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J Vasc Surg. Author manuscript; available in PMC 2017 February 17.

Published in final edited form as:
J Vasc Surg. 2011 November ; 54(5): 1273–1282. doi:10.1016/j.jvs.2011.04.054.

Results of endovascular aortic aneurysm repair with general, regional, and local/monitored anesthesia care in the American College of Surgeons National Surgical Quality Improvement Program database

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Abstract

Background—This study examined outcomes of endovascular repair of infrarenal abdominal aortic aneurysms (EVAR) using general, spinal, epidural, and local/monitored anesthesia care (MAC) in a multicenter North American hospital database reflecting contemporary anesthesia and surgical practices.

Methods—Elective EVAR cases performed between 2005 and 2008 were identified from the American College of Surgeons National Surgical Quality Improvement Program database using Current Procedural Terminology codes. Excluded were emergency cases and patients with concomitant procedures requiring general anesthesia. Patient-level comorbidities, characteristics,

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Competition of interest: none.

Presented at the 2010 Annual Meeting of the American Society of Anesthesiologists, San Diego, Calif, Oct 16–20, 2010.

AUTHOR CONTRIBUTIONS
Conception and design: ME, AE, MC, PG
Analysis and interpretation: ME, JS, RG, MC, PG, CG,KH
Data collection: Not applicable
Writing the article: ME, JS, AE, RG
Critical revision of the article: ME, JS, AE, RG, MC, PG, CG, KH
Final approval of the article: ME, JS, AE, RG, MC, PG, CG, KH
Statistical analysis: JS
Obtained funding: Not applicable
Overall responsibility: ME

and intraoperative and postoperative details were examined. Complications were analyzed individually and in aggregate categories, including wound, pulmonary, renal, venous thromboembolic, cardiovascular, operative, and septic. Length of stay (LOS) and 30-day mortality were examined. Characteristics and outcomes were described using mean ± standard deviation or count (%), and comparisons were evaluated for statistical significance using χ^2, Fisher exact test, and univariate linear regression. LOS was analyzed with linear regression techniques using a log transformation. Associations between anesthesia type and outcomes were examined using univariable and multivariable regression techniques.

Results—We identified 6009 elective EVAR procedures for analysis. General anesthesia was used in 4868 cases, spinal anesthesia in 419, epidural anesthesia in 331, and local/MAC in 391. Defined morbidity occurred in 11% of patients. Median LOS was 2 (interquartile range, 1–3) days, and mean LOS was 2.8 ± 4.3 days. The 30-day mortality rate was 1.1%. Significant multivariate associations were observed between anesthesia type, pulmonary morbidity, and log-LOS. General anesthesia was associated with an increase in pulmonary morbidity vs spinal (odds ratio [OR], 4.0; 95% confidence interval [CI], 1.3–12.5; $P = .020$) and local/MAC anesthesia (OR, 2.6; 95% CI, 1.0–6.4; $P = .041$). Use of general anesthesia was associated with a 10% increase in LOS for general vs spinal anesthesia (95% CI, 4.8%–15.5%; $P = .001$) and a 20% increase for general vs local/MAC anesthesia (95% CI, 14.1%–26.2%; $P < .001$). Trends toward increased pulmonary morbidity and LOS were not observed for general vs epidural anesthesia. No significant association between anesthesia type and mortality was observed.

Conclusions—In contemporary North American anesthetic and surgical practice, general anesthesia for EVAR was associated with increased postoperative LOS and pulmonary morbidity compared with spinal and local/MAC anesthesia. These data suggest that increasing the use of less-invasive anesthetic techniques may limit postoperative complications and decrease the overall costs of EVAR.

Endovascular repair of abdominal aortic aneurysms (EVAR) was introduced in 1990 with the goal of offering a lower-risk alternative to traditional open surgical repair.[1] Over time, EVAR has been proven to reduce certain classes of morbidity and hospital length of stay (LOS), with conflicting results regarding reductions in early-term and long-term mortality rates.[2,3] Significant rates of cardiac, renal, wound-related, and pulmonary morbidity still occur with EVAR due to the relatively high-risk population inherent with aneurysmal disease of the aorta.[4] Surgical teams interested in minimizing these complications have sought to capitalize on the less-invasive nature of EVAR and limit perioperative morbidity in several ways, including the use of alternative anesthesia strategies.

Various anesthetic techniques can be applied to successfully accomplish EVAR, including general anesthesia, regional anesthesia (including epidural and spinal anesthesia), and local anesthesia, with or without monitored anesthesia care (MAC).[5,6] Single-center and multicenter reports have examined the results with these various anesthetic techniques for EVAR, with varying results.[7–11] This study examined the results of various anesthetic techniques for EVAR in contemporary North American anesthetic and surgical practice by using a large, multicenter data source, the American College of Surgeons National Surgical Quality Improvement (ACS NSQIP) database.

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METHODS

Data source

The ACS NSQIP is a validated, prospective database derived from a systematic sampling of cases at 211 participating hospitals throughout North America. Available data include patient demographics, medical risk factors, and detailed information regarding procedural specifics and postoperative morbidity and mortality. All data are collected at participating sites by trained research nurses. Definitions for the variables collected in the NSQIP database have been described in previous reports.[12–14]

Study sample

Elective EVAR procedures performed between January 2005 and December 2008 were identified by querying the ACS NSQIP for cases with the use of Current Procedural Terminology (CPT) codes (American Medical Association, Chicago, Ill) for the deployment of the main body of an endovascular aortic stent graft (CPT codes 34800, 34802, 34803, 34804, 34805). The study excluded cases coded as emergencies with *International Classification of Disease, 9th Edition* code 441.3, which designates a ruptured abdominal aortic aneurysm, cases including codes for intraoperative open surgical conversion (CPT codes 34830–34832), cases involving an iliac artery exposure or conduit creation (CPT codes 34820 and 34833), and cases involving concomitant operative procedures requiring general anesthesia. This was done to minimize biases introduced from the analysis of cases in which anesthetic choices were limited or crossovers occurred between anesthetic techniques, or both. This sampling strategy resulted in the identification of 6009 elective EVAR cases for analysis.

