Survival after ruptured abdominal aortic aneurysm: Effect of patient, surgeon, and hospital factors

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Objective: **The purpose of this study was to determine the effects of patient, surgeon, and hospital factors on survival after repair of ruptured abdominal aortic aneurysm (AAA) and to compare them with risk factors for survival after elective AAA repair. It was hypothesized that patients operated on by high-volume surgeons with subspecialty training would have better outcomes, which might argue for regionalization of AAA surgery.**

Methods: **In this population-based retrospective cohort study, surgeon billing and administrative data were used to identify all patients who had undergone AAA repair between April 1, 1992, and March 31, 2001, in Ontario, Canada. Demographic information was collected for each patient, as well as numerous variables related to the surgeons and hospitals.**

Results: **There were 2601 patients with ruptured AAA repair, with an average 30-day mortality rate of 40.8%. Significant independent predictors of lower survival were older age, female gender, lower patient income quintile, performance of surgery at night or on weekends, repair in larger cities, surgeons with lower annual volume of ruptured AAA operations, and surgeons without vascular or cardiothoracic fellowship training. There were 13,701 patients with elective AAA repair, with an average 30-day mortality rate of 4.5%. Significant independent predictors of lower survival were similar, except gender was not significant, but the Charlson Comorbidity Index was. When the hazard ratios associated with predictive factors were compared, surgeon factors appeared to be more important in ruptured AAA repair, and patient factors appeared more important in elective AAA repair.**

Conclusion: **For elective AAA repair, and even more so for ruptured AAA repair, high-volume surgeons with subspecialty training conferred a significant survival benefit for patients. Although this would seem to argue in favor of regionalization, decisions should await a more complete understanding of the relationship between transfer time, delay in treatment, and outcome. (J Vasc Surg 2004;39:1253-60.)**

Abdominal aortic aneurysm (AAA) is a major cause of morbidity and mortality in the United States, particularly in men older than 55 years.[1] Several studies over the last decade have suggested that the incidence of AAA is increasing.[2-4] Elective treatment of AAA and treatment of ruptured AAA continue to present a significant challenge to surgeons and healthcare planners. Recent studies report a 30-day mortality rate of about 50% after repair of ruptured AAA, and about 5% after elective AAA repair.[3,5-9]

Survival after repair of ruptured AAA depends on a number of patient factors, such as age and comorbid conditions,[3,5-10] and the patient's management within the healthcare system, including accuracy of diagnosis, time from symptoms to surgery, and skill of the surgical team. The age of the patient cannot be changed, and comorbid conditions can be optimized but not eliminated. Regionalization, however, could result in AAAs being treated by high-volume surgeons with more advanced training, in high-volume hospitals.

The potential effect of modifying these surgeon and hospital variables on mortality has not been well studied, although some system factors have been studied individually.[10-15] Previous studies have been relatively small or focused on elective AAA repair,[10,12-19] or did not include patient, surgeon, and hospital factors in the same study.[11-13,15] The purpose of this study was to determine the effect of patient factors, surgeon volume and training, hospital type and volume, time of day of operation, and distance from the patient's home to the treating hospital on mortality after repair of ruptured AAAs and elective repair of AAAs. We used a large population-based data base from Ontario, Canada, and hypothesized that surgical skill and training are more important for repair of ruptured AAAs than for elective AAA repair.

METHODS

The Ontario Health Insurance Plan (OHIP) captures 95% of physician billings in Ontario, and was used to identify patients through the use of billing codes unique to AAAs, namely, R802, R816, and R817. Ruptured AAAs were identified in this data base by a supplemental fee code (E627). Data for all patients who underwent elective repair of an AAA or repair of a ruptured AAA were included. The available data spanned the period from April 1, 1992, to March 31, 2001. Patients were followed up to a maximum of 1 year, with in-hospital deaths captured in the Canadian

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Table I. Comparison between elective AAA repair and ruptured AAA repair, by each variable in the model

