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Deep Learning and Multivariable Models Select EVAR Patients for Short-Stay Discharge

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Abstract

Objectives: We sought to develop a prediction score with data from the Vascular Quality Initiative (VQI) EVAR in efforts to assist endovascular specialists in deciding whether or not a patient is appropriate for short-stay discharge.

Background: Small series describe short-stay discharge following elective EVAR. Our study aims to quantify characteristics associated with this decision.

Methods: The VQI EVAR and NSQIP datasets were queried. Patients who underwent elective EVAR recorded in VQI, between 1/2010–5/2017 were split 2:1 into test and analytic cohorts via random number assignment. Cross-reference with the Medicare claims database confirmed all-cause mortality data. Bootstrap sampling was employed in model. Deep learning algorithms independently evaluated each dataset as a sensitivity test.

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Conflicts of Interest
The authors unanimously report no relevant conflicts of interest.

Declaration of Conflicting Interests
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Disclosures
DSZ, BN, IH, CWH, PPG, MBM – No disclosures

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Supplemental material for this article is available online.

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Ethics Committee
An informed consent exemption was grant by the Johns Hopkins Medical Institutions Institutional Review Board. No study number was assigned

Results: Univariate outcomes, including 30-day survival, were statistically worse in the DD group when compared to the SD group (all P < 0.05). A prediction score, SD-EVAR, derived from the VQI EVAR dataset including pre- and intra-op variables that discriminate between SD and DD was externally validated in NSQIP (Pearson correlation coefficient = 0.79, P < 0.001); deep learning analysis concurred. This score suggests 66% of EVAR patients may be appropriate for short-stay discharge. A free smart phone app calculating short-stay discharge potential is available through QxMD Calculate https://qxcalc.app.link/vqidis.

Conclusions: Selecting patients for short-stay discharge after EVAR is possible without increasing harm. The majority of infrarenal AAA patients treated with EVAR in the United States fit a risk profile consistent with short-stay discharge, representing a significant cost-savings potential to the healthcare system.

Keywords

aneurysm; health services research; EVAR; care pathways

Introduction

System-, practitioner- and patient-level influences coalesced over the last 70 years to provide steady pressure toward decreasing in-patient hospital stays.[1] The Enhanced Recovery After Surgery (ERAS) pathway pioneered by colorectal surgeons is a contemporary effort credited with reducing post-operative hospitalization after major abdominal procedures without increasing harm to patients.[2] Aortic repair shifted from predominantly open surgery to endovascular intervention sometime in the mid-2000's.[3] Coeval clinical trials established endovascular repair's (EVAR) superior short-term outcomes in comparison to open aortic surgery, while requiring fewer inpatient days.[4,5] Single-, multi-center and national registry data—including work from our group—suggests median hospitalization post-EVAR is 3 days, a number relatively stable over the last decade.[6–8] Endovascular specialists in Europe and North America are challenging this norm.

In 2003, Jacques Bleyn proposed elective EVAR as an outpatient procedure at the 25th annual Charing Cross symposium.[9] Lachat, Bleyn and co-authors in Zurich and Antwerp tested Bleyn's theory, describing their experience with 100 consecutive outpatient EVAR's, reporting 100% 30-day survival with 4 readmissions for access vessel problems.[10] Furthermore, they found outpatient EVAR resulted in lower total costs when compared with a short inpatient stay. Case series from the United States and Canada followed, demonstrating similar results.[11,12] The Zurich and Buffalo groups considered urgency, comorbidities, living situation and distance from treating center when selecting patients, while the McGill group relied on proximity and physician intuition.

Our study aims to quantify characteristics associated with short-stay discharge following EVAR. We developed a prediction score in the Vascular Quality Initiative (VQI) EVAR dataset that incorporates pre- and intra-operative variables in efforts to assist endovascular specialists in deciding whether or not a patient is appropriate for short-stay discharge. External validation occurred in the National Surgical Quality Improvement Program (NSQIP) EVAR-specific dataset. We hypothesized that patients discharged soon after intervention would harbor fewer comorbidities and demonstrate shorter procedural times than patients hospitalized for longer, but demonstrate outcomes no different from one another.