Demographics and medical risk factors

All demographic and medical risk factor data were extracted directly from the ACS NSQIP database. Race was considered as white or nonwhite (including Hispanic, Asian, Native American, and black).

Age was considered as a continuous variable for the purpose of this analysis. The ACS NSQIP public-use file database contains a numeric age in years for all records but codes all individuals aged >90 years as 90 years to prevent the potential identification of individual patients during analysis. In the study sample for this analysis, 110 of 6009 patients (1.8%) were coded as having an age of 90 years.

American Society of Anesthesiology (ASA) classes were considered as ASA category 1, 2, and 3 compared with ASA classes 4 and 5 in the multivariable models owing to the relative paucity of patients in ASA classes 1, 2, and 5.

The estimated glomerular filtration rate (eGFR) was used to assess renal function and was calculated using the abbreviated Modification of Diet in Renal Disease formula.[15] Body mass index (BMI) was calculated using weight and height data (kg/m^2). Operative time was defined in the NSQIP data as the total operation time in minutes.

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Anesthesia type

Data regarding the type of anesthetic was extracted from the ACS NSQIP for all identified elective EVAR cases. Anesthesia type was designated in the ACS NSQIP database as general, epidural, spinal, local, MAC, and other. All cases designated as “local” or “MAC” were combined (local/MAC) because some form of local analgesia is required for the EVAR procedure even in the presence of centrally acting sedative and dissociative agents. This analysis excluded 15 cases coded as “other,” one coded as “none,” and 36 coded as “regional.”

End points

Three major outcomes were analyzed for the purposes of this investigation: morbidity, mortality, and length of stay. Postoperative complications (morbidity) were analyzed individually, and in aggregate categories, including:

- wound: superficial or deep surgical site infections;
- pulmonary: pneumonia, reintubation, or failure to wean from ventilator ≤48 hours from the end time of the surgical procedure;
- renal: postoperative renal function decline or need for dialysis;
- venous thromboembolic: deep vein thrombosis or pulmonary embolism;
- cardiovascular: myocardial infarction, cardiac arrest, or stroke;
- operative: return to operating room, postoperative bleeding, or graft failure; and
- septic: sepsis and septic shock.

Postoperative mortality was defined as death ≤30 days or during the same acute-care hospital stay, regardless of time. LOS was defined as the time from the EVAR procedure to hospital discharge or death.

Statistical analysis

Preoperative characteristics, medical risk factors, and procedural data were compared using univariate techniques, including χ^2 or Fisher exact tests for categoric variables and univariate linear regression or Kruskal-Wallis tests for continuous variables. Characteristics are described using mean ± standard deviation or count (%).

Morbidity and mortality associations were examined using logistic regression. LOS was log-transformed before analysis with linear regression to satisfy normality assumptions. Pairwise LOS comparisons were back-transformed for presentation as percent differences.

All multivariable analyses were adjusted for age, race, sex, current smoking status, and total work relative value units of the component CPT codes defining the surgical procedure (to account for overall procedural complexity). Additional covariates were included in the analyses of each of the grouped morbidity classes as well as mortality. Covariates for the multivariable analyses were selected according to previous full-sample analyses of the ACS NSQIP by the central ACS NSQIP statistical faculty (which are available to each participating site) examining predictors of the morbidity classes detailed above and mortality in vascular surgery patients. The selected covariates for each analysis are detailed in the tabulated results that follow in this report. All analyses were performed using SAS 9.2 software (SAS Institute, Cary, NC).

RESULTS

Study sample characteristics

Demographic and risk factor data are summarized in Table I. We identified 6009 elective EVAR cases. Types of anesthesia administered were general in 4868 cases (81%), spinal in 419 (7%), epidural in 331 (5.5%), and local/MAC in 391 (6.5%). The study sample consisted of 5027 men (84%) and 982 women (16%), with a mean age of 74 years. Most patients (85%) were white.

Patient characteristics varied according to anesthesia type (Table I). Significant differences were observed according to anesthesia type received in age, race, prior history of myocardial infarction, prior history of percutaneous coronary revascularization, BMI, ASA class, and current smoking. The mean values and prevalence of these factors are summarized in Table I. Otherwise, comorbidities and risk factors were generally similar between the anesthesia groups.

Procedural specifics

Procedural specifics are summarized in Table II. The mean operative time for the study sample was 158 minutes, with the surgeon designated as a vascular surgeon in 98% of cases. A surgical resident was involved in 64% of cases. The mean transfusion requirement was 2.3 units in the 11% of patients who required a transfusion. Most cases used femoral artery access through a groin incision.

Procedural specifics varied according to anesthesia type (Table II). Significant differences were observed according to anesthesia type received in operative time, surgeon speciality, involvement of a surgical resident, and the need for transfusion.