Parameter	*Ruptured AAA repair (N = 2601)*	*Elective AAA repair (N = 13,701)*
Patient factors		
Age (y)	71.9 ± 8.9	70.5 ± 7.7
Charlson Comorbidity Index	0.66 ± 1.05	0.62 ± 0.92
Male gender (%)	81.2	81.8
Income quintile	2.81 ± 1.48	2.96 ± 1.44
Distance from patient's home to hospital (km)	34.6 ± 74.6	34.5 ± 74.6
Surgeon factors		
Annual surgeon volume of ruptured AAA repairs	5.8 ± 4.2	4.0 ± 3.9
Annual surgeon volume of elective AAA repairs	21.3 ± 17.6	26.9 ± 18.1
Procedures performed, by surgeon specialty (%)		
General surgeon	21.6	17.5
Cardiothoracic surgeon	18.0	16.2
Vascular surgeon	60.4	66.3
Hospital/process factors		
After-hours repair (weeknight, weekend, holiday) (%)	64.1	7.8
Procedure performed in teaching hospital (%)	45.3	45.4
Population of city where operation performed	280,092 ± 196,606	296,716 ± 206,624
Annual hospital volume of ruptured AAA repairs	10.3 ± 7.7	7.1 ± 7.4
Annual hospital volume of elective AAA repairs	37.2 ± 36.8	50.6 ± 36.8
Year operation performed	1996 (±2.3)	1996 (±2.6)

Values represent mean ± SD.
AAA, Abdominal aortic aneurysm.

Institute for Health Information (CIHI) database and outpatient deaths captured in the census data base. Nonresidents of Ontario who underwent surgery in the province were excluded. Ethics approval was obtained from the institutional review board.

Data sources. Data were obtained from four sources: the CIHI data base, the OHIP data base (physician billings), census data, and the Ontario Physician Human Resources Data Center (OPHRDC) data base, which records information on the training and specialization of all physicians in Ontario. These data sources were linked together with an anonymous unique identifier. Table I) contains a list of all variables considered.

Patient factors. Information on patient age and gender were gathered from census data. Comorbidity was quantified with the Charlson Comorbidity Index,[20] which was calculated on the basis of preoperative comorbid conditions recorded on hospital discharge abstracts and recorded in the CIHI data base.[6] Information on individual patient income was not available. With postal codes and census data, socioeconomic status was determined from the average income in a neighborhood, and this figure was applied to all patients from that neighborhood. The population was then divided into roughly equal quintiles for analysis. The distance between the patient's home and the treating hospital represents a straight line, and was calculated with the longitude and latitude for each location.

Surgeon factors. Annual surgeon volume was calculated by enumerating the number of cases a given surgeon performed each year, which was available through the OHIP data base. The fellowship accreditation status of all physicians in Ontario was recorded in the OPHRDC data base.

Hospital factors. We identified the hospital at which patients underwent surgery, and categorized hospitals according to academic university affiliation (ie, teaching vs nonteaching hospitals). After-hours repairs were defined as operations performed on week nights between 6:00 PM and 7:00 AM, weekends, and holidays, and was determined with a supplemental fee code (E409, E410) in the OHIP database. Using the location of the hospital (from the CIHI database), we were able to use census data to determine the population of the city in which the hospital was located. Annual hospital volume was calculated by enumerating the number of operations performed by a hospital in a given year. The year the operation took place was determined with the date of admission.

Statistical analysis. Elective aneurysm repairs and repairs of ruptured aneurysms were considered separately. Correlation between continuous variables was examined. It was decided a priori that if any two variables were correlated with an $r > 0.70$, only one of those variables would be included in the multivariate models. None of the correlations resulted in $r > 0.70$. Further testing for colinearity with variation inflation factors (which tests for the significant increases in the standard error of parameter estimates that occur when two closely correlated variables are included in the same model) revealed no significant colinearity; thus all variables were entered into the multivariate models. After univariate proportional hazards survival analysis was performed for each variable, a multivariate model was constructed.

