of this study was to determine the relationship between overall hospital mortality, complications, and mortality after major complications. Our primary exposure variable was risk-adjusted mortality, assessed at the hospital level. For this purpose, we used standard risk-adjustment methods, which have been well described and validated previously.[3] Our models were based on backward stepwise logistic regression, including multiple patient-level and operation-level variables such as age, sex, functional status, American Society of Anesthesiologists class, the presence or absence of an emergency procedure, preoperative laboratory values (e.g., albumin and creatinine), preoperative coexisting illnesses (e.g., a history of myocardial infarction, chronic obstructive pulmonary disease, cerebrovascular disease, weight loss, long-term use of corticosteroids, and dialysis), and the type of procedure. Our final model included 13 variables with a C statistic of 0.88.

Furthermore, on the basis of the Hosmer–Lemeshow goodness-of-fit statistics, the model was well calibrated, with a good match between observed and expected deaths across all deciles of risk. Predicted probabilities of death from these models were then calculated for patients at each hospital to estimate the expected rates of death. Next, the ratio of observed-to-expected mortality was multiplied by the overall rate of death in the database to obtain the risk-adjusted rate of death for each hospital. We then ranked hospitals according to risk-adjusted mortality and divided them into five equal-sized groups (quintiles).

Using the same risk-adjustment model described above, we compared the complication incidence across the risk-adjusted hospital quintiles of mortality. To further evaluate the effect of specific complications on mortality, we compared the incidence of individual complications across the hospital quintiles. We used similar techniques to assess the relationship between mortality in patients with major complications and overall hospital mortality. To assess the generalizability of our findings, we repeated our analysis with the inclusion of all patients in the database. These results were essentially identical to those of our main analysis and are not presented here. Finally, to confirm the robustness of our findings, we performed procedure-specific analysis of the five procedures associated with the greatest number of perioperative deaths: colectomy, repair of abdominal aortic aneurysm, lower-extremity bypass, and above-knee and below-knee amputation.

In these analyses, we adjusted for the nonindependence of patients within hospitals (i.e., clustering) by creating robust standard errors. All statistical analyses were performed with the use of Stata software (version 10.0).

RESULTS

The risk-adjusted overall rates of death varied by a factor of nearly two across the hospital quintiles, from 3.5% in the hospitals with very low mortality (lowest quintile) to 6.9% in the hospitals with very high mortality (highest quintile) (odds ratio, 2.04; 95% confidence interval [CI], 1.73 to 2.39). Table 1 summarizes the study population, stratified according to hospital mortality quintiles. In general, patients at higher-mortality hospitals were more likely to be nonwhite and smokers. On balance, however, there was no evidence of systematic differences in case mix across hospital quintiles, evidenced by very similar overall expected rates of death. Furthermore, hospitals with very low mortality or very high mortality performed a very similar mix of procedures. For example, between very-low-mortality hospitals and very-high-mortality hospitals, there were nearly identical rates of colectomy (36.2% vs. 37.3%, P=0.05), gastrectomy (2.3% vs. 2.1%, P=0.19), and abdominal aortic-aneurysm repair (7.4% vs. 6.9%, P=0.07).

There were no clinically important differences in the rates of overall complications or major complications across quintiles of overall hospital mortality (Fig. 1). In terms of individual complication rates, very-high-mortality hospitals had slightly higher rates of unplanned intubation than did very-low-mortality hospitals (4.6% vs. 3.6%, P=0.02). However, there were no significant differences in

Table 1. Demographic and Clinical Characteristics of the Patients, According to Hospital Quintile of Mortality.*