Methods

All data are accessible upon approved request to the Vascular Quality Initiative (VQI) and the National Surgical Quality Improvement Program (NSQIP). Analytic methods are described herein and are reproducible with any statistical or deep learning software.

Patients

The Vascular Quality Initiative (VQI) is a patient safety organization endorsed by the Society for Vascular Surgery—among several other societies—aimed at improving vascular care delivery. De-identified patient information associated with vascular surgeries and interventions, including EVAR, are collected from several hundred hospitals around the United States and Canada. Dataset access requires participation in the registry and application to VQI Research Advisory Committee; we received approval to review all EVAR patients treated between 1/2003 and 5/2017. External validation of the VQI risk score occurred in an alternate dataset, the American College of Surgeons NSQIP. This registry tracks 30-day outcomes with data derived from patient charts rather than administrative information. Hospital enrollment is voluntary. An informed consent exemption was grant by the Johns Hopkins Medical Institutions Institutional Review Board.

Our unit of analysis was the patient. Analytic groups were created based on day of discharge, post-operative day 0 (POD0) or same-day, POD1 or next-day and >POD1 following elective EVAR. After confirming that POD0 and POD1 patients were not different at baseline and had outcomes no different from each other following EVAR, these 2 groups were combined to form the short-stay discharge (SD) group. Short-stay discharge patients were then compared to patients with delayed (>1 day) discharge post-EVAR (DD).

End Points

This study’s primary end point was survival at 30 days; survival data in the VQI EVAR set is cross-referenced with the Social Security Death Index, while those in NSQIP are abstracted by nurses. Canadian patients not returning for their scheduled follow-up visits are called by Canadian VQI data managers directly to verify their status. Should patients not be reachable directly, next of kin, family doctors and, finally, obituaries are queried. Failure to rescue and post-intervention complications, including cerebrovascular, cardiac, respiratory, renal, visceral and extremity organ, were compared between groups. Those patients dying in the hospital following a complication are considered rescue failures.

Univariable Statistical Analysis

All analyses were performed with STATA 15.1 (StataCorp, College Station, TX). Prior to analysis, patients in the VQI EVAR dataset were split 2:1 into analytic and validation cohorts. STATA’s random number generator assigned each patient an integer between 1 and 3. Analytic cohort patients’ pre-, intra- and post-intervention variables were compared between groups stratified by total hospitalization length. Variables with <95% reporting were excluded, except for a "distance from treating center" variable that was analyzed on a univariate basis, but not incorporated into the multivariable models and reported in a supplement only. The distance variable was complete on 8,589 patients, 27.4% of the total cohort. The CKD-EPI equation is a method accepted by the National Kidney Foundation to calculate estimated glomerular filtration rate (eGFR) which we applied to each patient.[13] Chi-square tests compared discrete variables. Histogram plots of continuous variables differentiated parametric and non-parametric distributions. Student t-tests and Wilcoxon rank-sum tests determined statistical significance for 2 group comparisons between parametrically and non-parametrically-distributed continuous variables respectively, while 1-way analysis of variance (ANOVA) and Kruskal-Wallis statistics evaluated three-group parametrically and non-parametrically-distributed continuous variables respectively.

Multivariable Statistical Analyses

Cox proportional hazard and multivariable logistic regression models were created with backward stepwise regression. Those covariates with P-values ≥0.1 were deemed non-significant and eliminated from the model, starting with the highest P-value first. Model discrimination was reported with the Harrell's c-statistic, while model fit is reported with a Hosmer-Lemeshow goodness of fit test. Hospital center average yearly volume skewed right on histogram visual analysis. Previous health services research established the logarithm of yearly patient volume as a preferred transformation prior to incorporation in multivariable regressions.[14] All variables entered into the model were evaluated for collinearity. Independent predictors of mortality at 30 days are suggested by a Cox proportional hazard model clustered by center, developed from all parameters present in Tables 1 and 2, as well as the log of yearly center volume.