Patient, surgeon, and hospital factors independently associated with survival were identified with a proportional hazards multivariate backward selection process. We were able to use this type of analysis because we had time-to-

Table II. Univariate survival analysis for elective AAA repair and ruptured AAA repair

	Ruptured AAA repair		*Elective AAA repair*	
Parameter	*Hazard ratio [95% CI]*	P	*Hazard ratio [95% CI]*	P
Patient factors				
Age (per 5 y)	1.226 [1.191–1.263]	<.0001	1.346 [1.332–1.359]	<.0001
Charlson Comorbidity Index (per increase of 1)	1.106 [1.062–1.152]	<.0001	1.383 [1.348–1.418]	<.0001
Male gender	0.746 [0.664–0.838]	<.0001	0.944 [0.877–1.016]	.12
Income quintile (per increase of 1)	0.946 [0.916–0.977]	.0008	0.945 [0.926–0.964]	<.0001
Distance from patient's home to hospital (km)	0.999 [0.999–1.000]	.09	1.000 [1.000–1.000]	.91
Surgeon factors				
Annual surgeon volume of ruptured AAA repairs (per 5 cases)	0.896 [0.844–0.952]	.0004	1.022 [1.042–1.002]	.28
Annual surgeon volume of elective AAA repairs (per 10 cases)	0.954 [0.927–0.982]	.001	0.995 [0.978–1.013]	.58
Vascular surgeon vs General surgeon	0.804 [0.715–0.904]	.0003	0.956 [0.885–1.032]	.25
Cardiothoracic surgeon vs General surgeons	0.679 [0.581–0.794]	<.0001	0.946 [0.857–1.043]	.26
Cardiothoracic surgeon vs Vascular surgeon	0.834 [0.729–0.954]	.007	0.987 [0.911–1.069]	.75
Hospital/process factors				
After-hours procedures (weeknight, weekend, holiday)	1.155 [1.044–1.278]	.005	1.724 [1.568–1.895]	<.0001
Teaching hospital	0.929 [0.844–1.023]	.13	1.051 [0.992–1.114]	.09
Population of city where operations performed	1.022 [0.996–1.048]	.09	0.998 [0.984–1.012]	.79
Annual hospital volume of ruptured AAA repairs (per 5 cases)	0.939 [0.909–0.971]	.0002	1.013 [1.000–1.024]	.25
Annual hospital volume of elective AAA repairs (per 10 cases)	0.980 [0.966–0.994]	.004	1.010 [1.001–1.019]	.02
Year operations performed	1.024 [1.001–1.047]	.04	1.147 [1.129–1.165]	<.0001

AAA, Abdominal aortic aneurysm; *CI*, confidence interval.

event data; that is, we collected both the date of the procedure and either the date of death or the date of the end of the study for those patients who lived to the end of the study. Proportional hazards survival analysis was used because it has superior power to logistic regression analysis. Unlike logistic regression, proportional hazards survival analysis does not require an arbitrary cut point in the data (eg, 30-day mortality), and it generates hazard ratios, which are analogous to odds ratios. Hazard ratios for variables were compared with a two-tailed z test between elective AAA repair and ruptured AAA repair. For ease of interpretation and to enable comparison with other studies, 30-day mortality was reported. All volume measures (ie, both hospital and surgeon volume of ruptured AAA repairs and elective AAA repairs) were analyzed in our multivariate survival analysis model as continuous variables. For the purposes of reporting data, cut points were selected to define high-volume and low-volume surgeons. These cut points were chosen a priori as the median. Rates were adjusted with multivariate logistic regression, using all variables identified as significant from the survival analysis other than the variable under consideration, modeling survival at 30 days.

All analyses were performed with the SAS statistical package, version 8.2 (SAS Institute, Cary, NC), with an alpha level of 0.05 to determine statistical significance.

RESULTS

Ruptured AAA repair. There were 2601 patients who underwent repair of ruptured AAAs, with a crude 30-day mortality rate of 40.8%. Means and proportions for all variables studied are given in Table I. The median annual surgeon volume of ruptured AAA repairs was five.