Associations with morbidity, mortality, and LOS

Overall, defined morbidity occurred in 11% of patients, median LOS was 2 days (interquartile range, 1–3 days), and mean LOS was 2.8 ± 4.3 days. The 30-day mortality rate was 1.1%.

Rates of predefined end points are summarized in Table III. Significant univariable differences were observed in morbidity and LOS according to anesthesia type (Table IV). Univariable associations were observed between general anesthesia and an increase in any morbidity vs local/MAC ($P = .018$), pulmonary morbidity vs spinal ($P = .010$) and vs local/MAC ($P = .042$), and longer log-LOS vs spinal ($P < .001$) and vs local/MAC ($P < .001$).

Multivariable analyses of morbidity, mortality, and LOS are summarized in Table IV. Significant multivariable differences were observed in morbidity and LOS according to anesthesia type. Use of general anesthesia was associated with a significant increase in

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pulmonary morbidity compared with spinal (odds ratio [OR], 4.0; 95% confidence interval [CI], 1.3–12.5; $P = .020$) and local/MAC anesthesia (OR, 2.6; 95% CI, 1.0–6.4; $P = .041$). Other significant predictors of increased pulmonary morbidity included current smoking, lower eGFR, ASA class 4 or 5, partial or total functional dependence, chronic obstructive pulmonary disease (COPD), and the volume of any necessary transfusion. Complete multivariable model results for pulmonary morbidity are presented in Table V (Hosmer-Lemeshow goodness of fit; $P > .05$).

Use of general anesthesia was also significantly associated with a prolonged LOS, with a 10% increase for general anesthesia compared with spinal (95% CI, 4.8%–15.5%; $P = .001$) and a 20% increase for general anesthesia compared with local/MAC (95% CI, 14.1%–26.2%; $P < .001$). Other significant predictors of increased LOS included age, female sex, nonwhite race, ASA class 4 or 5, percutaneous femoral artery access, decreased eGFR, any level of functional dependence other than independence; a history of congestive heart failure, COPD, angina, or diabetes; increased volume of necessary transfusion, and operative time. Complete multivariable model results for LOS are presented in Table VI.

Significant differences relative to general anesthesia were not observed for epidural anesthesia use with regard to decreased pulmonary morbidity or LOS.

DISCUSSION

The anesthetic techniques used during EVAR varied widely across North America, with general anesthesia being the most common, by a large margin. Although this was an observational study, the data presented suggest significant advantages to the use of spinal and local/MAC anesthesia compared with general anesthesia in the performance of elective EVAR. In the examined sample of 6009 elective EVAR cases from 211 North American hospitals from 2005 to 2008, the use of general anesthesia was associated with higher postoperative pulmonary complications and LOS than spinal and local/MAC anesthesia, even when adjusting for other important patient characteristics.

EVAR was developed as a less-invasive and potentially safer alternative to traditional open surgical repair for aortic aneurysms.[1] The most common surgical method for introduction of the EVAR device is a groin incision, and no aortic cross-clamping is required. As such, the procedure lends itself to local and regional anesthesia techniques in a way that open aneurysm repair does not. However, surgical teams have yet to discern in which patients this advantage can be most effectively used. Early reports from the investigational and European use of EVAR demonstrated the feasibility of nongeneral anesthesia and suggested locoregional anesthesia might have benefits.

The first report describing the feasibility of local anesthesia for EVAR was published by Henretta et al[6] in 1999. That report detailed no deaths or significant morbidity in a series of 47 consecutive patients. Also in 1999, Cao et al[5] reported results in 115 patients undergoing EVAR, with 61 receiving epidural anesthesia. Epidural anesthesia was associated with a reduction in the total hospital LOS and a lower utilization of the intensive care unit (ICU) compared with general anesthesia.

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The era of widespread American use of EVAR began in 1999 after U.S. Food and Drug Administration (FDA) approval of the AneuRx (Medtronic, Minneapolis, Minn) and the Guidant EVT (Guidant Corp, Indianapolis, Ind) devices for use. Since that time, other single-center reports of EVAR using locoregional anesthesia techniques have been published. In 2002, de Virgilio et al[7] published a report demonstrating equivalent safety for local and general anesthesia. However, their results demonstrated no differences in mortality, cardiac events, or pulmonary events in an examination of 229 patients undergoing EVAR during a 4-year period. In 2005, Verhoeven et al[11] reported that the use of primary local anesthesia was safe and associated with improvements in pulmonary morbidity and decreased ICU stay.

These single-center, retrospective reports demonstrated the safety of locoregional anesthetic techniques for EVAR compared with general anesthesia; furthermore, all but one suggested that significant benefits might be associated with these techniques. The studies were limited, however, because they reflected single-center practice patterns and included a relatively small number of patients in their analyses.

Larger multicenter observational studies of these issues have also been reported. Parra et al[8] reported associations among EVAR performed under local anesthesia with decreased LOS and a decrease in a variety of morbid events (including renal, wound, and cardiac complications) in a retrospective analysis of 424 patients undergoing EVAR as part of a phase II trial of the AneuRx device (Medtronic). More recently, investigators have used the European Collaborators on Stent-Graft Techniques for Aortic Aneurysm Repair (EUROSTAR) registry of EVAR procedures to examine issues of anesthesia type and outcome. In an initial analysis of 5557 patients undergoing EVAR, Ruppert et al[9] reported decreased ICU admissions, LOS, and cardiac complications in multivariable analyses of locoregional anesthesia techniques. In that report, the greatest reductions were seen with local anesthesia techniques for EVAR.