Characteristic	Very Low Mortality (N=17,379)	Low Mortality (N=16,780)	Medium Mortality (N=17,923)	High Mortality (N=15,953)	Very High Mortality (N=16,695)
Median age (yr)	63.6	63.0	63.9	61.7	62.4
Male sex (%)	52.0	52.0	51.2	54.4	51.6
Nonwhite race (%)†	18.9	14.5	14.6	24.1	26.4
Smoking within past year (%)	22.2	23.2	23.8	26.6	27.4
Preoperative functional status (%)					
Totally independent	82.0	83.1	85.2	84.1	83.7
Partially dependent	11.8	11.2	10.1	10.4	10.9
Totally dependent	6.3	5.7	4.7	5.5	5.4
ASA class ≥4 (%)	15.7	14.3	14.3	16.7	15.9
Coexisting condition (%)					
Diabetes	20.2	19.4	19.3	21.3	21.7
Chronic obstructive pulmonary disease	8.4	8.6	7.9	9.2	9.1
Congestive heart failure	2.4	3.1	2.0	2.6	2.5
Myocardial infarction	1.5	1.8	1.3	1.8	1.8
Peripheral vascular disease	11.5	11.7	9.9	12.3	12.0
Transient ischemic attack	3.7	4.1	3.8	4.3	4.5
Bleeding disorder	11.8	12.1	9.4	10.6	11.2
Ascites	4.9	4.2	3.9	3.6	3.6
Long-term use of corticosteroids	5.5	6.2	5.6	7.2	5.4
Emergency operation	18.3	18.8	19.3	18.2	19.5
Acute renal failure	1.4	1.7	1.5	1.7	1.7
Dialysis	3.6	4.1	3.1	4.6	4.7
Albumin <3.5 g/dl	26.9	23.5	28.1	27.4	27.0
Do-not-resuscitate status	1.9	1.4	2.0	1.5	1.4
Hypertension	58.2	56.9	57.6	58.6	59.3
Preoperative transfusion of >4 units	1.2	1.1	0.9	1.2	1.1
Weight loss of >10% in past 6 mo	6.9	8.1	5.5	6.2	5.6
Expected mortality (%)‡	5.2	5.4	4.8	5.1	4.8
Risk-adjusted mortality (%)	3.5	4.6	4.8	5.8	6.9

* ASA denotes American Society of Anesthesiologists.
† Race was self-reported.
‡ Expected mortality was derived from a risk-adjustment model that included age, sex, race, need for emergency surgery, laboratory values, procedure type, and coexisting illnesses.

the rates of urinary tract infection; deep venous thrombosis; postoperative bleeding; superficial, deep incisional, or organ-space infection; myocardial infarction; pneumonia; pulmonary embolism; stroke; fascial dehiscence; acute renal failure; or septic shock.

Although the incidence of complications was similar across hospital-mortality quintiles, the rate of death in patients with at least one major complication was markedly higher in hospitals with higher overall mortality. Patients who were treated at very-high-mortality hospitals had nearly two times the likelihood of dying after the development of a major complication as did their counterparts in very-low-mortality hospitals (21.4% vs. 12.5%, P<0.001). This relationship held true for individual complications as well (Table 2). In addition, with the exception of fascial dehiscence, mortality after a major complication was consistently higher in the very-high-mortality hospitals

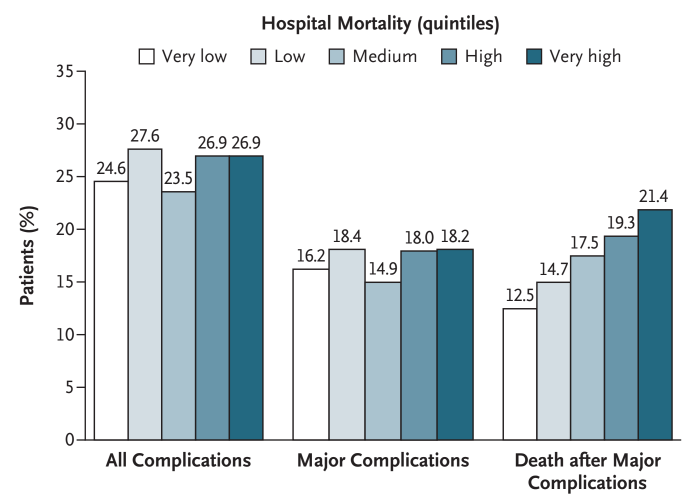

Figure 1. Rates of All Complications, Major Complications, and Death after Major Complications, According to Hospital Quintile of Mortality.