The results of univariate analysis and the multivariate Cox proportional hazards survival analysis are summarized in Tables II and III, and the Figure. Hazard ratios greater than 1 indicate decreased survival. Older age, female gender, lower income quintile, lower surgeon volume, and performance of surgery after hours and in larger cities were all associated with decreased survival at multivariate analysis (Table III; Fig). Increased survival was associated with operations performed by surgeons with vascular or cardiothoracic fellowship training. After ruptured AAA repair the only statistically significant independent volume-outcome relationship was between annual surgeon volume of ruptured AAA repairs and mortality. When annual surgeon volume of repair of ruptured AAAs was included in the multivariate model, neither annual hospital volume of elective repair or repair of ruptured AAAs nor annual surgeon volume of elective AAA repairs was significant.

There was a significant association between superior survival and patients operated on by high-volume vascular surgeons compared with those operated on by low-volume general surgeons (Table IV). Lower survival was associated with patient age older than 80 years and Charlson Comorbidity Index greater than 1 who were operated on after hours. However, the crude 30-day mortality in this subgroup of patients (47.6%) was not much higher than for all other patients (40.6%).

Table III. Multivariate survival analysis for elective and ruptured AAA repairs

Parameter	*Ruptured AAA repairs* *Hazard ratio [95% CI]*	P	*Elective AAA repairs* *Hazard ratio [95% CI]*	P	*Comparison* P*
Patient factors					
Age (per 5 y)	1.204 [1.161–1.248]	<.0001	1.360 [1.308–1.415]	<.0001	<.0001
Charlson Comorbidity Index (per increase in 1)	1.032 [0.981–1.085]	.23	1.376 [1.327–1.427]	<.0001	<.0001
Male gender	0.825 [0.717–0.949]	.0071	1.053 [0.913–1.213]	.48	.02
Income quintile (per increase of 1)	0.956 [0.919–0.995]	.03	0.959 [0.923–0.997]	.03	.92
Surgeon factors					
Surgeon volume of elective AAA repairs (per 10 cases)†	—	—	0.910 [0.880–.942]	<.0001	—
Surgeon volume of ruptured AAA repairs (per 5 cases)†	0.869 [0.807–0.936]	.0002	—	—	—
Vascular surgeon vs General surgeon	0.752 [0.651–0.868]	<.0001	0.855 [0.740–0.989]	.03	.22
Cardiothoracic surgeon vs General surgeon	0.699 [0.579–0.843]	.0002	1.033 [0.859–1.244]	.73	.004
Cardiothoracic surgeon vs Vascular surgeon	0.929 [0.787–1.096]	.38	1.209 [1.039–1.407]	.0143	.02
Hospital/process factors					
After hours	1.147 [1.014–1.297]	.03	2.675 [2.314–3.093]	<.0001	<.0001
Population (per 100,000)	1.048 [1.016–1.080]	.003	0.994 [0967–1.022]	.67	.012

AAA, Abdominal aortic aneurysm; *CI*, confidence interval.
**P* values compare magnitude of hazard ratios of variables between elective and ruptured AAA models.
†For ruptured AAA repairs, only surgeon volume was significant; for elective AAA repairs, only surgeon volume was significant. Risk factors not statistically significant for either ruptured or elective AAA repair not included.

Elective AAA repair. A total of 13,701 patients were identified in the data base. The crude 30-day mortality was 4.5%. The median surgeon volume of elective AAA repairs was 24 per year.

The results of univariate analysis and multivariate Cox proportional hazards survival analysis are summarized in Tables II and III, and the Figure. Older age, high Charlson Comorbidity Index, lower patient income quintile, lower surgeon volume, and operations performed after hours were associated with decreased survival. After elective AAA repair the only statistically significant independent volume-outcome relationship was between annual surgeon volume of elective AAA repairs and mortality. When annual surgeon volume of elective AAA repairs was included in the multivariate model, neither annual hospital volume of elective AAA repairs or repair of ruptured AAAs, nor annual surgeon volume of elective AAA repairs was significant.

