Volume standards for high-risk surgical procedures: Potential benefits of the Leapfrog initiative

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Background. *As part of a broader effort aimed at improving hospital safety, a large coalition of employers, the Leapfrog Group, will soon require hospitals caring for their employees to meet volume standards for 5 high-risk surgical procedures. We estimated the potential benefits of full nationwide implementation of these volume standards.*

Methods. *Using data from Nationwide Inpatient Sample and other sources, we first estimated the total number of each of the 5 procedures—coronary-artery bypass graft, abdominal aortic aneurysm repair, coronary angioplasty, esophagectomy, and carotid endarterectomy—performed each year in hospitals in US metropolitan areas. (Leapfrog exempts hospitals in rural areas to avoid access issues.) We then projected the effectiveness of volume standards (in terms of relative risks of mortality) for each procedure using data from a published structured literature review.*

Results. *With full implementation nationwide, the Leapfrog volume standards would save 2581 lives. Of the procedures, volume standards would save the most lives with coronary-artery bypass graft (1486), followed by abdominal aortic-aneyrysm repair (464), coronary angioplasty (345), esophagectomy (168), and carotid endarterectomy (118). In our estimates of the number of lives saved, we considered assumptions about how many patients would be affected and the effectiveness of volume standards (ie, strength of underlying volume-outcome relationships with each procedure).*

Conclusions. *If the Leapfrog volume standards are successfully implemented, employers and health-care purchasers could prevent many surgical deaths by requiring hospital volume standards for high-risk procedures. (Surgery 2001;130:415-22.)*

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LARGE, POPULATION-BASED STUDIES have consistently demonstrated higher surgical mortality rates with cardiovascular operations, major cancer resections, and certain other procedures at hospitals with low volumes of those procedures.[1-4] Patients undergoing major oncologic procedures at low-volume hospitals (LVHs) may also have poorer long-term survival.[5-7] However, despite increased attention to the idea of regionalizing certain procedures in both the medical literature and the lay media,[4,8-10] very few concerted efforts have been aimed at moving patients to high-volume hospitals (HVHs).

One notable exception is the Leapfrog safety initiative. Motivated in part by a report from the Institute of Medicine (IOM) on medical errors, several large employers and health-care purchasers in the United States have combined to leverage improvements in health-care quality. The Leapfrog coalition includes (among others) General Motors, General Electric, Verizon, the US Office of Personnel Management, and large coalitions of smaller companies, employing collectively over 20 million people in the Midwest and on the Pacific Coast. Additional employers are being actively recruited. To care for Leapfrog employees, hospitals will be required to meet 3 safety standards: (1) computerized order entry by physicians (to reduce medication errors for inpatients),[11] (2) ICUs staffed by full-time intensivists (shown to be associated with reduced mortality),[12-16] and (3) volume standards for 5 selected high-risk procedures and neonatal intensive care.

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Table I. Annual number of patients undergoing 5 selected operations, overall and at low-volume hospitals (LVH) in metropolitan statistical areas (MSAs)

Procedure (volume standard)	*Total number performed in US/yr*	*Total number performed in MSAs (previous column × .8)*	*Proportion currently performed at LVHs*			*Total number at LVHs in MSAs*
			California	*New York*	*Baseline estimate for US*	
CABG (500/yr)	383,788[25]	307,030	66%[4]	41%[18]	53.5%	164,261
Coronary angioplasty (400/yr)	531,981[25]	425,585	36%[4]	21%[37]	28.5%	121,292
AAA repair (30/yr)	37,068*[25]	29,654	64%[4]	61%†[38]	62.5%	18,534
CEA (100/yr)	152,859	122,287	64%[4]	71%[25]	67.5%	82,544
Esophagectomy (7/yr)	2,569‡[23]	2,055	82.5%[23]	§	82.5%	1,696

*Estimated by multiplying total number of AAA repairs (44,129) by proportion of AAA repairs performed for nonruptured (and thus elective) AAAs (84%).
† Hannan defined LVH as < 26 procedures per year.
‡ Because NIS data were unavailable for esophagectomies, annual number performed in California extrapolated to US estimate based on 1999 census data.
§ No data available.