Although rates of all complications and major complications did not vary significantly across hospital mortality quintiles, the rate of death in patients with major complications was almost twice as high in hospitals with very high overall mortality as in those with very low overall mortality (21.4% vs. 12.5%, P<0.001).

than in the very-low-mortality hospitals for each major complication. The largest differences in mortality after major complications between high-mortality hospital and low-mortality hospitals were observed in patients with stroke (46.4% vs. 22.5%, P<0.05), deep wound infection (7.1% vs. 3.2%, P<0.05), and septic shock (46.2% vs. 28.7%, P<0.001).

Analyses that were restricted to patients who underwent the five operations associated with the most perioperative deaths (colectomy, abdominal aortic-aneurysm repair, lower-extremity bypass, and above-knee and below-knee amputation) yielded virtually identical results (Table 3). For example, with colectomy, rates of death varied from 2.5% to 5.6%. The incidence of postoperative complications was very similar between the very-high-mortality hospitals and the very-low-mortality hospitals. In contrast, rates of death after a major complication were markedly higher in very-high-mortality hospitals than in very-low-mortality hospitals (20.4% vs. 11.4%, P<0.001).

DISCUSSION

The results of this study provide new insights into the mechanisms underlying variations in hospital mortality with surgery. Although rates of death for patients who underwent inpatient surgery varied by a factor of nearly two (3.5% to 6.9%) across hospitals, these differences could not be explained by differences in postoperative complications. Specifically, high- and low-mortality hospitals had nearly identical rates of postoperative complications. Conversely, rates of death among patients with major complications varied markedly between hospitals with high overall mortality and those with low overall mortality.

Although it is clinically intuitive that high-mortality hospitals would have more complications, our study adds to a growing body of evidence that complications and mortality are not correlated at the hospital level.[6-8] In many of these studies, relationships between complications and overall mortality disappear with risk adjustment, suggesting that postoperative complications are related more to patient factors than to quality of care.[9,10] Prompted by difficulties in the use of mortality or complications as a marker of hospital quality, Silber and colleagues popularized the use of the term "failure to rescue"— defined as death after a complication — as a measure of hospital quality.[2,9,10] Although these studies firmly established the importance of failure to rescue, they had certain limitations. The investigators used administrative data, which limited their ability to account fully for illness severity. The use of administrative data may also result in an inaccurate ascertainment of postoperative complications. Our study builds on these original studies with the use of highly detailed, prospective clinical data, ensuring both adequate risk adjustment and accurate ascertainment of postoperative complications.

Our study had several limitations. First, the National Surgical Quality Improvement Program does not collect information on all possible postoperative complications. For example, complications that are unique to individual operations, such as anastomotic leak for bowel operations, are not recorded. The complications that were included in the database were initially selected for their applicability across the many general and vascular surgical procedures being sampled. Therefore, we may have underestimated the degree to which some important complications vary across hospitals. Second, hospitals in the database may not be representative of all hospitals in the United States, a possibility that would threaten the generalizability of our findings. Although the database includes

Table 2. Incidence of Major Complications and Mortality after Complications, According to Hospital Quintile of Mortality.