Several risk models were developed to identify independent predictors of early discharge. Each was clustered by center, except for the NSQIP validation model, as NSQIP does not provide center identification. Similar to the Cox model, the initial multivariable logistic regression incorporated all variables in Tables 1 and 2; once again, the logarithm of yearly center volume was incorporated. Variables were removed iteratively when their impact on discrimination, the c-statistic, was less 0.05, creating a parsimonious model. Covariance matrix estimation with 1,000 bootstrap repetitions adjusted coefficients and P-values when applied to the analytic cohort, an internal validation. This same statistical method—bootstrapping—was applied to the VQI EVAR validation cohort (n = 8,438) and the NSQIP cohort (n = 14,134), in 2 external validation sets. Harrell's c-statistic with 95% confidence intervals are reported for each validation.

Deep Learning Analysis

Deep learning algorithms underpin automation involving visual and aural stimuli, including postal zip code processin,[15] drug discovery,[16] speech recognition,[17] and perhaps most dramatic, autonomous driving.[18] In brief, we define the parameters of a sequence of non-linear transformation, that minimizes an objective function by applying a stochastic gradient descent method or one of its variants. In most cases—including this work—the objective function we aim to minimize is the difference between the model output and the target label (i.e., supervised learning). In our current analysis, we applied a multilayer perceptron (MLP) model, selected due to the limited number of variables or "features" —32—available in Tables 1 and 2, as well as log of yearly center volume. Activation functions, including ReLU and Tanh, as well as batch normalization, dropout layers and different learning rate schemes were employed to adjust the error rate. Pytorch was the programming platform (pytorch.org).

Mobile Prediction Tool

A prediction score for short-stay discharge based on the externally-validated multivariable logistic regression was developed in the method described by Sullivan et al.[19] Low, medium and high potential categories were demarcated by the 25th and 75th prediction score percentiles. The VQI short-stay discharge algorithm was published as a free tool on the QxMD website, as well as incorporated into QxMD's free smart phone app, Calculate https://qxcalc.app.link/vqidis

Results

Cohort

The VQI EVAR dataset contains information on 31,382 patients treated between 1/2003 and 5/2017. Supplementary Figure 1a depicts our cohort development for the VQI dataset. Patients dying intraoperatively, receiving multiple EVAR's, urgent or emergent repair and those with missing or incorrect hospital length of stay information were excluded from analysis (n = 4,790). Same-day discharges occurred after 2010; the dataset was truncated at this year, removing 1,216 additional patients treated prior to 2010. The resulting cohort of 25,376 EVAR patients was then split into analytic (n = 16,938) and validation cohorts (n = 8,438) through random number assignment by the statistical software. Within the analytic cohort, 88 patients (0.5%) were admitted for intervention and discharged the same day (POD0), while 9,052 (53.4%) stayed 1 night in the hospital (POD1) and 7,798 (46.0%) were hospitalized for longer (POD >1).

Same-Day vs. Next-Day Discharge

Univariate comparison between the POD0 and POD1 groups demonstrated no statistical difference on 41 of 49 variables (Supplementary Tables 1a, b, 2 and 3). Survival at 30 days was 100% in the same-day discharge group vs. 99.9% in the next-day discharge group (P = 0.77). Based on these findings, we considered patients in the same-day and next-day discharge groups to be clinically no different. We continued our analysis with a comparison between the combined same-day/next-day, the short-stay discharge group, (SD) group and those patients with discharge delayed beyond 1 day in the hospital (DD).