The same group reported additional analyses of the EUROSTAR data in 2007 with patients stratified into high-risk and low-risk categories according to ASA class.[10] In that stratified analysis, the most significant benefits from local and regional anesthesia were seen in patients designated as high risk. Decreased ICU utilization was observed with local anesthesia and decreased early mortality was observed with regional anesthesia in high-risk patients. Other than this latter analysis of high-risk patients, none of these studies have demonstrated any effect on mortality with differing anesthetic techniques.

Our observations are consistent with many of these previously referenced findings. Our analysis showed the use of local/MAC and spinal anesthesia was associated with a significant decrease in pulmonary complications compared with general anesthesia in multivariable models adjusting for pertinent risk factors. Further, a decreased LOS was also seen favoring the use of local/MAC and spinal anesthesia. Significant associations relative to general anesthesia were not observed for epidural anesthesia. These findings were observed in a large sample of EVAR cases sampled from contemporary medical practice in North American hospitals and provide a "real-world" description of both the use of less-invasive anesthetic techniques and the relative value of those techniques in limiting morbidity.

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The EUROSTAR registry findings are quite similar to those reported here. Health systems in Europe, however, possess features that are quite different from the system in the United States, which may limit the applicability of their findings to American medical practice. In the initial EUROSTAR report by Ruppert et al,[9] the average LOS was 5.8 days, which is approximately double the LOS for EVAR observed in this report. This likely represents a greater caution toward discharge in the early days of EVAR, because EUROSTAR contains data from 1997 to 2004, and the ACS NSQIP contains data from 2005 to 2008. In addition, the devices available for use in European countries also differ from those approved by the FDA. Furthermore, the relative availability of EVAR to the general patient population in Europe relative to North America may differ because of differences in the respective health care delivery systems, which limit (and in some cases prohibit) EVAR or other surgical procedures in high-risk or elderly European patients. To this point, the high-risk patients described in Ruppert et al[10] described all patients with ASA class ≥3 as high risk, which would have included 93% of the study sample for this report.

European biases toward a more aggressive use of less-invasive anesthesia also likely play a role in the differences in outcomes among European and American studies. These differences are demonstrated in the distributions of general, regional, and local anesthesia reported in EUROSTAR (69%, 25%, and 6%) and the ACS NSQIP (81%, 13%, and 6%). The sum of these differences is significant. As such, this study represents the first large-scale demonstration of locoregional anesthetic benefit from American sources using contemporary technology.

As a separate concern, most of the preceding data presented regarding the benefits of using regional anesthesia have been derived from the use of epidural anesthesia. This report demonstrates clear benefits from the use of local/MAC and spinal anesthesia, but not epidural anesthesia, especially in relation to LOS. This finding is clearly different from the results of the preceding single-center and multicenter data presented and represents a unique and intriguing finding. The observed lack of significant associations between epidural anesthesia and decreased pulmonary morbidity or LOS could have been due to the effects of local anesthetic or adjuvant agents commonly used within epidural anesthetics. The volume and concentration of local anesthetics affects epidural dermatomal spread as well as the depth of analgesia or the degree of motor blockade, or both. When patients are supine, cephalad spread of local anesthetics or epidural narcotics to the midthoracic or lower cervical regions during a continued infusion may impair pulmonary mechanics, thus increasing the risk of postoperative pulmonary dysfunction and LOS. Narcotic adjuvants are also frequently added to local anesthetic epidural infusions. These agents also have the potential to centrally suppress respiratory drive and thereby affect rates of reintubation and LOS.

Potential mechanisms by which locoregional anesthesia may affect the morbidity of EVAR include avoidance of endotracheal intubation and mechanical ventilation as well as the potential for residual neuromuscular paralysis after reversal. Atelectasis ensues immediately after induction of general anesthesia and persists well into the postoperative phase.[16,17] Positive pressure ventilation results in atelectasis, diminishes functional residual capacity, and increases the risk of reintubation, especially in the elderly.[18] High-risk patients (ASA 4

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and 5 and elderly) are at a greater risk of postoperative pulmonary morbidity with general anesthesia, even after what appears to be adequate reversal of neuromuscular blockade. Furthermore, general anesthesia frequently involves the use of volatile anesthetics during the maintenance phase. Inhalational agents have been associated with immunosuppression, potentially increasing the risk of postoperative pneumonia in the setting of atelectasis, diminished cough reflex, or in patients at risk for aspiration.[19,20]

Locoregional anesthesia avoids mechanical ventilation and permits maintenance of spontaneous ventilation, thereby minimizing the patient's exposure to factors that increase the risk of postoperative pulmonary failure. Furthermore, locoregional anesthetic techniques provide preemptive analgesia and improve postoperative pain control relative to general anesthesia alone, which may reduce the incidence of hypertension and tachycardia related to surgical stress and postoperative pain. Locoregional techniques also allow for avoidance of ventilator weaning at the end of anesthesia, which can be challenging in compromised patients.

Our study showed that local/MAC and spinal anesthesia techniques were able to reduce LOS by 10% to 20%, even in the context of the shorter observed American hospital LOS. These anesthetic techniques were also associated with a 60% to 75% decrease in the odds of postoperative pulmonary complications, including pneumonia and failure to wean from the ventilator ≤48 hours of surgery. These complications obviously increase patient discomfort and commonly require admission to the ICU or extension of the ICU stay. Given the high estimated cost of such nosocomial pneumonias (>$12,000 per occurrence[21]) and the potential savings of the observed decreases in LOS, the significance of these data to contemporary American health care is obvious.