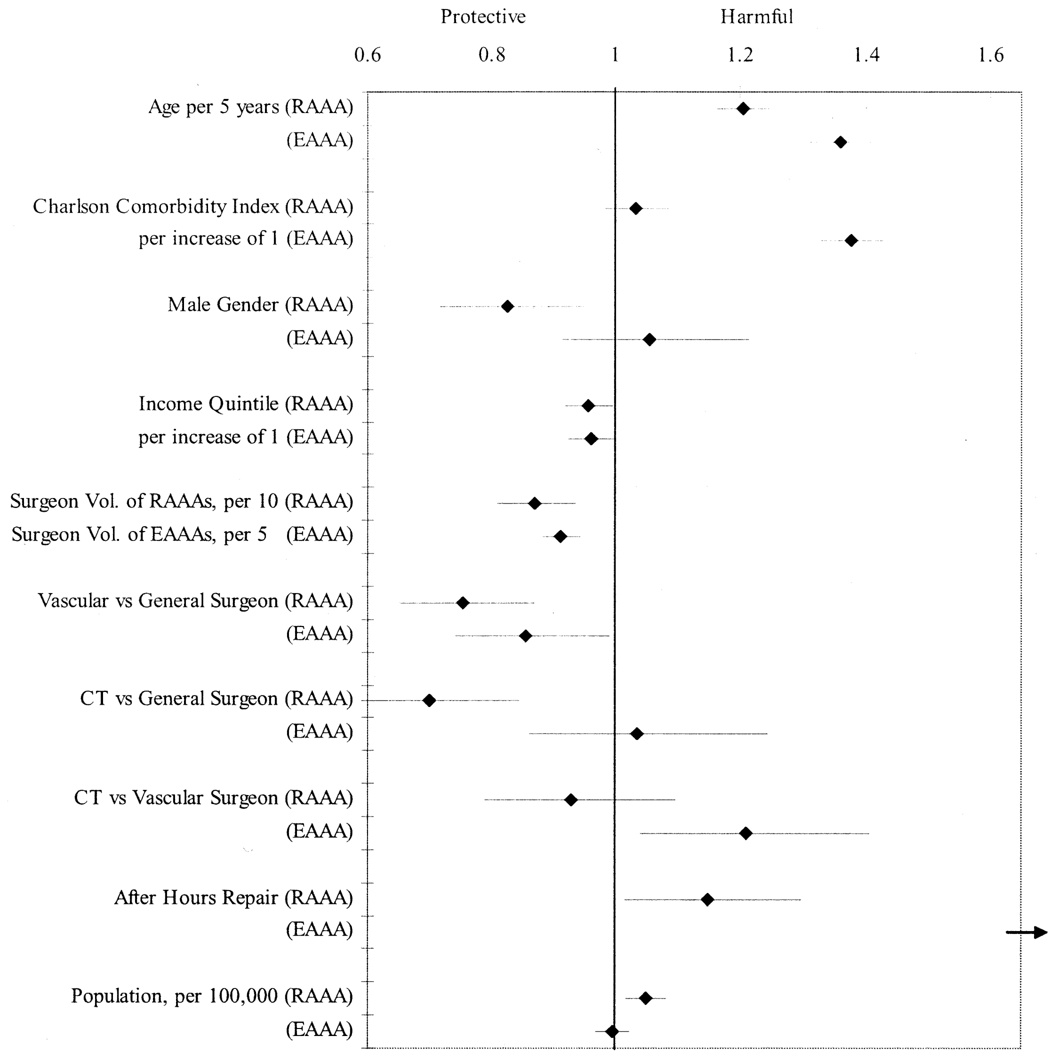
Patients operated on by surgeons with vascular surgery training had a modestly higher survival rate. High-volume vascular surgeons had significantly superior results compared with low-volume general surgeons (Table IV).

The hazard ratios for patient factors such as age, Charlson Comorbidity Index, and male gender were all statistically significantly greater for patients undergoing elective AAA repair compared with ruptured AAA repair (Table III). Statistical comparison of surgeon volume was not possible, because for patients undergoing repair of ruptured AAAs only surgeon volume of ruptured AAA repairs was significant, whereas for elective AAA repairs only surgeon volume of elective AAA repairs was significant. There was a statistically nonsignificant trend toward surgeon training having a greater effect on patients undergoing ruptured AAA repair compared with elective AAA repair.