Variable	Very Low Mortality	Low Mortality	Medium Mortality	High Mortality	Very High Mortality	Odds Ratio for Very High vs. Very Low Mortality (95% CI)
			percent of patients			
Incidence of complication						
Pneumonia	2.0	2.4	1.8	2.4	2.1	1.06 (0.70–1.60)
Mechanical ventilation >48 hr	6.6	7.1	6.3	7.0	8.1	1.24 (0.99–1.56)
Unplanned intubation	3.6	4.0	3.6	4.5	4.6	1.30 (1.04–1.63)
Acute renal failure	1.3	1.5	1.2	1.7	1.6	1.20 (0.90–1.60)
Myocardial infarction	0.5	0.4	0.5	0.4	0.5	1.06 (0.60–1.87)
Pulmonary embolism	0.7	0.6	0.7	0.7	0.7	1.00 (0.71–1.38)
Postoperative bleeding	1.2	1.6	1.1	1.6	1.4	1.15 (0.85–1.56)
Deep wound infection	2.1	1.7	1.7	2.1	1.9	0.92 (0.61–1.41)
Organ-space infection	3.3	3.8	2.9	3.2	3.3	1.00 (0.70–1.41)
Septic shock	1.6	2.5	1.4	2.3	2.5	1.55 (0.98–2.44)
Fascial dehiscence	1.9	1.7	1.4	1.7	1.9	1.01 (0.73–1.40)
Stroke	0.2	0.3	0.2	0.3	0.2	0.74 (0.42–1.29)
Mortality after major complication						
Pneumonia	16.5	15.9	20.6	17.0	25.5	1.73 (1.22–2.44)
Mechanical ventilation >48 hr	20.6	23.1	28.7	27.3	31.0	1.73 (1.36–2.20)
Unplanned intubation	24.8	27.2	26.8	32.4	38.4	1.89 (1.39–2.56)
Acute renal failure	35.9	43.3	47.7	43.1	48.3	1.67 (1.11–2.52)
Myocardial infarction	29.1	28.4	27.3	36.4	39.5	1.60 (0.86–2.96)
Pulmonary embolism	6.9	6.8	7.6	5.9	11.5	1.74 (0.77–3.96)
Postoperative bleeding	20.9	33.2	31.4	33.1	30.9	1.69 (1.08–2.66)
Deep wound infection	3.2	3.2	3.9	5.1	7.1	2.28 (1.11–4.71)
Organ-space infection	4.9	4.2	6.9	8.8	8.8	1.87 (1.06–3.30)
Septic shock	28.7	29.2	41.0	36.3	46.2	2.13 (1.35–3.35)
Fascial dehiscence	7.0	6.0	8.1	6.9	7.1	1.01 (0.56–1.81)
Stroke	22.5	30.4	35.0	41.3	46.4	2.99 (0.98–9.15)

hospitals of varying size and geographic location, large teaching hospitals tend to be overrepresented. Many observers might assume that failure to rescue may be a bigger problem in smaller community hospitals, with fewer in-house physicians and lesser resources. However, in analyses stratified according to teaching status, we found no evidence of differences in failure-to-rescue rates across hospital types (data not shown). By virtue of their participation in the National Surgical Quality Improvement Program and quality-improvement activities, study hospitals may also have lower rates of complications and death than hospitals not participating. For this reason, we may have underestimated the extent to which surgical mortality varies across hospitals. Finally, the program collects data on a random sample of all patients undergoing general and vascular surgery under regional or general anesthesia, not all patients undergoing each procedure. Although this sampling frame does not bias our main conclusions, it limited our ability to study mortality with most individual procedures.

Clinical mechanisms underlying mortality after surgical complications have yet to be elucidated; however, the ability to effectively rescue a patient from a complication relies on two distinct points of intervention: the timely recognition of a com-

Table 3. Rates of Death, Major Complications, and Death after Major Complications for the Five Operations with the Largest Number of Deaths, According to Hospital Quintile of Mortality.

