Outcomes of endovascular treatment of ruptured abdominal aortic aneurysms

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Introduction: **The successful application of endovascular techniques for the elective repair of abdominal aortic aneurysms (AAAs) has stimulated a strong interest in their possible use in dealing with a long-standing surgical challenge: the ruptured abdominal aortic aneurysm (RAAA). The use of a conventional open procedure to repair ruptured aneurysms is associated with a high operative mortality of 45% to 50%. In this study, we evaluated the current frequency of endovascular repair of RAAAs in four large states and the impact of this technique on patient outcome.**

Methods: **We examined discharge data sets from 2000 through 2003 from the four states of California, Florida, New Jersey, and New York, whose combined population represents almost a third of the United States population. Proportions and trends were analyzed by χ^2 analysis and continuous variables by the Student's *t* test.**

Results: **We found that since the year 2000, endovascular repair has begun to emerge as a viable treatment option for RAAAs, accounting for the repair of 6.2% of cases in 2003. During the same period, the use of open procedures for RAAAs declined. The overall mortality rate for the 4-year period was significantly lower for endovascular vs open repair (39.3% vs. 47.7%, $P = .005$). Moreover, compared with open repair, endovascular repair resulted in a significantly lower rate of pulmonary, renal, and bleeding complications. Survival after endovascular repair correlated with hospital experience, as assessed by the overall volume of elective and nonelective endovascular procedures. For endovascular repairs, mortality ranged from 45.9% for small volume hospitals to 26% for large volume hospitals ($P = .0011$). Volume was also a determinant of mortality for open repairs, albeit to a much lesser extent (51.5% for small volume hospitals, 44.3% for large volume hospitals; $P < .0001$).**

Conclusion: **We observed a benefit to using endovascular procedures for RAAAs in institutions with significant endovascular experience; however, the analysis of administrative data cannot rule out selection bias as an explanation of better outcomes. These data strongly endorse the need for prospective studies to clarify to what extent the improved survival in RAAA patients is to be attributed to the endovascular approach rather than the selection of low-risk patients.**

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The diffusion of endovascular techniques has proven beneficial to the elective repair of abdominal aortic aneurysms (AAAs), both by reducing operative mortality and by lowering complication rates in patients with an anatomic configuration suitable to this type of surgical repair.[1-3] The successful application of the endovascular approach in the treatment of elective AAA repair has prompted a strong interest about its possible use in dealing with the long-standing challenge of a ruptured AAA (RAAA). Surgery for RAAAs is associated with high operative mortality of approximately 45% to 50% when conventional open repair is performed.[4-6] The high mortality associated with RAAAs has only minimally diminished over the past two decades, despite improved surgical techniques and perioperative care.[4]

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Competition of interest: none.

Additional material for this article may be found online at www.mosby.com/jvs.

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Although the minimally invasive nature of endovascular techniques holds potential advantages for the treatment of RAAAs compared with conventional open repair, their application encounters logistical and practical barriers such as the need for constant availability of an endovascular team, possible delays owing to the need for a preoperative computed tomography scan for the assessment of aortic anatomy, the availability of devices, and the need for a surgeon who has appropriate experience. Several institutions with expertise in endovascular techniques have reported promising results with endovascular repair of RAAAs,[7-13] but a clear understanding is lacking of the overall impact of this technique on mortality and adverse events in general practice. To address this gap, we analyzed the hospital discharge databases from 2000 through 2003 for the four states of California, Florida, New Jersey and New York, whose combined population represents almost a third of the United States population. We examined the rate of adoption of endovascular techniques for the treatment of RAAA and evaluated their impact on in-hospital mortality and other perioperative outcomes.

METHODS

Data sources and study population. Discharge data for patients, who received surgical repair of a RAAA, were extracted from public data sets of California, Florida, New

Jersey, and New York for the years 2000 through 2003. Data sets were obtained from the following state agencies: California's Office of Statewide Health Planning and Development (http://www.oshpd.cahwnet.gov/HQAD/PatientLevel/index.htm); Florida State Agency for Healthcare Administration (http://www.floridahealthstat.com); New Jersey Department of Health and Senior Services (http://www.state.nj.us/opra/index.html); and New York State Health Department, Statewide Planning and Research Cooperative System (http://www.health.state.ny.us/nysdoh/sparcs/sparcs.htm#general). These databases contain clinical, demographic, and payment information associated with each hospital discharge.

We chose state-based data sets from four populous states instead of the available national data sets (ie, National Hospital Discharge Survey and the Nationwide Inpatient Sample) because state-based data sets represent a census of all discharges, whereas the national databases provide statistically derived national estimates. For studying the endovascular treatment of RAAAs, for which the number of "real" observations is small, the reliability of statistical estimates of these national databases would be limited.