Although it may ultimately include more direct performance measures (eg, risk-adjusted mortality), the Leapfrog standard is based entirely on annual hospital procedures. The 5 surgical procedures—coronary-artery bypass surgery (CABG), coronary angioplasty, elective abdominal aortic-aneurysm (AAA) repair, carotid endarterectomy (CEA), and esophageal cancer surgery—were selected because of strong evidence of their volume-outcome relationships.[1,3,4,17-22] In this study, we estimated the number of lives that could be saved if the Leapfrog volume standards for the 5 surgical procedures are fully implemented.

METHODS

Calculations of lives saved

Number of patients at low-volume hospitals. To calculate the number of patients who could potentially benefit from volume standards, we first estimated the total number of each of the 5 surgical procedures performed each year in the US (Table I). We used data from the 1997 Nationwide Inpatient Sample (NIS) to estimate the numbers of CABGs, coronary angioplasties, AAA repairs, and CEAs performed. The NIS is a probabilistic sample of hospital discharge data from over 1000 hospitals across the US. The weights provided with the data allowed us to calculate national estimates. Because NIS data were not available for esophagectomies, we estimated the total US counts by using data from California[23] and extrapolating it from 1999 census data.[24]

In determining the number of patients potentially affected by volume standards, we excluded most patients undergoing emergent operations who would not be appropriate for transfer to HVHs. For example, patients with ruptured AAAs were excluded from our analysis. To estimate the number of elective AAA repairs subject to volume standards, we multiplied the total number of AAA repairs performed annually (44,129)[25] by the proportion performed for nonruptured AAAs (84%), estimated from national Medicare data.[26] Because of their relative infrequency, however, we adjusted our calculations for patients undergoing truly "emergent" CABG and coronary angioplasties. Emergent CABG operations, which most often occur because of acute complications of coronary angioplasty, represent a very small proportion of all CABGs (less than 5%). Emergent coronary angioplasties, most commonly performed as alternatives for lytic therapy in patients with acute myocardial infarction, are similarly infrequent. CEA and operations for esophageal cancer are rarely performed emergently.

To avoid access issues and other unintended negative consequences in rural areas, the Leapfrog Group will implement the volume standards only in urban areas. We assumed that 80% of the 5 procedures were performed in hospitals in metropolitan areas, based on our analysis of the 1997 data from the American Hospital Association file of the proportion of hospital beds in metropolitan statistical areas (Sandra M. Sharp, MS, personal communication).

To calculate the proportion of patients likely to be affected, we then estimated the proportion of patients currently undergoing the 5 procedures at LVHs, defined according to the volume standards of the Leapfrog Group (Table I). Leapfrog selected these volume standards after reviewing the analysis by Dudley et al[4] and by consulting with experts in health services research. Population-based studies necessary for estimating the proportion of patients currently at LVHs come primarily from California and New York. For CABG and coronary angioplasty, California has substantially more LVHs than

Table II. Projected in-hospital mortality rates with 5 procedures at low-volume (LVHs) and high-volume (HVHs) hospitals

Procedure	*Overall mortality*	*Relative risk of mortality (LVH vs HVH)*	*Projected in-hospital mortality*	
			HVH	*LVH*
CABG	2.9%[25]	1.38[17]	2.4%*	3.3%*
Coronary angioplasty	1.0%[25]	1.33[37]	0.9%*	1.2%*
Elective AAA repair	4.9%[28]	1.60[28]	4.2%	6.7%
CEA	0.6%[25]	1.28[39]	0.5%*	0.7%*
Esophagectomy	14%[23]	3.01[23]	5.9%	15.8%

*"Back-calculated" from estimates of overall mortality rate (above), relative risks of mortality at LVHs and HVHs, and estimated distribution of patients at LVHs and HVHs (Table I).

New York, which has stricter restrictions on the delivery of cardiovascular health care (enforced in part through its Certificate of Need process).[18] Because relevant information from other parts of the US was not available, we averaged estimates from those states for our baseline analysis. For CEA and AAA repair, the proportion of patients undergoing operations at LVHs is very similar in California and New York. Because no data were available from New York for esophagectomies, we relied exclusively on the data from California.[23]

Projected effectiveness of volume standards. In projecting mortality reductions likely to be achieved with volume standards for the 5 surgical procedures, we relied on point estimates from Dudley et al[4] for our baseline analysis. In their systematic review of the volume-outcome literature, they selected the "single best study" for each procedure based on several explicit criteria, including case-mix adjustment, sample size, location of study, and currency of the data. They then used data from the chosen articles to determine the odds ratio for mortality between LVHs and HVHs. We converted these odds to relative risks using the formula described by Zhang and Yu[27] (Table II).