Type of Surgery	Very Low Mortality	Very High Mortality	Odds Ratio for Very High vs. Very Low Mortality (95% CI)
	percent of patients		
Colectomy			
Overall mortality	2.5	5.6	2.29 (1.76–2.98)
All complications	24.7	28.1	1.19 (0.95–1.50)
Major complications	15.4	17.6	1.17 (0.94–1.46)
Mortality after major complications	11.4	20.5	2.08 (1.54–2.82)
Abdominal-aortic-aneurysm repair			
Overall mortality	3.1	7.3	2.49 (1.63–3.81)
All complications	17.4	19.3	1.13 (0.87–1.46)
Major complications	13.6	15.5	1.26 (0.86–1.56)
Mortality after major complications	15.6	26.3	1.94 (1.04–3.62)
Above-knee amputation			
Overall mortality	10.0	15.0	1.59 (1.00–2.53)
All complications	25.7	26.6	1.05 (0.75–1.47)
Major complications	18.9	18.6	0.98 (0.67–1.43)
Mortality after major complications	20.8	35.2	2.08 (0.94–4.60)
Lower-extremity bypass			
Overall mortality	1.9	2.9	1.55 (0.92–2.60)
All complications	24.0	23.6	0.97 (0.81–1.17)
Major complications	11.5	11.1	0.95 (0.75–1.22)
Mortality after major complications	8.2	12.7	1.63 (0.76–3.53)
Below-knee amputation			
Overall mortality	4.2	8.4	2.07 (1.18–3.63)
All complications	23.7	25.4	1.09 (0.82–1.46)
Major complications	15.5	17.3	1.14 (0.81–1.60)
Mortality after major complications	14.5	29.7	2.49 (1.10–5.63)

plication and the effective management of that complication. The former relies on an efficient, collaborative team with established and effective systems of communication. The quality of nursing care is clearly central to such communication and may explain previous studies that showed an association between a high nurse-to-bed ratio and low surgical mortality.[11-13] In addition to timely recognition, the effective management of complications is also crucial. This management includes multiple complex processes, including the timely administration of antibiotics in patients with sepsis, the rapid transfer of a patient to an intensive care unit (ICU), and the availability of interventional cardiologists during an acute myocardial infarction. Because complications may result in an escalation of care, with transfer to the ICU, it is also crucial to focus on this setting.[14-16] For example, Pronovost and colleagues showed the importance of ICU characteristics (i.e., staffing levels of physicians and nurses) on postoperative outcomes. They found that a system of daily rounds with a certified intensivist was associated with a reduction in in-hospital mortality by a factor of three and that an increased nurse-to-patient ratio was associated with a halving of in-hospital mortality.[17]

Efforts that are aimed at reducing rates of surgical complications are essential. In this study, approximately one in six patients who underwent general or vascular surgery had a surgical complication, and more than half of such complications were serious. Among ongoing efforts that are aimed at reducing complication risks, the Surgical Care Improvement Project is focusing on hospital compliance with several evidence-based processes of care. The CMS has enacted a policy to deny reimbursements to hospitals for so-called never events, including urinary tract infections, pressure ulcers, retained foreign bodies after surgery, and many other events. Finally, intraoperative checklists have become an increasingly promising and popular approach for reducing risks of complications.[18]

Although the value of avoiding complications in the first place is obvious, our findings also suggest that improving the care that patients receive once complications have occurred is crucial for reducing mortality. Such initiatives could focus on structural or organizational factors, such as promoting minimum standards for nurse staffing, ICU organization, or other hospital attributes associated with proficiency in treating patients whose condition is critical or unstable. Alternatively, such initiatives could focus on specific processes of care. As one example of such a strategy, the timely implementation of the established, evidence-based guidelines of the international Surviving Sepsis Campaign has resulted in a significant reduction in mortality among critically ill patients.[19,20] Given the results of our study, strategies for ensuring the timely recognition and effective management of complications will be important in reducing deaths after inpatient surgery.

Supported by a training grant from the National Cancer Institute (T32 CA009672, to Dr. Ghaferi), grants from the National Cancer Institute (R01-CA098481 and K05-CA115571-01, to Dr. Birkmeyer), and a career development award from the Agency for Healthcare Research and Quality (K08-HS017765, to Dr. Dimick).