Patients were selected by using the International Classification of Diseases, 9th Revision, Clinical Modification (ICD-9-CM) system codes. Patients undergoing repair of a RAAA were identified through a combination of the following ICD-9 diagnosis and procedure codes: 441.3—ruptured abdominal aneurysm (primary and all secondary diagnosis), 39.71 for endovascular repair (primary and all secondary procedures) and 39.52, 39.25, 38.34, 38.44 for open repair (primary and all secondary procedures). The ICD-9 code for endovascular repair was introduced in October 2000; therefore, data for endovascular repair for the year 2000 correspond to a 3-month period. Patients who received both endovascular and open procedures during the same admission were considered separately. Information regarding the day of the procedure in relation to the date of admission was not available for the state of New Jersey.

We assessed the comorbidities (primary and all secondary diagnosis) of diabetes mellitus, hypertension, emphysema, coronary disease, peripheral vascular disease, renal disease, cerebrovascular disease, and disorder of lipid metabolism. Complications included (primary and all secondary diagnosis) cardiac, postoperative stroke, respiratory complications, bleeding, infection, shock, acute renal failure and mesenteric infarction. A list of ICD9 diagnosis codes for comorbidities and complications is provided in Table I (online only). The codes corresponding to acute renal failure (584) and acute vascular insufficiency of intestine (557.0) could include patients who developed these morbidities preoperatively.

Statistical analysis. All statistical analysis was performed with the SAS system software (SAS Institute Inc, Cary, NC). Means were compared with the Student's *t* test, proportions were analyzed by using the χ^2 test, and trends for proportions were analyzed by using the χ^2 test for trends. Statistical significance was expressed as *P* values and

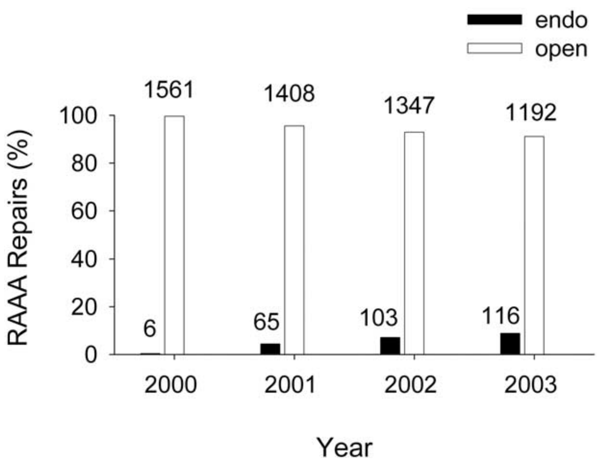

Fig 1. Relative usage of open or endovascular procedures for the treatment of ruptured abdominal aortic aneurysm (RAAA) from the states of California, Florida, New Jersey and New York. Data for endovascular repair for the year 2000 are based only on the last three months of the year 2000.

95% confidence intervals (95% CI). CIs for proportions were calculated using normal approximation to the binomial distribution. Procedure frequencies were analyzed by using Poisson regression methods. We used multivariate logistic regression analysis to determine predictors of mortality. The dichotomous covariates included in the statistical model were procedure (open or endovascular), demographic variables of age (younger or older than 65), sex, and race; and all comorbidities from Table I (online only). Results of the multivariate logistic regression are presented as odds ratios (ORs) with the appropriate 95% CIs.

RESULTS

Case volume and distribution. To evaluate the extent to which endovascular techniques are being adopted for the management of RAAA, we examined the proportion of RAAA cases treated by endovascular surgery in the years 2000 through 2003 and compared this with the number of patients treated with conventional repair during the same time period. The use of endovascular techniques for the repair of RAAAs steadily increased from 0.3% of the cases in 2000 to 6.2% in 2003 (Fig 1). A corresponding decline of conventional repairs occurred during the same time period (from 70.3% of RAAA cases in 2000 to 63.2% in 2003). Overall, there was a progressive 15% reduction in the number of RAAA cases admitted to hospitals during 2000 to 2003, from 2218 cases in 2000 to 1881 cases in 2003.

To understand whether the increasing number of endovascular RAAA repairs was due to a few select programs or was the reflection of more widespread adoption of this procedure, we examined the distribution of endovascular and open repair patients among hospitals. Most RAAA endovascular repairs were performed in hospitals with <5 cases over a 4-year span (Fig 2, *A*). Thus, it does not appear that this technique was restricted to high-volume hospitals.