Mortality rates at low-volume hospitals. We then applied assumptions about the efficacy-of-volume standards to the estimates of current mortality rates at LVHs. For many high-risk procedures, there is evidence that surgical mortality rates have declined over the last decade. For this reason, we relied on recent overall mortality estimates from the NIS[25]—instead of older data from the volume-outcome studies on which the efficacy-of-volume standards were derived—for CABG, coronary angioplasty, and CEA. We then derived estimates of current mortality rates at LVHs by "back-calculation," using 3 variables: the current overall mortality for each procedure, the proportion of patients at LVHs and HVHs, and the relative risk of mortality at LVHs versus HVHs. Since the NIS database does not contain information about current overall mortality rates for elective AAA repair and esophagectomy, we used rates reported in the original volume-outcome studies.[23,28]

Lives saved. For each procedure, we calculated the number of lives potentially saved as the difference between expected deaths with and without volume standards (Table III). Because our calculations were based on multiple assumptions, we performed sensitivity analyses on 2 variables: (1) the number of patients affected (ie, moved) by the volume-standards policy and (2) the effectiveness of the volume standards in reduced mortality. Varying the number of affected patients accounts for uncertainty in the proportion of patients currently at LVHs in metropolitan areas and in how "successful" the Leapfrog standards will be in redistributing patients. In testing a range of assumptions about the true effectiveness of the volume standards, we varied the relative risk of mortality, LVH versus HVH, with each procedure. If the volume standards were only half as effective for a certain procedure, a baseline relative risk of 1.4 (hypothetically) would be reduced to 1.2. If twice as effective, the baseline relative risk would be increased to 1.8.

RESULTS

In our baseline analysis, we estimated that full implementation of the volume standards would save 2581 lives each year in the US (Table III). The greatest number of deaths would be prevented with CABG (1486 deaths annually), followed by elective AAA repair (464 deaths annually), and coronary angioplasty (345 deaths annually). Lives potentially saved with esophagectomy and CEA were 168 and 118, respectively.

In the sensitivity analysis, the number of lives saved with each procedure varied according to assumptions about the number of affected patients by the volume standards and assumptions about effectiveness. As expected, the benefits fall proportionally as fewer patients are affected (Fig 1). For example, if only 50% of the patients estimated to

Table III. Number of lives potentially saved by implementation of Leapfrog volume standards

Procedure	*Total patients at LVHs in MSAs*	*Expected deaths without volume standards*	*Expected deaths with volume standards*	*Lives saved by volume standards*
CABG	164,261	5428	3942	1486
Coronary angioplasty	121,292	1405	1059	345
AAA repair	18,534	1242	778	464
CEA	82,544	543	425	118
Esophagectomy	1,696	267	99	168
Total	388,327	8884	6304	2581

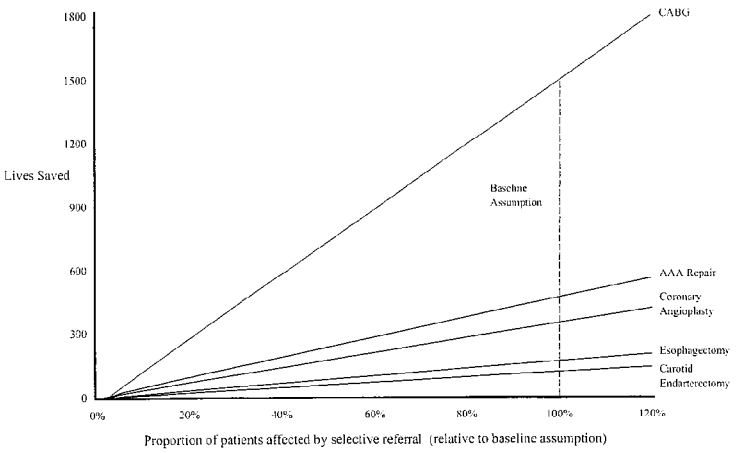

Fig 1. Number of lives saved by Leapfrog volume standards for 5 procedures according to proportion of patients affected by volume standards (relative to baseline assumption).

be at metropolitan LVHs were moved to HVHs, 1290 total lives would be saved. Similarly, the number of lives saved with each procedure is directly proportional to the relative risk of mortality, LVH versus HVH (Fig 2). Thus, if the volume standards were only half as effective as our baseline assumptions, 1290 lives would be saved.