SD vs. DD

By contrast, univariate analysis demonstrated these groups to differ on 46 of 49 pre-, intra- and post-intervention variables (Tables 1, 2 and 3). Survival at 30 days for the SD group was 99.9% vs. 98.5% for the DD group (P < 0.001).

Center-Level Variables

Yearly center volume appears in Table 1, demonstrating that statistically more patients are discharged within 1 day of EVAR than those admitted beyond post-EVAR day 1 at centers reporting to VQI. The distance variable was created by VQI for a subset of 8,589 patients, including 64 (0.7%) patients discharged on the day of EVAR, 4,037 (47%) discharged the next day and 4,488 (52.3%) discharged more than 1 day after intervention (Supplement Table 4). Same-day discharge patients resided 27 miles (IQR 12–49) from the treating center, while next-day discharge patients and those hospitalized longer than 1 day lived 17 miles (IQR 8–39) and 16 miles (IQR 7–39) away, respectively (P<0.001). As distance information was available for <95% of the cohort, this variable was not incorporated into the multivariable models and appears in the Supplement.

Cox Proportional Hazards Model

A Cox proportional hazards model in Supplementary Table 5 proposes factors independently predicting 30-day mortality with excellent discrimination (Harrell's c = 0.86). Notably, categorization in the DD group is associated with an increased odds of death compared to the SD group (HR 6.10, 95%CI 2.64–14.10, P < 0.001).

Multivariable Logistic Regression Predicting Shorter vs. Longer Hospitalization

Table 4 lists variables independently associated with longer hospitalization (Harrell's c = 0.71, 95%CI 0.70–0.72). Those variables independently predicting discharge delayed beyond 1 day included procedures lasting between 118 and 159 minutes or longer than 160 minutes (OR 2.00, P < 0.001 and OR 4.72, P < 0.001 respectively), residence in a nursing home prior to intervention (OR 2.37, P < 0.001), epidural or general anesthesia (OR 2.33, P = 0.02 and OR 1.93, P < 0.001 respectively) and a uni-iliac endograft (OR 1.62, P < 0.001). Internal model validation by bootstrapping with 1,000 repetitions yielded an AUROC of 0.71 (95%CI 0.70–0.72).

External Validation: VQI Validation Cohort

The first external sample included 8,438 EVAR patients selected at random from the VQI dataset that were not included in the analytic cohort. Same-day discharge, next-day discharge and longer post-EVAR hospitalization occurred in 43 (0.5%), 4,432 (52.5%) and 3,963 (47.0%) patients respectively. Bootstrap model validation with 1,000 repetitions produced an AUROC of 0.71 (95%CI 0.70–0.73).

External Validation: NSQIP Cohort

Within the NSQIP dataset were 30,986 patients treated between 2005 and 2014. Supplementary Figure 1b depicts our cohort development for the NSQIP cohort. Patients who underwent EVAR before 2010, dying intraoperatively, with missing or incorrect length of stay and receiving elective or urgent repairs were removed (n = 16,852), leaving 14,134 EVAR patients in the NSQIP external validation cohort. Of these, 85 patients (0.6%) were discharged POD0, 7,263 (51.3%) POD1 and 6,786 (48.0%) POD >1. Bootstrap model validation with 1,000 repetitions produced an AUROC of 0.73 (95%CI 0.71–0.75).

Deep Learning Model

The deep learning multi-layer perceptron (MLP) yielded an AUROC of 0.69 (Table 4). Altering the activation function, employing batch normalization, ensemble and dropout layers, as well as different learning rates schemes did not change the error rate.