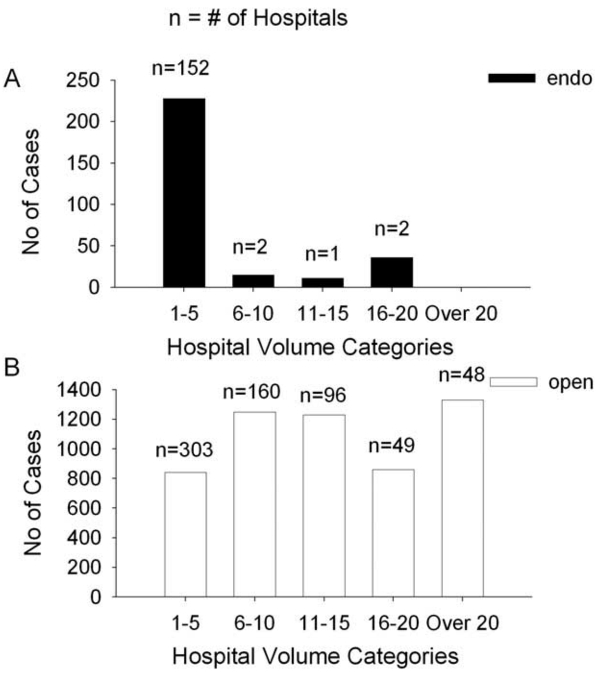

Fig 2. Distribution of endovascular **(A)** and open **(B)** procedures for the repair of ruptured abdominal aortic aneurysm performed during a 4-year period (2000 through 2003) as a function of hospital volume.

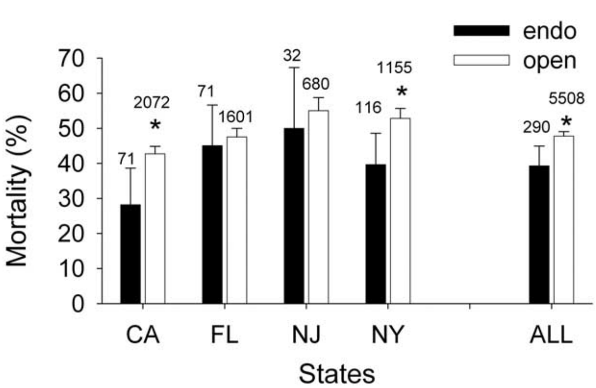

Fig 3. In hospital mortality of ruptured abdominal aortic aneurysm patients who received open or endovascular repair, for each state and for all four states combined over 4 years (2000 through 2003). Actual number of cases and 95% confidence intervals are shown for each bar (*$P < 0.05$).

For conventional repair, we found that procedures were more evenly distributed between high- and low-volume hospitals (Fig 2, *B*).

Mortality and complications. To evaluate mortality, we combined data for the 4-year period from all four states. During this period, a lower mortality was observed for endovascular repair compared with open repair (Fig 3). The advantage of endovascular repair was variable among the states, however. Only in the individual states

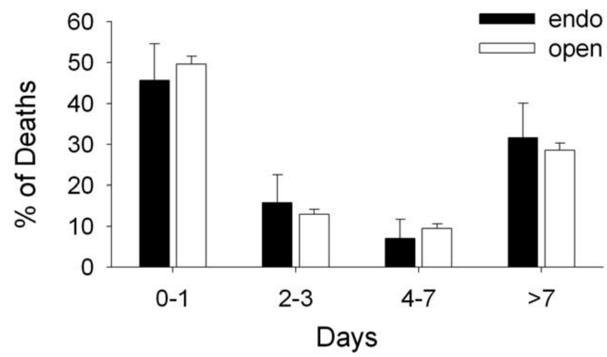

Fig 4. Timing of death occurrence during hospitalization for ruptured abdominal aortic aneurysm in patients receiving either endo or open procedures. Data from each state and for all 4 years (2000 through 2003) were combined. 95% confidence intervals are shown.

of California and New York did the difference between open and endovascular-associated mortality reach statistical significance. When all four states and all 4 years were combined, the overall in-hospital mortality rate was 39.3% for endovascular repair and the mortality rate for open repair was 47.7% (P = .005) (Fig 3). During the 4-year period, 20 patients were found to have received both procedure codes during the same admission, potentially the result of conversion of endovascular repair to an open repair. Surprisingly, the mortality among these conversions was 35%.

The timing of death during the hospital stay revealed a bimodal distribution for both open and endovascular repair: most of the deaths occurred ≤24 hours from time of admission, with a second peak after the first week (Fig 4). To assess for the potential impact of delay in surgical treatment of RAAAs, we compared mortality of patients who had surgery on the same day of admission with the mortality of patients treated at a later time. The percentage of surgeries performed on the same day of admission was 72% for open repairs and 59% for endovascular repairs. For open procedures, mortality was lower when the surgery was performed on the day of admission (45.7% vs 51.7% P = .001). For endovascular repairs, however, we did not observe a significant difference in mortality between procedures performed on the same day of admission and those that were performed later (38.6% vs 33.3% P = .42). We assume that patients who were not immediately treated presented with less acute symptoms and perhaps were more hemodynamically stable; however, it is impossible to determine this from the data sets studied.