DISCUSSION

The universal adoption of the Leapfrog volume standards for the 5 high-risk procedures could have substantial benefits, saving approximately 2500 lives each year in the US. As demonstrated in the sensitivity analysis, the precise projections of the benefits likely to be achieved depend on many underlying assumptions. However, despite varying estimates of the effectiveness of, and the number of patients affected by, the volume standards, the number of lives potentially saved remains substantial. Our findings are also generally in line with 2 previous analyses. Dudley et al estimated that 500 lives would be saved each year in California by adopting "selective referral" for 10 procedures (including the 5 selected by Leapfrog).[4] Birkmeyer et al estimated that 800 to 4000 lives could be saved by regionalizing a similar group of 10 procedures in the US Medicare population.[29]

There should be little controversy that HVHs have lower mortality rates with the 5 procedures selected by the Leapfrog Group (Table IV). In addition to the structured literature review on which our analysis was based, the IOM recently released its synthesis of the evidence.[22] A total of 88 volume-outcome studies (of several hundred reviewed) met its criteria for currency and scientific rigor. Of these, 77% were found to be statistically significant in inverse relationships between hospital volume and mortality. The remaining 23% did not have significant volume-outcome associations, but no study demonstrated a statistically significant association in the opposite direction. The IOM report acknowledged, as have others,[30] that the majority of volume-outcome studies have relied on administrative data, raising concerns about adequacy of risk adjustment. However, the IOM panel found no evidence that studies based on clinical data reported weaker volume-outcome relationships than those based on administrative data. In

Table IV. Summary of volume-outcome studies of procedures selected for inclusion by Leapfrog Group, as summarized by Dudley et al

	Number of studies				
Procedure	*Total*	*High volume SS* better*	*NS† trend toward high volume better*	*NS† trend toward high volume worse*	*High volume SS* worse*
CABG [17-19,31,40-46]	11	9	2	0	0
Coronary angioplasty [37,47-51]	6	6	0	0	0
Elective AAA repair [19,28,31,38,52-56]	9	9	0	0	0
CEA [20,21,39,57-62]	9	6	3	0	0
Esophagectomy[3,23]	2	2	0	0	0

*Statistically significant.
†Not significant.

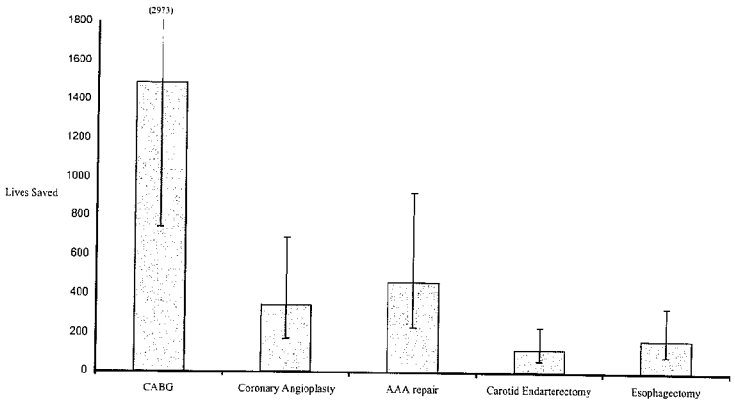

Fig 2. Number of lives saved by Leapfrog volume standards for 5 procedures according to excess mortality at low-volume hospitals. *Shaded columns* indicate projected lives saved from baseline estimates. *Error bars* indicate projected lives saved in sensitivity analysis when excess mortality estimate is varied from 50% to 200% of our baseline estimate.

fact, all 16 studies with the highest-quality scores in the IOM report (all based on clinical data) reported statistically significant relationships between volume and mortality.

Although the general direction of the effect is clear, there remains considerable uncertainty about point estimates of volume-outcome relationships with specific procedures. The volume-outcome literature is too heterogeneous for formal meta-analysis. To avoid potential biases associated with "handpicked" estimates, we used point estimates from the structured literature review by Dudley et al, who identified the "single best" study for each procedure based on several explicit criteria for study quality (including sample size, adequacy of risk adjustment, and currency). However, relying on data from individual studies makes point estimates of the volume-outcome relationships considerably less precise. It also discounts substantial variation in results across studies. A few studies, including a well-known one from Veterans Affairs hospitals,[30] have shown essentially no volume-outcome effect; others have demonstrated relationships considerably stronger than we used in our analysis.