No potential conflict of interest relevant to this article was reported.

References

1. Centers for Medicare & Medicaid Services home page. (Accessed September 4, 2009, at http://www.cms.hhs.gov/.)
2. Silber JH, Williams SV, Krakauer H, Schwartz JS. Hospital and patient characteristics associated with death after surgery: a study of adverse occurrence and failure to rescue. Med Care 1992;30:615-29.
3. Khuri SF, Daley J, Henderson W, et al. The Department of Veterans Affairs' NSQIP: the first national, validated, outcome-based, risk-adjusted, and peer-controlled program for the measurement and enhancement of the quality of surgical care. Ann Surg 1998;228:491-507.
4. American College of Surgeons National Surgical Quality Improvement Program. ACS NSQIP data collection overview. (Accessed September 4, 2009, at https://acsnsqip.org/main/program_data_collection.asp.)
5. CPT 2006: current procedural terminology. Chicago: American Medical Association, 2005.
6. Houghton A. Variation in outcome of surgical procedures. Br J Surg 1994;81:653-60.
7. Dudley RA, Johansen KL, Brand R, Rennie DJ, Milstein A. Selective referral to high-volume hospitals: estimating potentially avoidable deaths. JAMA 2000;283:1159-66.
8. Halm EA, Lee C, Chassin MR. Is volume related to outcome in health care? A systematic review and methodologic critique of the literature. Ann Intern Med 2002;137:511-20.
9. Silber JH, Rosenbaum PR. A spurious correlation between hospital mortality and complication rates: the importance of severity adjustment. Med Care 1997;35: Suppl:OS77-OS92.
10. Silber JH, Rosenbaum PR, Schwartz JS, Ross RN, Williams SV. Evaluation of the complication rate as a measure of quality of care in coronary artery bypass graft surgery. JAMA 1995;274:317-23.
11. Aiken LH, Clarke SP, Sloane DM, Sochalski J, Silber JH. Hospital nurse staffing and patient mortality, nurse burnout, and job dissatisfaction. JAMA 2002;288:1987-93.
12. Sasichay-Akkadechanunt T, Scalzi CC, Jawad AF. The relationship between nurse staffing and patient outcomes. J Nurs Adm 2003;33:478-85.
13. Carayon P, Gürses AP. A human factors engineering conceptual framework of nursing workload and patient safety in intensive care units. Intensive Crit Care Nurs 2005;21:284-301.
14. Pronovost PJ, Angus DC, Dorman T, Robinson KA, Dremsizov TT, Young TL. Physician staffing patterns and clinical outcomes in critically ill patients: a systematic review. JAMA 2002;288:2151-62.
15. Pronovost PJ, Needham DM, Waters H, et al. Intensive care unit physician staffing: financial modeling of the Leapfrog standard. Crit Care Med 2004;32:1247-53.
16. Birkmeyer JD, Dimick JB. Potential benefits of the new Leapfrog standards: effect of process and outcomes measures. Surgery 2004;135:569-75.
17. Pronovost PJ, Jenckes MW, Dorman T, et al. Organizational characteristics of intensive care units related to outcomes of abdominal aortic surgery. JAMA 1999; 281:1310-7.
18. Haynes AB, Weiser TG, Berry WR, et al. A surgical safety checklist to reduce morbidity and mortality in a global population. N Engl J Med 2009;360:491-9.
19. Dellinger RP, Levy MM, Carlet JM, et al. Surviving Sepsis Campaign: international guidelines for management of severe sepsis and septic shock: 2008. Crit Care Med 2008;36:296-327. [Erratum, Crit Care Med 2008;36:1394-6.]
20. Zambon M, Ceola M, Almeida-de-Castro R, Gullo A, Vincent JL. Implementation of the Surviving Sepsis Campaign guidelines for severe sepsis and septic shock: we could go faster. J Crit Care 2008;23:455-60.