We asked whether survival with endovascular or open ruptured AAA repair correlated with overall hospital endovascular or open aneurysm repair volume (both elective and nonelective). An analysis of this relationship suggested a transition point at approximately 100 cases per 4 years (or 25 cases/year). Mortality for endovascular repairs was 45.9% for small volume hospitals (<100 endovascular cases in 4 years) and 26% for large volume hospitals (>100

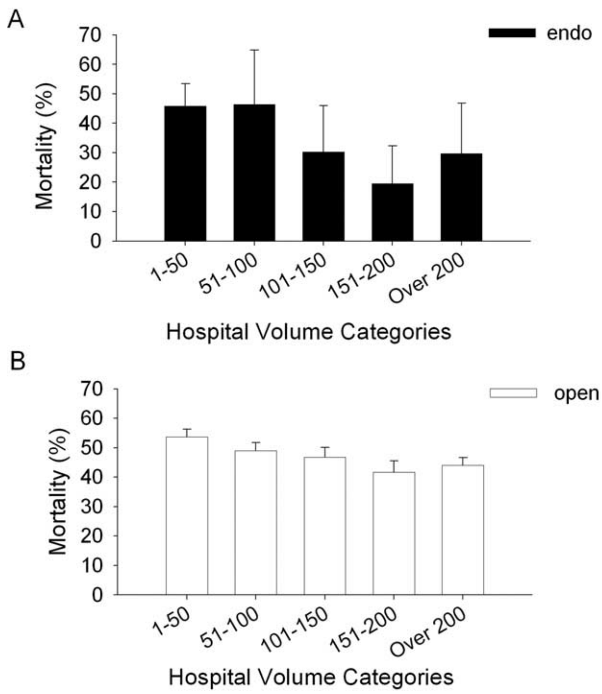

Fig 5. Relationship between mortality of ruptured abdominal aortic aneurysm (RAAA) and hospital volume (elective and non-elective cases from 2000 through 2003) for **(A)** endovascular repair (*P* for trend = .02, or **(B)** open repair (*P* for trend < .0001). Data from each state and for all four years were combined. The number of RAAA cases in each volume category for endovascular repair is: 166 for 1-50; 28 for 51-100; 33 for 101-150; 36 for 151-200; and 27 for >200. The number of RAAA cases in each volume category for open repair is 1410 for 1-50; 1219 for 51-100; 879 for 101-150; 620 for 151-200; and 1380 for >200. Open vs endo $P = .03$. 95% confidence intervals are shown.

endovascular cases in 4 years) ($P = .0011$) (Fig 5, *A*). Mortality for open repairs was 51.5% for small volume hospitals (<100 open repair cases in 4 years) and 44.3% for large volume hospitals (>100 open repair cases in 4 years) ($P < .0001$) (Fig 5, *B*). Thus, increased hospital experience appears to enhance outcome for both procedures.

Table II summarizes the rates of operative complications for the two groups. Compared with endovascular repair, open repair was associated with a significantly higher rate of pulmonary (21.7% vs 32.4%), bleeding (26.2% vs 34.1%), and renal complications (acute renal failure: 14.8% vs 24.8%; urinary: 4.5% vs 8.5%). No statistically significant differences between the two techniques were noted for postoperative infections, shock, postoperative stroke, cardiac, and mesenteric artery complications.

Finally, we observed a decreased death rate associated with endovascular repair compared with open repair, after controlling for demographics and comorbidities in logistic regression analysis (OR, 0.748; 95% CI, 0.579, 0.967; $P = .0264$).

Comorbidities. To assess for potential differences in the baseline characteristics of patients selected to receive

Table II. Rate of complications in patients undergoing endo or open procedures

	Open		*Endo*				
	(%)	*n*	*(%)*	*n*	*OR*	*95% CI*	P
Cardiac	12.7	702	15.2	44	0.82	0.59-1.14	.2289
PO stroke	0.8	45	1.4	4	0.59	0.21-1.65	.3079
Respiratory	32.4	1782	21.7	63	1.72	1.30-2.29	.0002
Bleeding	34.1	1879	26.2	76	1.46	1.12-1.90	.0055
Infection	5.8	321	4.5	13	1.32	0.75-2.32	.3379
Shock	3.4	187	1.4	4	2.51	0.93-6.81	.0609
Mesenteric	5.2	289	6.9	20	0.75	0.47-1.19	.2229
ARF	24.8	1364	14.8	43	1.89	1.36-2.63	.0001
Urinary	8.5	467	4.5	13	1.97	1.12-3.47	.0161

OR, Odds ratio; *CI,* confidence interval; *PO,* postoperative; *ARF,* acute renal failure.