Do the benefits of procedure volume standards depend on the underlying mechanisms of volume-outcome relationships? Many assume a causal relationship—that higher volume leads directly to better outcomes ("practice makes perfect"). However, the reverse relationship—that better outcomes lead to more referrals and thus higher volumes—may be equally plausible in many settings.[31] The distinction between these 2 causal models may be important for policies that create new HVHs. For policy initiatives (such as Leapfrog) that simply increase patient flow to established HVHs, however, better outcomes would be achieved either way, to the degree suggested by strength of the observed volume-outcome relationships.

It is important to consider other potential, indirect benefits of the Leapfrog initiative in surgical procedures. Although its initial focus is exclusively

on procedural volume standards, the Leapfrog initiative leaves open the possibility of replacing volume standards with more direct quality measures (at least for procedures performed commonly enough to allow for adequately precise measures of hospital-specific mortality). Surgical quality could be improved considerably if hospitals responded to these incentives, collected data on their own performance, and participated in collaborative quality improvement initiatives.[32,33]

Unintended harms. Many of the potential downsides of regionalization policies are most relevant to patients living in isolated rural areas. These include unreasonable travel burdens, problems with continuity of care after operation, and underutilization of some procedures.[34] Losing surgical volume could threaten the financial viability of local hospitals or their ability to recruit and retain surgeons, with attendant effects on patient access to routine surgical care. By restricting its initial efforts to metropolitan areas, however, the Leapfrog Group is trying to avoid many of these problems.

There may be other potential harms, however. First, procedure-volume standards would create incentives for hospitals near the volume thresholds to increase the number of procedures they perform. This pressure would create the potential for unnecessary operations for patients with "discretionary" conditions, such as lifestyle-limiting coronary artery disease, small AAAs, and asymptomatic carotid stenosis.

Second, concentrating certain procedures in a few HVHs could reduce the proficiency of the remaining hospitals and their surgeons in delivering emergency care that must be handled locally. For example, the local general surgeon no longer performing elective repair of AAAs could be less prepared for emergency operation on a ruptured aneurysm. For nonemergent procedures, the volume standards might turn some LVHs into very LVHs, increasing mortality risks for their remaining patients.

Third, the Leapfrog initiative could affect the delivery and quality of care for procedures other than the 5 directly targeted. For example, the restrictions on where CABG can be performed have obvious implications for where heart-valve replacement can be offered. Policies aimed at improving the quality of AAA repair and CEA could diminish the quality of other related procedures. For example, could hospital- or surgeon-specific performance with lower extremity bypass suffer as a result of lower total volumes of major vascular procedures? Although the data necessary to answer these questions are currently unavailable, policy makers may need to consider individual procedures in the context of all high-risk procedures in subspecialties.

How should surgeons respond? The Leapfrog initiative may redirect many patients undergoing certain procedures to HVHs, but its direct effects may be modest. Although their numbers are growing, Leapfrog companies represent only 20 million employees and retirees, less than 10% of the total US population. Thus, many regions will be largely unaffected by the Leapfrog initiative, although these companies have a powerful presence particularly in the Midwest and on the Pacific Coast. However, its indirect effects could be substantial. Efforts in the private sector may pressure other regulatory bodies and the government to follow suit. For example, the Health Care Financing Agency, a Leapfrog liaison, is exploring volume standards for the Medicare population. Even without regulatory intervention, the Leapfrog initiative, which has received considerable attention in the lay media,[35] may also increase the flow of patients to HVHs simply by making them more aware of the importance of volume for certain procedures.

For these reasons, surgeons and their professional societies will need to respond to initiatives emphasizing surgical volume. Because many surgeons resent any infringement on their professional autonomy, resistance will be a natural response. In resisting, surgeons could simply deny that procedure volume is important or assert that the benefits of volume standards are outweighed by some of the harms outlined above. If they choose this tack, however, surgeons may threaten their credibility with patients, payers, and policy makers. For example, some may ask, "Would a surgeon undergo a pancreatic resection at a hospital performing, on average, only 2 procedures a year?" In addition, many may question surgeons' motives in resisting volume standards. Finally, surgeons will also risk giving up their influence in policy implementation.