An obvious explanation, however, is not apparent for the differences in spinal and epidural anesthesia in their observed advantages relative to general anesthesia in the performance of EVAR. It is possible that the smaller sample receiving epidural anesthesia resulted in the lack of a significant association, which would be suggested by the observed trends toward an association (especially with regard to pulmonary complications). Plausible mechanisms can be put forth, though, to explain the observed differences. In addition to the potential mechanisms underlying the lack of an observed association discussed above, it is also possible that epidural anesthesia was associated with increased crystalloid fluid administration due to prolonged sympatholysis relative to spinal anesthesia and that this fluid volume was associated with a slightly higher rate of pulmonary complication (and accordingly LOS). It is also possible that epidural anesthetics were associated with a small but significant incidence of complications found with the more complicated technique involving catheter placement (ie, postepidural headache), which may also have resulted in occasional increases in LOS. Unfortunately, the data points collected as part of NSQIP will not allow these questions to be addressed.

This study possesses a number of other limitations that deserve comment. As with almost all secondary analyses of existing databases, the database was not specifically designed to assess the question of interest. The ACS NSQIP is a quality-of-care tool that is not optimized to assess specifics of endovascular surgical and anesthetic care. Detailed data

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regarding patient anatomy, device selection, anesthetic techniques, monitoring, or conversion between anesthetic techniques were not collected and cannot be analyzed.

Patients were also not randomized to their anesthesia type, eliminating any control for known (or unknown) confounding factors. Individual anesthetic selections were made according to surgeon and anesthesiologist preference, incorporating the biases of those individuals as well as patient-specific factors such as anatomy, medical risk, available resources, and procedural complexity. As such, this report represents a large, uncontrolled investigation of anesthetic technique as it was applied in contemporary medical practice and was not a test of an a priori hypothesis.

Furthermore, data were also lacking for analysis regarding surgeon and institutional identity. This raises the possibility that the biases of individuals and institutions and the potential for unbalanced confounding factors in the absence of randomization, such as the observed tendency for general anesthesia for longer (and presumably more complex) cases, may have produced the observed differences. The likelihood, though, of such a type I error is mitigated somewhat by the use of multivariable methods to control for potential confounding factors as identified by univariable analyses of these data and prior analyses of morbidity and mortality in vascular surgery patients throughout the ACS NSQIP.

It is also possible that other missing data points such as the time of surgery, the day of the week of surgery, and urinary retention affected our findings, especially with regard to LOS. Further mitigation of unmeasured confounding would require more detailed data or advanced observational methods, such as propensity score modeling, hierarchical modeling, or instrumental variable analysis. In the analysis we have described, implementation of these methods is limited by the relatively small number of patients in each exposure category, as well as by the relatively small proportion of high-risk pulmonary patients.

CONCLUSIONS

This study represents a large-sample investigation of the benefits and liabilities of differing anesthesia types in the performance of EVAR in North America using contemporary anesthetic and surgical techniques. The results suggest that the use of general anesthesia for the performance of EVAR is associated with higher rates of pulmonary morbidity and a 10% to 20% increase in LOS relative to locoregional anesthetic techniques, specifically local/MAC and spinal anesthesia. These data support an increase in the use of local anesthesia/MAC or spinal anesthesia in EVAR patients suitable for such anesthetic approaches to reduce pulmonary morbidity and length of stay.

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Table I

Patient characteristics by type of anesthesia during endovascular aneurysm repair (*EVAR*)

Variable[a]	Elective EVAR (n = 6009)	Anesthesia General (n = 4868)	Spinal (n = 419)	Epidural (n = 331)	Local/MAC (n = 391)	*P*[b]
Age, years	74.1 ± 8.5	73.8 ± 8.6	74.8 ± 7.7	74.8 ± 8.5	75.3 ± 8.9	.0008
Nonwhite race	877 (14.6)	695 (14.3)	86 (20.5)	32 (9.7)	64 (16.4)	.0002
Female sex	982 (16.3)	779 (16.0)	71 (17.0)	61 (18.4)	71 (18.2)	.4716
Body mass index, kg/m^2	28.0 ± 5.6	28.1 ± 5.6	27.6 ± 6.9	28.3 ± 5.3	27.2 ± 4.9	.0044
Diabetes	862 (14.4)	707 (14.5)	62 (14.8)	38 (11.5)	55 (14.1)	.4879
Current smoker	1690 (28.1)	1400 (28.8)	125 (29.8)	74 (22.4)	91 (23.3)	.0090
Ever smoker	3794 (77.5)	3031 (77.1)	289 (80.3)	239 (82.4)	235 (75.1)	.0704
Functional status						
Independent	5747 (95.6)	4668 (95.9)	394 (94.0)	318 (96.1)	367 (93.9)	.0919
Partially/totally dependent	262 (4.4)	200 (4.1)	25 (6.0)	13 (3.9)	24 (6.1)	
History of						
COPD	1104 (18.4)	885 (18.2)	69 (16.5)	65 (19.6)	85 (21.7)	.2175
Congestive heart failure	82 (1.4)	62 (1.3)	3 (0.7)	7 (2.1)	10 (2.6)	.0680
Myocardial infarction	70 (1.2)	65 (1.3)	1 (0.2)	0	4 (1.0)	.0227[c]
Angina	132 (2.2)	100 (2.1)	9 (2.2)	7 (2.1)	16 (4.1)	.0715
Prior CABG	1461 (24.3)	1186 (24.4)	99 (23.6)	88 (26.6)	88 (22.5)	.6289
Prior PTCI	1265 (21.1)	1047 (21.5)	83 (19.8)	49 (14.8)	86 (22.0)	.0295
Hypertension	4758 (79.2)	3868 (79.5)	334 (79.7)	246 (74.3)	310 (79.3)	.1685
Revascularization or amputation	335 (5.6)	261 (5.4)	30 (7.2)	15 (4.5)	29 (7.4)	.1314
Dialysis dependence[c]	77 (1.3)	58 (1.2)	8 (1.9)	5 (1.5)	6 (1.5)	.5823
Transient ischemic attack	419 (7.0)	335 (6.9)	35 (8.4)	22 (6.7)	27 (6.9)	.7172
Stroke						
No residual disability	280 (4.7)	232 (4.8)	19 (4.5)	14 (4.2)	15 (3.8)	.8320
Residual disability	299 (5.0)	244 (5.0)	22 (5.3)	14 (4.2)	19 (4.9)	.9229
Transfer status						
Other hospital or facility	138 (2.3)	107 (2.2)	12 (2.9)	9 (2.7)	10 (2.6)	.7545
Admitted directly from home	5871 (97.7)	4761 (97.8)	407 (97.1)	322 (97.3)	381 (97.4)	