Table III. Percentage of patients with coexisting conditions

	Open		*Endo*				
	(%)	*n*	*(%)*	*n*	*OR*	*95% CI*	P
Diabetes	9.8	539	14.5	42	0.64	0.46-0.90	.0094
Hypertension	49.0	2700	49.7	144	0.97	0.77-1.23	.8329
Emphysema	31.4	1728	24.8	72	1.38	1.05-1.82	.0189
Coronary	23.7	1307	32.8	95	0.64	0.50-0.82	.0005
PVD	9.0	498	11.0	32	0.80	0.55-1.17	.2510
Renal	6.9	381	7.2	21	0.95	0.60-1.50	.8323
Cerebral	3.5	195	4.5	13	0.78	0.44-1.39	.4003
Lipids	5.6	307	11.0	32	0.47	0.32-0.70	.0001
Hypotension	15.9	877	12.4	36	1.34	0.94-1.91	.1099

OR, Odds ratio; *CI,* confidence interval; *PVD,* peripheral vascular disease.

either open or endovascular repairs, we examined the preoperative comorbidities of the two groups of patients. More patients in the endovascular repair group had diabetes mellitus, coronary artery disease, and hyperlipidemia (all differences were statistically significant) (Table III). Conversely, emphysema affected a greater proportion of patients undergoing open repair. There were no differences in age distribution: mean age was 74.9 for endovascular and 74.2 for open procedures ($P = .96$).

Length of stay and discharge status. As anticipated, there was a shorter length of stay for RAAA patients who survived endovascular repair (mean, 13.4 days; 95% CI, 11.2, 15.7) compared with those who survived open repair (mean, 19.0 days; 95% CI, 18.1, 19.9; $P = .003$). The median lengths of stay for the endovascular and open procedures were, respectively, 8.5 and 13.0 days.

The condition of patients at the time of discharge and their general outcome might be at least in part reflected by their disposition. Thus, we examined the dispositions of patients surviving a RAAA repair (Fig 6). Two thirds of the patients who received open repair (63.2%) were transferred to acute or intermediate care facilities, nursing homes, or required additional services at home; whereas, slightly fewer patients (51%) who had endovascular repair were treated in this manner ($P < .05$).

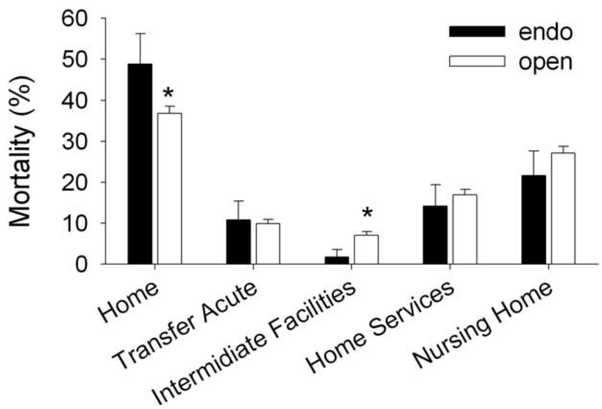

Fig 6. Disposition of patients who survived endovascular or open repair of a ruptured abdominal aortic aneurysm. The frequency of different dispositions, subsequent to hospital discharge, are shown. Data from each state and for all four years were combined (**P* < .05). *Transfer Acute,* transfer to acute care facility. 95% confidence intervals are shown.

DISCUSSION

Over the past decade, in light of marked improvements in perioperative outcomes, the vascular surgical community has increasingly adopted an endovascular approach to the elective repair of AAAs.[1-3,11] The public has embraced this innovation because of its less invasive nature and the consequent avoidance of physiologic or emotional stresses associated with conventional open surgery. The application of endovascular techniques for the treatment of RAAAs has been impeded by several factors, however, including the need for an endovascular surgical team that is available on short notice, immediate access to appropriate imaging facilities, and the need to stock a range of highly expensive endovascular devices so that all variants in aortic anatomy can be urgently treated.[14] There is little doubt that innovations in the treatment of RAAAs would be welcomed, given the high mortality rate of 45% to 50% still associated with current treatment paradigms.[10,15] Indeed, the operative mortality for open repair of RAAAs has undergone only a modest reduction over the past four decades, despite numerous advances in surgical technique and critical care.[4]

In this study, we examined the discharge data sets of four states for the years 2000 through 2003 to assess the diffusion of endovascular treatment of RAAA and its impact on patient outcomes. Our results show that since the year 2000, endovascular repair is progressively, albeit slowly, emerging in the community at large as an alternative modality for the treatment of RAAAs. In 2003, 6.2% of RAAAs were treated with endovascular techniques (Fig 1). Although this number is on the rise, most aneurysms are still treated with conventional surgery.