SD-EVAR Score and Mobile Prediction Tool

A short-stay discharge (SD-EVAR) score was derived from the coefficients for variables presented in Table 4 to predict patients appropriate for short-stay discharge. Point values appear in Supplementary Table 6. Supplementary Figure 2 is a calibration graph comparing the probability of hospitalization longer than 1 day predicted by the VQI EVAR dataset against the probability observed in the NSQIP dataset (Pearson correlation coefficient 0.79, $P < 0.001$). High, medium and low likelihood categories for short-stay discharge correspond to point values of ≤14, 15–19 and ≥20 respectively, associated with percentages of 63–100%, 49–63% and 0–49%. A calculator developed from this model to assist in patient evaluation and incorporated to the QxMD app may be accessed at http://qxcalc.app.link/vqidis. Supplementary Figure 3 is a screen shot of the calculator.

Example Patient Calculations

First, a 75 year-old woman driven to the interventional suite from home with comorbid hypertension, COPD, a BMI of 29 and a hemoglobin of 12.6 receives an uncomplicated bifurcated EVAR under GETA lasting 80 minutes. Her SD-EVAR score is 12 and she is likely someone amenable to discharge home later in the day after close monitoring. The next patient is a 65 year-old woman with hypertension and a BMI of 27. Her pre-op hemoglobin was 13.5. During a somewhat challenging procedure under GETA that lasted 245 minutes, the decision was made to deploy a uni-iliac graft and involve vascular surgery to create a right to left femorofemoral bypass. Though her SD-EVAR score equals 18, treating her aneurysm required open left lower extremity revascularization, a procedure most reasonable clinicians would agree is not appropriate for same-day discharge. Therefore, clinical judgment trumps scoring and this patient would stay until the vascular surgery team felt certain that her lower extremity revascularization and the associated wounds required no further in-hospital monitoring, likely 3–5 days depending on the post-operative course. Lastly, an 81 year-old man transported to the hospital from his nursing home with comorbid hypertension, ESRD, CHF, a BMI of 31 and pre-op hemoglobin of 12.9 receives a bifurcated EVAR, implanted over 145 minutes under local anesthesia. Clinical intuition and an SD-EVAR score of 23 would almost certainly dictate this gentleman stay in the hospital for close post-EVAR surveillance.

Discussion

Our health economy balances need against resources. Fuchs summarizes changing medical practice and payment in the United States since 1950 as interplay between these 2 factors, with hospital stay as one variable in a complex equatio.[1] Cardiac revascularization and colectomy operations evolved into short stay therapies during that period via technological innovation and reimagined care pathways.[2,20] Bleyn predicted similar advances in aortic intervention, which he and others demonstrated are feasible.[9–11,21] Same-day discharge after

EVAR is a more aggressive strategy than that commonly practiced in the United States, evidenced by 175-fold fewer patients managed this way in both of the national datasets employed in our study. We developed and externally validated a tool to guide short-stay discharge following EVAR without increasing harm.

Survival and Outcomes

Patients discharged on the day of EVAR demonstrate no survival difference in comparison to those patients discharged the day after intervention. Moreover, complications occurred at frequencies no different from each other. These findings validate an interventionalist's intuition that a patient will tolerate aortic repair without requiring in-hospital care. Quantifying and transmitting this intuition to others is a challenging task, usually the province of training and experience. We suggest the criteria in Supplementary Table 6 serve as a guide.

Lachat and Bleyn et al. successfully selected patients for same-day discharge based on anatomic, clinical, technical, social and geographic criteria, similar to those we arrived at.[10] As in our study, no SD patients died within 30 days. Unlike the European groups, patients in our study's short-stay discharge group developed complications other than those related to access vessels with SD-EVAR scores starting at 10. Moreover, in the patients with hospital stays longer than 1 day, complications occurred at risk scores of 6 and higher, suggesting some duration of surveillance is still essential in EVAR patients; the exact time is beyond the scope of this study, but SD candidate patients should likely be first cases to afford maximum observation length. This tool is not intended to predict complication-free treatment, rather supplement clinical judgment and prognosticate which patients are most appropriate for short-stay discharge following adequate observation post-intervention.