DISCUSSION

We found that patient, surgeon, and hospital factors were independently associated with survival after AAA repair, although their importance appeared to vary depending on whether the surgery was elective or for a ruptured AAA. The only factors that were not associated with survival were hospital teaching status, hospital volume of elective or ruptured AAA repairs, and distance from the patient's home to the hospital.

In terms of patient risk factors for mortality, increasing age and Charlson Comorbidity Index were statistically significantly more important in patients undergoing elective AAA repair than in those undergoing surgery to repair a ruptured AAA (Table III). Indeed, the Charlson Comorbidity Index was not associated with survival after ruptured AAA repair, which may be because patients with a significant burden of comorbid disease died before they reached the hospital. Despite universal coverage of hospital and physician care in Canada, patients in lower income quintiles had lower survival after repair of both ruptured and unruptured AAAs. An effect of income on survival has been shown before in Canada,[21,22] and may be due to a combination of an increase in unmeasured risk factors in patients of lower socioeconomic status and different postoperative care among income quintiles. We found that men undergoing repair of a ruptured AAA were more likely to survive than women were, but there was no gender effect for elective AAA repair (Table III). There is disagreement in the literature regarding the effect of gender on survival after surgery to repair a ruptured AAA.[23-26] Whether this represents gender bias in the diagnosis and treatment of the disease or is due to another mechanism is unclear.



Hazard ratios *(diamonds)* and 95% confidence intervals for multivariate survival analysis for elective and ruptured abdominal aortic aneurysms.

With regard to hospital factors, the size of the city in which the operating hospital was located did not effect mortality after elective surgery, but patients with ruptured AAAs who were operated on in larger cities had a lower survival rate than those operated on in smaller cities (Table III). The reason for this association cannot be determined without more detailed information about the effect of city size on referral patterns, interhospital transfers, time between onset of symptoms and arrival at the hospital, and deaths outside of hospital. After-hours repair resulted in an increase in mortality after both elective and ruptured AAA repair, although the effect was much larger for elective surgery. This finding for ruptured AAAs is similar to previous work,[12] although our study contained more covariates, and the definition of after-hours repair was more comprehensive than in the previous study. This effect may be related to staff fatigue, suboptimal staffing patterns, and longer delay to access the operating room. However, it seems unreasonable to attribute the large effect of after-hours repair in elective surgery (12.9% 30-day mortality, compared with 3.7%) solely to these factors. The relatively small proportion of elective operations performed after hours were probably more likely to have been urgent or involved symptomatic AAAs, which are associated with a higher mortality risk than are asymptomatic AAAs.

Patients of surgeons with higher annual volume were more likely to survive after surgery, for both elective and ruptured AAA repairs. This volume-outcome relationship has been shown before for elective AAA repair[15] and many other surgeries.[27-33] Whether surgeons who have higher annual volume become better surgeons and therefore produce superior outcomes or better surgeons with superior

Table IV. Crude and adjusted mortality after AAA repair, by selected variables

Parameter	Ruptured AAA repair		Elective AAA repair	
	Crude 30-d mortality (%)	*Adjusted 30-d mortality* (%)*	*Crude 30-d mortality (%)*	*Adjusted 30-d mortality* (%)*
Business hours	37.2	38.3	3.6	3.7
After hours	42.7	45.3	14.6	12.9
Low-volume surgeon†	45.1	45.4	5.4	5.3
High-volume surgeon‡	36.7	40.1	3.6	3.7
General surgeons	51.2	48.3	5.2	4.6
Cardiothoracic surgeons	35.1	38.6	4.6	4.9
Vascular surgeons	38.5	42.1	4.3	4.2
Low volume and training in general surgery†	52.7	53.3	5.8	5.8
High volume and training in vascular surgery‡	35.2	40.5	3.5	3.5
Patients older than 80 years, Charlson Comorbidity Index >1, and after hours	47.6	50.6	—	—
All others	40.6	42.7	—	—

AAA, abdominal aortic aneurysm.
*Adjusted for all other significant variables.
†Low volume for elective repairs, less than median of 24; for ruptured repairs, less than median of 5.
‡High volume for elective repairs, median of 24 or greater; for ruptured repairs, median of 5 or greater.

outcomes garner more referrals and thus become high-volume surgeons remains unclear.