A common perception is that the use of endovascular techniques for the repair of RAAAs is confined to academic or large-volume centers. Instead, our findings suggest that endovascular repair is being used frequently at low-volume centers. Most of the endovascular repairs of RAAA were performed by hospitals with a volume of <5 endovascular RAAA cases over 4 years combined. Only a handful of institutions applied endovascular techniques to a large number of patients with a RAAA (Fig 2). In fact, 228 of the 290 endovascular repairs we have reported were performed at centers where the utilization of this approach approximated one RAAA patient per year.

Several reports from single institutions that have applied endovascular therapy for the treatment of RAAAs have shown positive outcomes and a general reduction of the in-hospital mortality rate.[9-13,16,17] In agreement with these reports, our study shows that the in-hospital mortality for endovascular repair of RAAA was significantly reduced compared with the in-hospital mortality from open repair (Fig 3), albeit the degree of reduction that we observed was much less significant (only 8.4%) than that reported in these single-institution studies.

It should be noted that although a statistically significant reduction in mortality was observed when data from all four states and each of the four years were merged, an individual analysis of each state and each year was less convincing. For example, when New Jersey and Florida were analyzed separately, we were unable to demonstrate a difference between the two techniques. Even in New York and California, differences in outcome were not evident for each of the years, although this in part may be related to the small patient numbers. These findings, however, led us to explore whether the advantage of endovascular repair might be confined to specific settings or conditions.

The occurrence of death over time was almost identical when open or endovascular procedures were compared (Fig 4). This observation suggests that the two types of repair are subject to similar causes of ultimate failure. The bimodal distribution of the timing of death reflects the initial risk of succumbing to hypovolemic shock and then the subsequent, eventually lethal, complications of respiratory and multisystem organ failure. We found that the decrease in mortality observed for endovascular repair of RAAAs strongly correlated with the experience of the institution, as assessed by the volume of both elective and nonelective endovascular repair (Fig 5). An inverse relation between hospital volume and surgical mortality for selected procedures has been previously reported.[18,19] The Leapfrog group, a nonprofit organization advocating for patient safety and quality in healthcare, has encouraged patients and payers to select hospitals that meet minimal standards of volume for certain high-risk procedures, including AAA repair. The current recommendation for AAA repair is 30 cases per year.[20] Our results show that this volume-outcome relationship is particularly striking when an endovascular approach is used.

In addition to the improved mortality associated with endovascular repair of RAAAs, we observed a general amelioration of perioperative outcomes, including a significantly lower proportion of respiratory, bleeding, and renal complications, a shorter length of stay, and more patients going home after surgery (Table II, online only, and Fig 6). We also analyzed preoperative comorbidities to determine whether patient cohorts were similar. With the exception of emphysema, the proportion of coexisting conditions affecting the two groups of patients revealed that more patients with diabetes, coronary artery disease, and hyperlipidemia were selected for an endovascular repair (Table III). Evidence for this type of adverse selection for endovascular repair has been previously reported.[2]

It should be considered that the improvement in outcome observed for endovascular patients could be due to a selection bias in which hemodynamically stable patients or those with more favorable anatomy were chosen to undergo endovascular procedures. In effect, diffusion of endovascular repair of RAAAs is still in its earliest phase; therefore, it is conceivable that providers who have chosen to become "early adopters" of the endovascular approach select patients based upon circumstances favoring this procedure. Moreover, institutions that perform large numbers of endovascular RAAA repairs may accomplish this through referral from other institutions. Obviously, such referrals would require that these patients be hemodynamically stable.

Unfortunately, administrative data sets do not provide information relative to the hemodynamic stability at the time of admission of patients presenting with a RAAA. Nor do they provide information about aneurysm anatomy. Thus, the possibility of patient selection must be kept in mind when our findings, as well as those from institutional series, are being analyzed. Further studies with a prospective design would be required to scrupulously determine the role of patient selection in the improvement of mortality after the application of endovascular techniques to RAAA.

Several limitations should be taken into account before drawing conclusions from research studies based on these administrative data sets: (1) errors in coding and incomplete documentation may reduce the quality of the information, (2) assessment of risk factors and, therefore, comparisons that require risk factor-adjustment, as mentioned, are limited by the lack of detailed records about the severity of illness, and (3) lack of access to patient identifiers impedes the conduct of longitudinal analysis. Despite these weaknesses, administrative data sets have been demonstrated to be a valid tool for outcomes research purposes.[21,22] In particular, major procedures performed in the operating room tend to be coded more accurately and completely in administrative data than other types of intervention.[23]

CONCLUSIONS

Our findings show (1) a trend of increasing utilization of the endovascular repair for RAAAs and a corresponding decline in the use of open procedures, and (2) a significant reduction in mortality and complication rates for patients receiving endovascular repair that correlates with the volume of procedures carried out by a hospital. These results encourage further diffusion and application of endovascular procedures for the repair of RAAAs.