Instead, surgeons could implement alternative approaches to improving surgical quality. For example, if hospitals and surgeons wish to defuse the current focus on proxy measures of quality (such as volume), they could initiate systematic efforts to monitor more direct measures of their performance. There are several successful templates for this approach in cardiac surgical procedures and in the VA.[32,36] Unfortunately, tracking risk-adjusted mortality and morbidity requires substantial commitment and investment of resources. In addition, sample size issues limit the usefulness of this approach for procedures performed relatively infrequently (eg, esophagectomy), or those associated with low event

rates (eg, CEA), particularly at LVHs. Patients and payers may also insist on public disclosure of quality measures, another potential obstacle.

Finally, surgeons could decide to work with policy makers to find a middle ground. For example, for cardiac operations and other common vascular procedures, the surgeons and their societies could work toward universal adoption of programs for measuring performance directly. If volume standards are the only practical approach for less common procedures (eg, major cancer resections), at least surgeons can help to ensure that sensible volume standards are selected.

Surgeons also must get involved in the clinical science underlying these policy initiatives. As a start, surgeons could help fill in the gaps in the volume-outcome literature. Although the volume-outcome literature is extensive, much more research is needed about processes of care responsible for better outcomes at HVIIs and about the relative importance of surgeon-versus-hospital factors with various procedures. Surgeons should also participate in studying the real consequences of policy initiatives, such as the Leapfrog effort. In addition to assessing the benefits, researchers need to monitor potentially negative effects of volume-based initiatives on access, patient satisfaction, and training programs, to name just a few areas needing future study. By taking the lead in these areas, surgeons can help to ensure that volume standards are implemented in the ways that optimize patient benefits while minimizing unintended harms.

REFERENCES

1. Luft HS, Bunker JP, Enthoven AC. Should operations be regionalized? The empirical relation between surgical volume and mortality. N Engl J Med 1979;301:1364-9.
2. Houghton A. Variation in outcome of surgical procedures. Br J Surg 1994;81:653-60.
3. Begg CB, Cramer LD, Hoskins WJ, Brennan MF. Impact of hospital volume on operative mortality for major cancer surgery. JAMA 1998;280:1747-51.
4. 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.
5. Porter GA, Soskolne CL, Yakimets WW, Newman SC. Surgeon-related factors and outcome in rectal cancer. Ann Surg 1998;227:157-67.
6. Gillis CR, Hole DJ. Survival outcome of care by specialist surgeons in breast cancer: a study of 3786 patients in the west of Scotland. BMJ 1996;312:145-53.
7. Roohan PJ, Bickell NA, Baptiste MS, Therriault GD, Ferrara EP, Siu AL. Hospital volume differences and five-year survival from breast cancer. Am J Public Health 1998;88:454-7.
8. Birkmeyer JD. High-risk surgery—Follow the crowd. JAMA 2000;283:1191-3.
9. Marsa L. Not every hospital is created equal. The Los Angeles Times 2000 Sep 25.