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Variable[a]	Elective EVAR (n = 6009)	Anesthesia General (n = 4868)	Spinal (n = 419)	Epidural (n = 331)	Local/MAC (n = 391)	*P*[b]
ASA class						
1–3 (no disturbance, mild, severe)	4914 (81.8)	3965 (81.5)	365 (87.1)	277 (83.7)	307 (78.5)	.0078
4–5 (life-threatening, moribund)	1093 (18.2)	901 (18.5)	54 (12.9)	54 (16.3)	84 (21.5)	
eGFR (mL/min)[d]	68.6 ± 23.0	68.9 ± 23.0	68.2 ± 23.3	66.6 ± 23.0	67.8 ± 23.3	.2683
Chronic dyspnea	1489 (24.8)	1197 (24.6)	93 (22.2)	91 (27.5)	108 (27.6)	.2038

ASA, American Society of Anesthesiologists; *eGFR,* estimated glomerular filtration rate; *MAC,* monitored anesthesia care; *PTCI,* percutaneous transluminal coronary intervention.

[a]Data are shown as mean ± standard deviation or number (%).

[b]*P* values for overall tests of differences among the four anesthesia categories from χ^2 or Fisher exact test for categoric variables and one-way analysis of variance for continuous variables.

[c]Fisher exact test used in place of χ^2 (categoric). Dialysis indicated or creatinine level >6.0 mg/dL.

[d]Set to 0 for preoperative dialysis.

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Table II

Procedural specifics by type of anesthesia during endovascular aneurysm repair (*EVAR*)

Variable[a]	Elective EVAR (n = 6009)	Anesthesia General (n = 4868)	Spinal (n = 419)	Epidural (n = 331)	Local/MAC (n = 391)	*P*[b]
Surgeon speciality						
Vascular surgeon	5868 (97.7)	4738 (97.3)	417 (99.5)	330 (99.7)	383 (98.0)	.0020
Cardiothoracic or general surgeon	141 (2.4)	130 (2.7)	2 (0.5)	1 (0.3)	8 (2.1)	
Resident involved	3849 (64.2)	3050 (62.8)	259 (62.4)	268 (81.5)	272 (69.7)	<.0001
Patients requiring transfusion	666 (11.1)	561 (11.5)	24 (5.7)	38 (11.5)	43 (11.0)	.0042
Units transfused (among those)	2.3 ± 2.1	2.4 ± 2.2	1.7 ± 1.1	1.5 ± 0.7	1.7 ± 1.2	<.0001[c]
Operative time (minutes)	157.5 ± 67.2	159.7 ± 68.8	137.4 ± 53.1	156.5 ± 58.4	152.1 ± 63.4	<.0001[c]
Access type						
Percutaneous[d]	2661 (44.3)	2253 (46.3)	159 (38.0)	92 (27.8)	157 (40.2)	<.0001
Any open femoral access	3348 (55.7)	2615 (53.7)	260 (62.1)	239 (72.2)	234 (59.9)	
Single iliac or aortic extension	1666 (27.7)	1305 (26.8)	127 (30.3)	93 (28.1)	141 (36.1)	.0007
Multiple extensions	508 (8.5)	396 (8.1)	45 (10.7)	26 (7.9)	41 (10.5)	.1266
Hypogastric embolization	103 (1.7)	88 (1.8)	4 (1.0)	8 (2.4)	3 (0.8)	.1919
Endograft configuration						
Bifurcated modular						
One docking limb	2714 (45.2)	2165 (44.5)	156 (37.2)	143 (43.2)	250 (63.9)	<.0001
Two docking limbs	2158 (35.9)	1741 (35.8)	192 (45.8)	144 (43.5)	81 (20.7)	<.0001
Unibody bifurcated	441 (7.3)	364 (7.5)	26 (6.2)	16 (4.8)	35 (9.0)	.1399
Aorto-uni-iliac	257 (4.3)	209 (4.3)	19 (4.5)	17 (5.1)	12 (3.1)	.5598
Aortoaortic tube	480 (8.0)	422 (8.7)	28 (6.7)	12 (3.6)	18 (4.6)	.0003
Total work relative value units	38.7 ± 14.8	38.3 ± 14.8	41.2 ± 13.4	39.9 ± 12.8	40.8 ± 16.8	<.0001

MAC, Monitored anesthesia care.