Our data do suggest, however, that significant endovascular experience is necessary when treating these patients and, perhaps, this approach should be limited to centers with high endovascular volume. Unfortunately, patients do not always have the opportunity to select the hospital to which they present, particularly when they are being transported with a RAAA. As endovascular techniques are more broadly applied, however, the number of hospitals with expertise will continue to increase. Although the risks and benefits of aortic endografts over the long term are still to be elucidated, the excessive mortality rate of conventional RAAA repair mandates the exploration of alternative strategies with better prospects for survival.

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AUTHOR CONTRIBUTIONS

Conception and design: G.G, P.A, A.G, A.M, C.K
Analysis and interpretation: G.G, N.E, R.N, P.A, A.G, A.M, R.A, J.M, N.M, C.K
Data collection: N.E
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Critical revision of the article: G.G, N.E, R.N, P.A, A.G, A.M, R.A, J.M, N.M, C.K
Final approval of the article: G.G, N.E, R.N, P.A, A.G, A.M, R.A, J.M, N.M, C.K
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REFERENCES

1. Akkersdijk GJ, Prinssen M, Blankensteijn JD. The impact of endovascular treatment on in-hospital mortality following non-ruptured AAA repair over a decade: a population based study of 16,446 patients. Eur J Vasc Endovasc Surg 2004;28:41-6.
2. Anderson PL, Arons RR, Moskowitz AJ, Gelijns A, Magnell C, Faries PL, et al. A statewide experience with endovascular abdominal aortic aneurysm repair: rapid diffusion with excellent early results. J Vasc Surg 2004;39:10-9.
3. Prinssen M, Verhoeven EL, Buth J, Cuypers PW, van Sambeek MR, Balm R, et al. A randomized trial comparing conventional and endovascular repair of abdominal aortic aneurysms. N Engl J Med 2004;351: 1607-18.
4. Bown MJ, Sutton AJ, Bell PR, Sayers RD. A meta-analysis of 50 years of ruptured abdominal aortic aneurysm repair. Br J Surg 2002;89:714-30.
5. Davidovic L, Markovic M, Kostic D, Cinara I, Markovic D, Maksimovic Z, et al. Ruptured abdominal aortic aneurysms: factors influencing early survival. Ann Vasc Surg 2005.
6. Korhonen SJ, Ylonen K, Biancari F, Heikkinen M, Salenius JP, Lepantalo M, Finnvasc Study Group. Glasgow Aneurysm Score as a predictor of immediate outcome after surgery for ruptured abdominal aortic aneurysm. Br J Surg 2004;91:1449-52.
7. Alsac JM, Desgranges P, Kobeiter H, Becquemin JP. Emergency endovascular repair for ruptured abdominal aortic aneurysms: feasibility and comparison of early results with conventional open repair. Eur J Vasc Endovasc Surg 2005;30:632-9.
8. Hechelhammer L, Lachat ML, Wildermuth S, Bettex D, Mayer D, et al. Midterm outcome of endovascular repair of ruptured abdominal aortic aneurysms. J Vasc Surg 2005;41:752-7.
9. Kapma MR, Verhoeven EL, Tielliu IF, Zeebregts CJ, Prins TR, Van der Heij B, et al. Endovascular treatment of acute abdominal aortic aneu-