As demonstrated by the risk score in Supplementary Table 6, age and comorbid disease influence discharge decisions significantly, as does procedure length, confirming our first and second hypotheses. Our third hypothesis regarding outcome was not confirmed in the most rigorous sense, as it appears discharge the day of or the day after intervention correlates with superior outcomes in comparison to patients admitted to the hospital for more than 1 day. However, we cannot establish this finding without a dataset containing more robust follow-up information than VQI-EVAR offers.

Potential

During the European groups' study periods, a total of 96 of 253 (38%) EVAR patients were discharged the same day[10]; the Buffalo group achieved a similar result.[11] We believe the proportion of patients eligible for same-day discharge is much higher, approaching 66%, which includes both the low- and intermediate-risk category patients from the VQI-EVAR analytic cohort. The Buffalo group identified several preventable reasons for increased stay, including femoral cut-down rather than percutaneous access, urinary retention and acute renal dysfunction requiring hydration.[11]

Regarding cost, Lachat et. al demonstrated a 14% lower expenditure on patients discharged on the day of intervention.[10] While we do not address financial data in this work, shorter hospital stays with similar outcomes lead intuitively to lower costs. The 18,000 patients treated with EVAR in the United States per year[22] signify a potential $75 million savings by accelerating discharge practices.[23]

Deep Learning

Big data is an ubiquitous topic in modern medicine. Wrangling variables into clinically-relevant patterns and decision-making tools has been the province of classical statistics over decades, but can become overwhelming when datasets comprise thousands of variables, an evolving phenomenon driven by electronic medical records; Golas et al. employed 34,631 variables in efforts to predict heart failure readmissions in a Massachusetts health system.[24] Training linear transformation to perform the iterative work associated with developing multivariable models is far less time consuming than manually locating important features in data. Anecdotally a skilled machine learning programmer reproduced the statistical results in this study within 2 hours. Deep learning techniques in our study confirmed various multivariable statistical methods, generating a c-statistic of 0.69 that was below the 95% confidence interval of bootstrapped internal and external validation models. This is not dissimilar from the experience published by Golas et al., though their group accepted incremental improvement of 0.04 in their c-statistic as evidence that deep learning provided value to their prediction model; the final Golas et al. model demonstrated a c-statistic of 0.71, which they described performing moderately well. Improving on established techniques requires datasets with more variables than the 40 employed in our analysis, though it would seem the degree to which a result may be refined is predicated on input quality rather than quantity. Deep learning is efficient, accurate and flexible when fed with excellent data. Areas where this approach succeeds include image-intensive medical specialties, like pathology and radiology, largely because the data is binary, voluminous and not dependent on human entry.[25,26]

Limitations

This study reports physician behavior related to EVAR discharge, rather than an objective measure of patient fitness. Bias relating to patient selection, local custom, as well as interventionalist training and skill is present. Follow-up information is poor in the VQI EVAR dataset, with 40% of patients receiving an in-person or phone follow-up within 1 year.[27] Readmission and reintervention information are therefore limited. Both the VQI and NSQIP registries rely on accurate information collected by health professionals with various certifications and training; a recent audit in January, 2017 resulted in changes to the mortality status of 3.5% of patients in VQI. Anatomic data is not present in VQI or NSQIP beyond aneurysm size. Overlap between the 2 registries is unquantifiable, as each set contains de-identified patient data.

One caution when interpreting an SD-EVAR result revolves around uni-iliac device implantation. Though this adds 3 points to a patient’s score, it is unlikely any patient—no matter what score they receive—will be deemed appropriate for short-stay discharge after this procedure, as it necessitates open femorofemoral bypass surgery. Furthermore, though commercially-available aortouni-iliac devices are reported in both VQI and NSQIP, uni-iliac anatomy may be created from bifurcated grafts. We reported the results as analyzed, but advise any physician applying this score to a patient receiving a uni-iliac EVAR to defer to their vascular surgery colleagues on discharge.

Finally, this model is not perfectly predictive. Math should never supersede clinical judgment.