10. Comarow A. Higher volume, fewer deaths. US News & World Report 2000 Jul 17.
11. Bates DW, Leape LL, Cullen DJ, Laird N, Petersen LA, Teich JM, et al. Effect of computerized physician order entry and a team intervention on prevention of serious medication errors. JAMA 1998;280:1311-6.
12. Manthous CA, Amoateng-Adjepong Y, al-Kharrat T, Jacob B, Alnuaimat HM, Chatila W, et al. Effects of a medical intensivist on patient care in a community teaching hospital. Mayo Clin Proc 1997;72:391-9.
13. Carson SS, Stocking C, Podsadecki T, Christenson J, Pohlman A, MacRae S, et al. Effects of organizational change in the medical intensive care unit of a teaching hospital: a comparison of 'open' and 'closed' formats. JAMA 1996;276:322-8.
14. Ghorra S, Reinhert SE, Cioffi W, Buczko G, Simms HH. Analysis of the effect of conversion from open to closed surgical intensive care unit. Ann Surg 1999;229:163-71.
15. Hanson CW, Deutschman CS, Anderson HL, Reilly PM, Behringer EC, Schwab CW, et al. Effects of an organized critical care service on outcomes and resource utilization: a cohort study. Crit Care Med 1999;27:270-4.
16. Pronovost PJ, Jenckes MW, Dorman T, Garrett E, Breslow MJ, Rosenfeld BA, et al. Organizational characteristics of intensive care units related to outcomes of abdominal aortic surgery. JAMA 1999;281:1310-7.
17. Hannan EL, Kilburn H, Bernard H, O'Donnell JF, Lubacik G, Shields EP. Coronary artery bypass surgery: the relationship between in hospital mortality rate and surgical volume after controlling for clinical risk factors. Med Care 1991;26:1094-1107.
18. Grumbach K, Anderson GM, Luft HS, Roos LL, Brook R. Regionalization of cardiac surgery in the United States and Canada. Geographic access, choice, and outcomes. JAMA 1995;274:1282-8.
19. Hannan EL, O'Donnell JF, Kilburn H, Bernard HR, Yaxici A. Investigation of the relationship between volume and mortality for surgical procedures performed in New York State hospitals. JAMA 1989;262:1094-1107.
20. Cebul RD, Snow RJ, Pine R, Hertzer NR, Norris DG. Indications, outcomes, and provider volumes for carotid endarterectomy. JAMA 1998;279:207-13.
21. Wennberg DE, Lucas FL, Birkmeyer JD, Bredenberg CE, Fisher ES. Variation in carotid endarterectomy in the Medicare population. JAMA 1998;279:1278-81.
22. Committee on Quality of Health Care in America and the National Cancer Policy Board. Interpreting the volume-outcome relationship in the context of health care quality. Washington: Institute of Medicine; 2000.
23. Patti MG, Corvera CU, Glasgow RE, Way LW. A hospital's annual rate of esophagectomy influences the operative mortality rate. J Gastrointest Surg 1998;2:186-92.
24. Population division USCB. Population Estimates Program. Washington; 1999.
25. Agency for Health Care Research and Quality. HCUPnet, Healthcare cost and utilization project. Rockville, Md; 1997.
26. Cronenwett JL, Birkmeyer JD, editors. The Dartmouth atlas of healthcare. Chicago: American Hospital Publishing; 2000.
27. Zhang J, Yu KF. What's the relative risk? A method of correcting the odds ratio in cohort studies of common outcomes. JAMA 1998;280:1690-1.
28. Kazmers A, Jacobs L, Perkins A, Lindenauer SM, Bates E. Abdominal aortic aneurysm repair in Veterans Affairs medical centers. J Vasc Surg 1996;23:191-200.
29. Birkmeyer JD, Lucas FL, Wennberg DE. Potential benefits of regionalizing major surgery for Medicare patients. Eff Clin Pract 1999;2:277-83.