[a]Continuous variables are expressed as mean ± standard deviation; categoric variables as number (%).

[b]*P* values for overall tests of differences among the four anesthesia categories from χ^2 test for categoric variables and one-way analysis of variance or Kruskal-Wallis test for continuous variables.

[c]Kruskal-Wallis test used in place of one-way analysis of variance (continuous).

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[d]Defined by absence of a femoral code.

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Table III

Outcomes by type of anesthesia during endovascular aneurysm repair (*EVAR*)

Variable[a]	Elective EVAR (n = 6009)	Anesthesia General (n = 4868)	Spinal (n = 419)	Epidural (n = 331)	Local/MAC (n = 391)
Morbidity (any of below)	677 (11.3)	567 (11.7)	37 (8.8)	43 (13.0)	30 (7.7)
Wound problems					
Superficial wound infection	97 (1.6)	84 (1.7)	8 (1.9)	4 (1.2)	1 (0.3)
Deep wound infection	34 (0.6)	31 (0.6)	2 (0.5)	0	1 (0.3)
Organ space wound infection	3 (0.1)	1 (0.0)	0	1 (0.3)	1 (0.3)
Wound dehiscence	16 (0.3)	15 (0.3)	0	1 (0.3)	0
Any superficial or deep wound infection	130 (2.2)	115 (2.4)	9 (2.2)	4 (1.2)	2 (0.5)
Pulmonary					
Pneumonia	73 (1.2)	67 (1.4)	2 (0.5)	3 (0.9)	1 (0.3)
Unplanned reintubation	99 (1.7)	91 (1.9)	0	4 (1.2)	4 (1.0)
Failure to wean from ventilator	75 (1.3)	71 (1.5)	1 (0.2)	2 (0.6)	1 (0.3)
Any pulmonary morbidity	168 (2.8)	155 (3.2)	3 (0.7)	5 (1.5)	5 (1.3)
Venous thromboembolic					
Deep venous thrombosis	35 (0.6)	30 (0.6)	1 (0.2)	3 (0.9)	1 (0.3)
Pulmonary embolism	9 (0.2)	8 (0.2)	0	1 (0.3)	0
Genitourinary					
Acute renal insufficiency	35 (0.6)	29 (0.6)	2 (0.5)	3 (0.9)	1 (0.3)
Acute renal failure	50 (0.8)	46 (0.9)	1 (0.2)	2 (0.6)	1 (0.3)
Urinary tract infection	99 (1.7)	81 (1.7)	8 (1.9)	5 (1.5)	5 (1.3)
Any renal insufficiency or renal failure	79 (1.3)	69 (1.4)	3 (0.7)	5 (1.5)	2 (0.5)
Cardiovascular					
Stroke	27 (0.5)	21 (0.4)	2 (0.5)	1 (0.3)	3 (0.8)
Cardiac arrest	25 (0.4)	20 (0.4)	1 (0.2)	2 (0.6)	2 (0.5)
Myocardial infarction	15 (0.3)	14 (0.3)	0	1 (0.3)	0
Operative					
Postoperative hemorrhage/transfusions	31 (0.5)	26 (0.5)	1 (0.2)	3 (0.9)	1 (0.3)
Graft failure	56 (0.9)	45 (0.9)	2 (0.5)	5 (1.5)	4 (1.0)

Variable[a]	Elective EVAR (n = 6009)	Anesthesia General (n = 4868)	Spinal (n = 419)	Epidural (n = 331)	Local/MAC (n = 391)
Return to operating room	260 (4.3)	214 (4.4)	13 (3.1)	18 (5.4)	15 (3.8)
Septic					
Sepsis	62 (1.0)	49 (1.0)	6 (1.4)	6 (1.8)	1 (0.3)
Septic shock	53 (0.9)	46 (0.9)	1 (0.2)	3 (0.9)	3 (0.8)
Death	68 (1.1)	60 (1.2)	1 (0.2)	4 (1.2)	3 (0.8)
Post-op surgical length of stay, days	2.8 ± 4.3	2.9 ± 4.2	2.1 ± 1.8	2.7 ± 5.1	2.3 ± 6.1
Length of stay, days	2 (1, 3)	2 (1, 3)	1 (1, 2)	2 (1, 3)	1 (1, 2)

MAC, Monitored anesthesia care.

[a]Data are presented as mean ± standard deviation, number (%), and median (interquartile range).

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Table IV

Regression model results for anesthesia groups vs morbidity and mortality outcomes

	Overall anesthesia	General vs spinal		General vs epidural		General vs MAC/local	
Outcomes	***P***	**OR (95% CI)**	***P*[a]**	**OR (95% CI)**	***P*[a]**	**OR (95% CI)**	***P*[a]**
Renal morbidity[b]							
Unadjusted	.3398						
Multivariable model[c]	.2803						
Pulmonary morbidity[b]							
Unadjusted	.0047	4.6 (1.5–14.4)	.0095	2.1 (0.9–5.3)	.0958	2.5 (1.0–6.2)	.0417
Multivariable model[d]	.0126	4.0 (1.3– 12.5)	.0195	1.9 (0.8–4.7)	.1711	2.6 (1.0–6.4)	.0409
Mortality[b]							
Unadjusted	.3536						
Multivariable model[e]	.3463						
Wound morbidity[b]							
Unadjusted	.0958						
Multivariable model[f]	.1403						
Any morbidity[b]							
Unadjusted	.0279	1.4 (1.0–1.9)	.0831	0.9 (0.6–1.2)	.4626	1.6 (1.1–2.3)	.0181
Multivariable model[g]	.0514						
		% Difference (95% CI)	*P*	% Difference (95% CI)	*P*	% Difference (95% CI)	*P*
Length of stay[h]							
Unadjusted	<.0001	16.80 (10.8–23.1)	<.0001	5.20 (–0.9 to 11.6)	.0945	20.10 (13.7–26.9)	<.0001
Multivariable model[g]	<.0001	10.00 (4.8–15.5)	.0001	3.60 (–1.9 to 9.4)	.2046	20.00 (14.1–26.2)	<.0001

CI, Confidence interval; *MAC*, monitored anesthesia care; *OR,* odds ratio.