Conclusion

Selecting patients for short-stay discharge post-EVAR is possible without increasing harm. Up to 66% of infrarenal AAA patients treated in the United States may fit the appropriate risk profile for same-day discharge, representing a significant cost-savings to the healthcare system.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Abbreviation List

AAA	Abdominal Aortic Aneurysm
EVAR	Endovascular Aneurysm Repair
SD	Short-stay Discharge
DD	Delayed Discharge
VQI	Vascular Quality Initiative
NSQIP	National Surgical Quality Improvement Program
CI	Confidence Interval
ERAS	Enhanced Recovery After Surgery

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Table 1.

Baseline Demographics, Combined Same-Day/Next-Day (SD) Discharge Patients vs. Those Hospitalized More Than 1 Day (DD).

Discharge day category	SD	DD	P value
n, (%)	88 (1)	7,798 (99)	
Center yearly volume, median (25–75%), patients	1 (l-l)	13 (7–24)	<0.00l
Age, median (25–75%), y	71 (66–77)	75 (69–81)	<0.00l
Women, %	9 (10)	1,809 (23)	0.004
Pre-hospital domicile, %			0.40
Home	88 (100)	7,627 (98)	
Nursing home	0	151 (2)	
Homeless	0	8 (0)	
Primary Insurer			0.33
Medicare	51 (58)	4,279 (55)	
Medicaid	2 (2)	133 (1)	
Private	24 (27)	1,744 (22)	
Self-pay, DoD or non-US insurance	1 (1)	285 (4)	
Unknown	10 (11)	1,358 (17)	
White race, %	77 (89)	6,955 (90)	0.87
Hispanic, %	4 (5)	195 (3)	0.23
Hypertension, %	71 (81)	6,681 (86)	0.17
Diabetes, %	18 (20)	1,671 (21)	0.82
Tobacco abuse, %	76 (86)	6,655 (85)	0.81
CAD, %	24 (27)	2,378 (31)	0.51
ESRD, %	0	130 (2)	0.40
eGFR <60mL/min/1.73 m^2, %	24 (28)	3,088 (41)	0.01
Pre-op Statin, %	60 (68)	5,474 (70)	0.03
CHF, %	5 (6)	1,106 (14)	0.02
COPD, %	21 (24)	2,775 (36)	0.02
Family Hx AAA, %	12 (14)	599 (8)	0.04
BMI, mean (95%CI), kg/m^2	29 (28–30)	28 (28–28.0)	0.17
Unfit for open repair, %	10 (11)	1,629 (21)	0.03
Pre-op hemoglobin, mean (95%CI), g/dL	14 (13–14)	13 (13–13)	0.03
Previous oAAA or EVAR, %	10 (11)	484 (6)	0.05
Previous peripheral bypass or stent, %	5 (6)	723 (9)	0.25
Major amputation, %	0	42 (1)	0.50
AAA max AP diameter, mean (95%CI), mm	55 (53–58)	56 (56–57)	0.40

Table 2.

Intra-Operative Details.

Discharge day category	**SD (n = 88)**	**DD (n = 7,798)**	**P value**
Procedure time, median (25–75%), min	109 (74–142)	135 (101–189)	<0.00l
Contrast, mean (95%CI), mL	94 (81–107)	107 (106–109)	0.05
Crystalloid, mean (95%CI), mL	1,502 (1,372–1,631)	1,933 (1,908–1,958)	<0.00l
EBL, median (25–75%), mL	100 (50–200)	150 (100–300)	<0.00l
Intra-op pRBC transfused, mean (95%CI), units	0 (0–0)	0 (0–0)	0.21
Anesthesia, %			<0.00l
Local	13 (15)	245 (3.2)	
Epidural	5 (6)	361 (4.7)	
GETA	70 (80)	7,163 (92.2)	
Graft configuration, %			0.01
Bifurcated	79 (91)	6,878 (89.7)	
Uni-iliac	3 (3)	640 (8.3)	
Aorto-aortic	5 (6)	152 (2.0)	
Intra-op conversion to open, %	0	13 (0.2)	0.70
Endoleak on completion, %	22 (25)	1,877 (24.4)	0.89

Table 3.