30. Khuri SF, Daley J, Henderson W, Hur K, Hossain M, Soybel D, et al. Relation of surgical volume to outcome in eight common surgical operations. Ann Surg 1999;230:414-23.
31. Luft HS, Hunt SS, Maerki SC. The volume-outcome relationship: practice makes perfect or selective referral patterns? Health Serv Res 1987;22:157-82.
32. O'Connor GT, Plume SK, Olmstead EM, Morton JR, Maloney CT, Nugent WC, et al. A regional intervention to improve the hospital mortality associated with coronary artery bypass graft surgery. JAMA 1996;275:841-6.
33. Hannan EL, Kilburn H, Racz M, Shields E, Chassin MR. Improving the outcomes of coronary artery bypass surgery in New York State. JAMA 1994;271:761-6.
34. Finlayson SRG, Birkmeyer JD, Tosteson ANA, Nease RFJ. Patient preferences about location of care: implications for regionalization. Med Care 1999;37:204-9.
35. Freudenheim M. Big companies lead effort to reduce medical errors. The New York Times 2000 Nov 16.
36. Khuri SF, Daley J, Henderson WG, Hur K, Demakis J, Aust JB. 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.
37. Hannan EL, Racz M, Ryan TJ, McCallister DB, Johnson LW, Arani DT, et al. Coronary angioplasty volume-outcome relationships for hospitals and cardiologists. JAMA 1997;277:892-8.
38. Hannan EL, Kilburn H, O'Donnell JF, Bernard HR, Shields EP, Lindsey M. A longitudinal analysis of the relationship between in-hospital mortality in New York State and the volume of abdominal aortic aneurysm surgeries performed. Health Serv Res 1992;27:517-42.
39. Hannan EL, Popp AJ, Tranner B, Fuestel P, Waldman J, Shah D. Relationship between provider volume and mortality for carotid endarterectomies in New York State. Stroke 1998;29:2292-7.
40. Farley DE, Ozminkowski RJ. Volume-outcome relationships and in-hospital mortality. Med Care 1992;30:77-94.
41. Hughes RG, Hunt SS, Luft HS. Effects of surgeon volume and hospital volume on quality of care in hospitals. Med Care 1987;25:489-503.
42. Kelly JV, Hellinger FJ. Heart disease and hospital deaths. Health Serv Res 1987;22:369-95.
43. Riley G, Lubitz J. Outcomes of surgery among the Medicare aged. Health Care Financ Rev. 1985;7:37-47.
44. Showstack JA, Rosenfeld KE, Garnick DW, Luft HS, Schaffarzick RW, Fowles J. Association of volume with outcome of coronary artery bypass graft surgery. Scheduled vs nonscheduled operations [published correction appears in JAMA 1987;257:2438]. JAMA 1987;257:785-9.
45. Shroyer AL, Marshall G, Warner BA, Johnson RR, Guo W, Grover FL, et al. No continuous relationship between Veterans Affairs hospital coronary artery bypass grafting surgical volume and operative mortality. Ann Thorac Surg 1996;61:17-20.
46. Zelen J, Bilfinger TV, Anagnostopoulos CE. Coronary artery bypass grafting: the relationship of surgical volume, hospital location, and outcome. NY State J Med 1991;91:290-2.
47. Jollis JG, Peterson ED, DeLong ER, Mark DB, Collins SR, Muhlbaier LH, et al. The relationship between the volume of coronary angioplasty procedures at hospitals treating Medicare beneficiaries and short-term mortality. N Engl J Med 1994;331:1625-9.
48. Jollis JG, Peterson ED, Nelson CL, Stafford JA, DeLong ER, Muhlbaier LH, et al. Relationship between physician and hospital coronary angioplasty volume and outcome in elderly patients. Circulation 1997;95:2485-91.
49. Kimmel SE, Berlin JA, Laskey WK. The relationship between coronary angioplasty procedure volume and major complications. JAMA 1995;274:1137-42.
50. Phillips KA, Luft HS, Ritchie JL. The association of hospital volumes of percutaneous transluminal coronary angioplasty with adverse outcomes, length of stay, and charges in California. Med Care 1995;33:502-14.
51. Ritchie JL, Phillips KA, Luft HS. Coronary angioplasty: statewide experience in California. Circulation 1993;88: 2735-43.
52. Amundsen S, Skaerven R, Trippestad A, Soreide O. Abdominal aortic anuerysms: is there an association between surgical volume, surgical experience, hospital type and operative mortality. Acta Chir Scand 1990;156:323-7.
53. Kelly JV, Hellinger FJ. Physician and hospital factors associated with mortality of surgical patients. Med Care 1986;24:785-800.
54. Maerki SC, Luft HS, Hunt SS. Selecting categories of patients for regionalization. Med Care 1986;24:148-58.
55. Pilcher DB, Davis JH, Ashikaga T, Bookwalter J, Butsch DW, Chase CR, et al. Treatment of abdominal aortic aneurysm in an entire state over 7 1/2 years. Am J Surg 1980;139:487-94.
56. Wen SW, Simunovic M, Williams JI, Johnston KW, Naylor CD. Hospital volume, calender age, and short term outcomes in patients undergoing repair of abdominal aortic aneurysms: the Ontario experience. J Epidemiol Community Health 1996;50:207-13.
57. Manheim LM, Sohn MW, Feinglass J, Ujiki M, Parker MA, Pearce WH. Hospital vascular volume and procedure mortality rates in California, 1982-1994. J Vasc Surg 1998;28:45-56.
58. Edwards WH, Morris JA, Jenkins JM, Bass SM, MacKenzie EJ. Evaluating quality, cost-effective health care. Vascular database predicated on hospital discharge abstracts. Ann Surg 1991;213:433-8.
59. Fisher ES, Malenka DJ, Solomon NA, Bubolz TA, Whaley FS, Wennberg JE. Risk of carotid endarterectomy in the elderly. Am J Public Health 1989;79:1617-20.
60. Kantonen I, Lepantalo M, Salenius JP, Matzke S, Luther M, Ylonen K. Influence of surgical experience on the results of carotid surgery. Eur J Vasc Endovasc Surg 1998;15:155-60.
61. Karp HR, Flanders WD, Shipp CC, Taylor B, Martin D. Carotid endarterectomy among Medicare beneficiaries: a statewide analysis of 9918 cases. Stroke 1998;29:46-52.
62. Perler BA, Dardik A, Burleyson GP, Gordon TA, Williams GM. Influence of age and hospital volume on the results of carotid endarterectomy. J Vasc Surg 1998;27:25-31.