[a] *P* value for contrast.

[b] Logistic regression.

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[c]Model covariates for renal: age, gender, race, current smoker, total work relative value units, femoral access, American Society of Anesthesiologists class, estimated glomerular filtration rate, functional status, body mass index, diabetes, hypertension, history of congestive heart failure.

[d]Model covariates for pulmonary: age, gender, race, current smoker, total work relative value units, femoral access, American Society of Anesthesiologists class, estimated glomerular filtration rate, functional status, history of congestive heart failure, chronic obstructive pulmonary disease, angina, cerebrovascular accident; red blood cell transfusions, dyspnea.

[e]Model covariates for mortality: age, gender, race, current smoker, total work relative value units, femoral access, American Society of Anesthesiologists class, estimated glomerular filtration rate functional status, body mass index; history of congestive heart failure, chronic obstructive pulmonary disease, angina, cerebrovascular accident; red blood cell transfusions, prior percutaneous transluminal coronary intervention, prior coronary artery bypass grafting.

[f]Model covariates for wound: age, gender, race, current smoker, total work relative value units, femoral access, body mass index, diabetes, history of chronic obstructive pulmonary disease, operative time, long-term steroid use.

[g]Model covariates for any morbidity and length of stay: age, gender, race, current smoker, total work relative value units, femoral access, American Society of Anesthesiologists class, estimated glomerular filtration rate, functional status, body mass index, diabetes; history of congestive heart failure, chronic obstructive pulmonary disease, angina, cerebrovascular accident; red blood cell transfusions, operative time.

[h]Linear regression (log-transformed for analysis, back-transformed results are presented).

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Table V

Complete multivariable logistic regression results for pulmonary morbidity

Variable	OR (95% CI)	*P*
General anesthesia vs		.0126
Spinal	3.96 (1.25–12.54)	.0195
Epidural	1.89 (0.76–4.73)	.1711
Monitored anesthesia care/local	2.58 (1.04–6.41)	.0409
Age, years	1.01 (0.99–1.03)	.5297
Female	1.14 (0.77–1.69)	.5139
Nonwhite	1.47 (0.98–2.21)	.0663
Current smoker	1.55 (1.07–2.23)	.0197
Total work relative value units	1.00 (0.99–1.01)	.9202
Access (percutaneous vs femoral)	1.48 (1.0–2.18)	.0504
ASA class (4–5 vs 1–3)	1.50 (1.04–2.16)	.0287
Estimated glomerular filtration rate	0.99 (0.98–0.99)	.0004
Functionally dependent (partial/total vs independent)	2.09 (1.23–3.56)	.0064
History of		
Congestive heart failure	1.93 (0.85–4.40)	.1164
Congestive obstructive pulmonary disease	1.71 (1.16–2.53)	.0069
Angina	1.35 (0.56–3.28)	.5050
Cerebrovascular accident	0.92 (0.56–1.52)	.7394
Units transfused	1.32 (1.22–1.43)	<.0001
Chronic dyspnea	1.13 (0.77–1.65)	.5416

ASA, American Society of Anesthesiologists; *CI*, confidence interval; *OR*, odds ratio.

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Table VI

Multivariable linear regression results for log-length of stay

Variable	β (95% CI)	*P*
General anesthesia vs		<.0001
Spinal	0.095 (0.046–0.144)	.0001
Epidural	0.035 (−0.019 to 0.090)	.2046
Monitored anesthesia care/local	0.182 (0.132–0.232)	<.0001
Age, years	0.003 (0.002–0.005)	<.0001
Female	0.101 (0.067–0.136)	<.0001
Nonwhite	0.075 (0.040–0.111)	<.0001
Current smoker	0.008 (−0.023 to 0.037)	.6608
Total work relative value units	0.000 (−0.001 to 0.001)	.7934
Access (percutaneous vs femoral)	0.030 (0.000 0.060)	.0495
ASA class (4–5 vs 1–3)	0.100 (0.068–0.133)	<.0001
Estimated glomerular filtration rate	−0.002 (−0.002 to −0.001)	<.0001
Functionally dependent (partial/total vs independent)	0.285 (0.223–0.347)	<.0001
Body mass index	−0.001 (−0.004 to 0.001)	.2725
History of		
Congestive heart failure	0.294 (0.187–0.402)	<.0001
Diabetes	0.040 (0.005–0.076)	.0259
Congestive obstructive pulmonary disease	0.072 (0.040–0.105)	<.0001
Angina	0.121 (0.037–0.205)	.0048
Cerebrovascular accident	0.037 (−0.005 to 0.079)	.0867
Units transfused	0.085 (0.071–0.099)	<.0001
Operative time, min	0.002 (0.0017–0.0021)	<.0001

ASA, American Society of Anesthesiologists; *CI*, confidence interval.