Outcomes.

Discharge day category	SD (n = 88)	DD (n = 7,798)	P value
Length of stay, median (25–75%), days	0	3 (2–5)	<0.00l
Post-op length of stay, median (25–75%), days	0	2 (2–4)	<0.00l
ICU stay, median (25–75%), days	0	0 (0–2)	<0.00l
Post-op pRBC, median (25–75%), units	0 (0–0)	0 (0–0)	<0.00l
Any complication, %	5 (6)	1,333 (17)	0.005
Failure to rescue, %	0	73 (1)	0.36
Post-op stroke, %	0	29 (0)	0.57
Post-op Ml, %	0	133 (2)	0.22
New post-op dysrhythmia, %	2 (2)	357 (5)	0.30
Post-op vasopressors	0	490 (6)	0.02
New post-op CHF, %	0	124 (2)	0.23
Post-op pneumonia, %	0	76 (1)	0.35
Post-op ventilator dependence, %	1 (1)	156 (2)	0.56
Intestinal ischemia, %	0	52 (1)	0.44
Post-op renal dysfunction			0.13
Acute kidney injury, %	1 (1)	450 (6)	
New dialysis requirement, %	0	51 (1)	
Leg embolus, %	0	134 (2)	0.82
Surgical site infection, %	0	62 (1)	0.87
Reoperation, %	0	307 (4)	0.06
Discharge Disposition			<0.00l
Home, %	83 (94)	6,800 (87)	
Rehab, %	0	489 (6)	
Nursing Home, %	0	385 (5)	
Other hospital, %	5 (6)	31 (0)	
Dead, %	0	75 (1)	

Table 4.

Multivariable Model Containing Factors Associated With Same-Day Discharge Derived From Variables in Tables 1a, 1b and 2, as Well as the Log of Yearly Center Volume.

	Odds Ratio	95%CI	P value
Procedure time, > 160 min	4.72	3.92–5.67	<0.001
Pre-hospital nursing home	2.37	1.63–3.44	<0.00l
Epidural	2.33	1.18–4.62	0.02
Procedure time, 118–159 min	2.00	1.72–2.33	<0.001
GETA	1.93	1.46–2.55	<0.00l
Uni-iliac graft	1.62	1.28–2.05	<0.00l
Age, >80 y	1.55	1.41–1.71	<0.00l
Procedure time, 89–117 min	1.50	1.31–1.72	<0.001
CHF	1.38	1.22–1.57	<0.001
eGFR <60 mL/min/l.73 m^2	1.27	1.17–1.38	<0.00l
COPD	1.21	1.11–1.31	<0.00l
Hypertension	1.19	1.09–1.30	<0.001
Age, 74–79 y	1.12	1.04–1.21	0.004
BMI,27.5–31.1 kg/m^2	0.92	0.85–0.99	0.03
BMI, >3 l.2kg/m^2	0.92	0.85–1.01	0.08
Female	0.77	0.70–0.85	<0.00l
Pre-op hemoglobin, 12.4–13.6 g/dL	0.75	0.67–0.84	<0.001
Pre-op hemoglobin, 13.7–14.7 g/dL	0.63	0.55–0.71	<0.001
Pre-op hemoglobin, >14.8 g/dL	0.52	0.45–0.59	<0.00l
H-L GoF 10.9, P = 0.21			
AUROC			
Analytic cohort	0.71		
Analytic cohort, internal validation	0.71 (0.70–0.72)		
VQI external validation cohort	0.71 (0.70–0.73)		
NSQIP external validation cohort	0.73 (0.71–0.75)		
Deep learning MLP	0.69		