rysm with a bifurcated stentgraft. Eur J Vasc Endovasc Surg 2005;29:510-5.
10. Lee WA, Hirneise CM, Tayyarah M, Huber TS, Seeger JM. Impact of endovascular repair on early outcomes of ruptured abdominal aortic aneurysms. J Vasc Surg 2004;40:211-5.
11. Ohki T, Veith FJ. Endovascular grafts and other image-guided catheter-based adjuncts to improve the treatment of ruptured aortoiliac aneurysms. Ann Surg 2000;232:466-79.
12. Ohki T, Veith FJ, Sanchez LA, Cynamon J, Lipsitz EC, Wain RA, et al. Endovascular graft repair of ruptured aortoiliac aneurysms. J Am Coll Surg 1999;189:102-12; discussion, 112-3.
13. Veith FJ, Ohki T, Lipsitz EC, Suggs WD, Cynamon J. Endovascular grafts and other catheter-directed techniques in the management of ruptured abdominal aortic aneurysms. Semin Vasc Surg 2003;16:326-31.
14. Towne JB. Endovascular treatment of abdominal aortic aneurysms. Am J Surg 2005;189:140-9.
15. Noel AA, Gloviczki P, Cherry KJ Jr, Bower TC, Panneton JM, Mozes GI, et al. Ruptured abdominal aortic aneurysms: the excessive mortality rate of conventional repair. J Vasc Surg 2001;34:41-6.
16. Resch T, Malina M, Lindblad B, Dias NV, Sonesson B, Ivancev K. Endovascular repair of ruptured abdominal aortic aneurysms: logistics and short-term results. J Endovasc Ther 2003;10:440-6.
17. Veith FJ, Ohki T, Lipsitz EC, Suggs WD, Cynamon J. Treatment of ruptured abdominal aneurysms with stent grafts: a new gold standard? Semin Vasc Surg 2003;16:171-5.
18. Birkmeyer JD, Siewers AE, Finlayson EV, Stukel TA, Lucas FL, Batista I, et al. Hospital volume and surgical mortality in the United States. N Engl J Med 2002;346:1128-37.
19. Sollano JA, Gelijns AC, Moskowitz AJ, Heitjan DF, Cullinane S, Saha T, et al. Volume-outcome relationships in cardiovascular operations: New York State, 1990-1995. J Thorac Cardiovasc Surg 1999;117:419-28; discussion, 428-30.
20. Birkmeyer JD, Finlayson EV, Birkmeyer CM. Volume standards for high-risk surgical procedures: potential benefits of the Leapfrog initiative. Surgery 2001;130:415-22.
21. Malenka DJ, McLerran D, Roos N, Fisher ES, Wennberg JE. Using administrative data to describe casemix: a comparison with the medical record. J Clin Epidemiol 1994;47:1027-32.
22. Wennberg JE, Roos N, Sola L, Schori A, Jaffe R. Use of claims data systems to evaluate health care outcomes. Mortality and reoperation following prostatectomy. JAMA 1987;257:933-6.
23. Quan H, Parsons GA, Ghali WA. Validity of procedure codes in International Classification of Diseases, 9th revision, clinical modification administrative data. Med Care 2004;42:801-9.

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Table I (online only). List of International Classification of Diseases, 9th Revision, Clinical Modification (ICD-9-CM) codes for comorbidities and postoperative complications

	ICD9 code	*Description*
Comorbidities		
Diabetes	250	Diabetes mellitus
Hypertension	401	Essential hypertension
	402	Hypertensive heart disease
	403	Hypertensive renal disease
	404	Hypertensive heart and renal disease
	405	Secondary hypertension
Emphysema	490	Bronchitis, not specified as acute or chronic
	491	Chronic bronchitis
	492	Emphysema
	493	Asthma
	494	Bronchiectasis
	496	Chronic airway obstruction, not elsewhere classified
Coronary	413	Angina pectoris
	414	Other forms of chronic ischemic heart disease
	412	Old myocardial infarction
	429.2	Cardiovascular disease, unspecified
Peripheral vascular disease	443.9	Peripheral vascular disease, unspecified
	440	Atherosclerosis
Renal	585	Chronic renal failure
	403	Hypertensive renal disease
	582	Chronic glomerulonephritis with unspecified pathologic lesion in kidney
Cerebral	434	Occlusion of cerebral arteries
	433	Occlusion and stenosis of precerebral arteries
	437	Other and ill-defined cerebrovascular disease
	438	Late effect of cerebrovascular disease
Lipids	272.0	Disorder of lipoid metabolism. Pure hypercholesterolemia
Postoperative complications		
Cardiac	997.1	Cardiac complications. Cardiac arrest during or resulting from a procedure. Cardiac insufficiency during or resulting from a procedure Cardiorespiratory failure during or resulting from a procedure. Heart failure during or resulting from a procedure
Postoperative stroke	997.02	Iatrogenic cerebrovascular infarction or hemorrhage
Respiratory	997.3	Respiratory complications. Mendelson's syndrome resulting from a procedure. Pneumonia (aspiration) resulting from a procedure
	518.5	Pulmonary insufficiency following trauma and surgery. Adult respiratory distress syndrome. Pulmonary insufficiency following: shock, surgery, trauma. Shock lung
Bleeding	285.1	Acute posthemorrhagic anemia. Anemia due to acute blood loss.
	998.1	Hemorrhage or hematoma or seroma complicating a procedure
Infection	998.5	Postoperative infection
	998.59	Other postoperative infection. Abscess: postoperative intra-abdominal postoperative, stitch postoperative, subphrenic postoperative, wound postoperative. Septicemia postoperative
	996.62	Infection and inflammatory reaction due to internal prosthetic device, implant, and graft–due to other vascular device, implant, and graft (arterial graft, arteriovenous fistula or shunt, infusion pump, vascular catheter (arterial) (dialysis) (venous)
Shock	998.0	Postoperative shock. Collapse NOS during or resulting from a surgical procedure. Shock (endotoxic) (hypovolemic) (septic) during or resulting from a surgical procedure
Renal	584	Acute renal failure
	997.5	Urinary complications due to procedure
Mesenteric	557.0	Acute Vascular insufficiency of intestine
	997.71	Vascular complications of mesenteric artery