Vascular surgeons had better outcomes than general surgeons. For ruptured AAAs, the patients of high-volume surgeons trained in vascular surgery had an adjusted 30-day mortality rate of 40.5%, compared with 43.9% for all other surgeons, for an absolute risk difference of 3.4%. In our study 1667 ruptured AAAs were repaired by surgeons who were not high-volume vascular surgeons. We could speculate that, had all of these patients been operated on by high-volume vascular surgeons, 57 deaths might have been prevented over the study period. Although the absolute difference in adjusted 30-day survival between high-volume vascular surgeons (3.5%) and all other surgeons (5.0%) was smaller for elective repairs, the number of elective operations is much greater than the number of ruptured AAA repairs. There were 8675 patients who underwent elective AAA repair by surgeons who were not high-volume vascular surgeons. If all patients had undergone surgery by high-volume vascular surgeons, 130 lives might have been saved over the study period.

The association between surgeon volume and specialty with mortality suggests that there may be a benefit to regionalizing repair of AAAs to high-volume vascular surgeons. However, an important caveat is that for patients with a ruptured AAA regionalization may cause an increased length of time between the onset of symptoms and surgery as patients are transferred from one hospital to another. Although distance to the hospital was not a significant predictor of survival in our study, the exact nature of the effect of delay in treatment on survival has not been fully elucidated.[15,34-38] The reason distance to hospital did not affect survival is difficult to determine. Among those who lived farther from the hospital there may be a balance between presumably lower survival due to longer delays, and perhaps higher survival due to a greater percentage of patients who died out of hospital and thus only the healthiest patients arrived at emergency rooms. Informed policy decisions about regionalization cannot be made until the magnitude of this penalty is compared with the benefit of being operated on by high-volume vascular surgeons. As well, patients may value having surgery closer to home, which may negate the small survival advantage for elective AAA repair.

To determine whether there are patients with a ruptured AAA in whom surgery should not be offered because of an extremely high mortality rate, we studied those patients older than 80 years, had a Charlson Comorbidity Index greater than 1, and were operated on after hours. The 30-day survival rate was 52.4% (Table IV). Therefore, solely on the basis of administrative data, like other studies,[25,27,28] we were unable to identify a group of patients who will not benefit from repair of a ruptured AAA.[37,39] It should be noted that a study that included data on preoperative cardiac arrest and blood pressure at presentation had more success in identifying patients whose chance of survival approached zero.[40]

The limitations of this study must be acknowledged. A formal validation study has not been performed for the use of these administrative data to study vascular surgery outcomes. This was a retrospective study using administrative data bases, and thus information about many important clinical parameters, such as delay in treatment, blood pressure at presentation, and aneurysm anatomy, was not available. However, age and Charlson Comorbidity Index were used as measures of patient comorbidity, and have been shown to be valid measures of comorbidity in other studies.[6,20] Patients with ruptured AAAs who died before surgery did not appear in the data base, and thus this study could not address the potential effect of changes to prehospital care on survival of patients with ruptured AAAs. Income quintile was assigned to patients ecologically, that is, on the basis of neighborhood average, and thus some were inevitably misclassified. However, this approach to measuring socioeconomic status with administrative data bases has been frequently used and is valid.[41-44] Because multiple analyses were performed, some associations may have occurred by chance. However, we have reported all variables that were examined in this study, and the sample size was large.

We believe that the strengths of this study outweigh its limitations. The data base was large and population-based, containing information on all patients undergoing AAA repair in Ontario during the study period. We evaluated the independent association of patient, surgeon, and hospital factors on survival after AAA repair. Each type of factor was important. The effects of surgeon volume and specialty on survival support the concept of regionalization, but further research is required to determine the length of delays that would be caused by transferring patients, and the magnitude of the effect of these delays on survival.

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