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Variation in center-level frailty burden and the impact of frailty on long-term survival in patients undergoing repair for abdominal aortic aneurysms

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Abstract

Objectives—Frailty is increasingly recognized as a key determinant in predicting postoperative outcomes. Centers that see more frail patients may not be captured in risk adjustment, potentially accounting for poorer outcomes in hospital comparisons. We aimed to 1) determine the effect of frailty on long-term mortality in patients undergoing elective abdominal aortic aneurysm (AAA) repair and 2) evaluate the variability in frailty burden among centers in the Vascular Quality Initiative (VQI) database.

Methods—Patients undergoing elective open and endovascular AAA repair (2003–2017) were identified and those with complete data on component variables of the VQI-derived Risk Analysis Index (VQI-RAI) and centers with ≥ 10 AAA repairs were included. VQI-RAI characteristics are: sex, age, body mass index, renal failure, congestive heart failure, dyspnea, preoperative ambulation and functional status. Frailty was defined as VQI-RAI ≥ 35 based on prior work in surgical patients using other quality improvement databases. This corresponds to the top 12% of patients at-risk in the VQI. Center-level VQI-RAI differences were assessed by Analysis of Variance

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(ANOVA) test. Relationships between frailty and survival were compared by Kaplan-Meier analysis and log-rank test for open and endovascular procedures. Multivariable hierarchical Cox proportional hazards regression models were calculated with random intercepts for center, controlling for frailty, race, insurance, AAA diameter, procedure type, AAA case-mix, and year.

Results—A total of 15,803 patients from 185 centers were included. VQI-RAI scores ranged from 4 to 56 (mean 27.6, SD 5.9) and varied significantly across centers (F=2.41, p<0.001). The percentage of frail patients per center ranged from 0–40.0%. In multivariable analysis, frailty was independently associated with long-term mortality (hazard ratio 2.88, 95% CI 2.6–3.2) after accounting for covariates and center-level variance. Open AAA repair was not associated with long-term mortality after adjusting for frailty (hazard ratio 0.98, 0.86–1.13). There was a statistically significant difference in the percentage of frail patients compared to non-frail patients who were discharged to a rehabilitation facility or nursing home following both open (40.5% vs. 17.8%, p<0.0001) and endovascular repair (17.7% vs. 4.6%, p<0.0001).

Conclusions—There is considerable variability of preoperative frailty among VQI centers performing elective AAA repair. Adjusting for center-level variation, frailty but not procedure type had a significant association with long-term mortality; however, both frailty and procedure type were associated with non-home discharge. Routine measurement of frailty preoperatively by centers to identify high-risk patients may help mitigate procedural and long-term outcomes and improve shared-decision making regarding AAA repair.

Table of Contents Summary:

This VQI study of 15,803 patients undergoing elective open and endovascular abdominal aortic aneurysm (AAA) repair found that frailty varied significantly across centers and that it predicted long-term mortality. Routine pre-operative screening to identify high-risk patients may help mitigate procedural complications and long-term mortality.

Keywords

Frailty; Risk Analysis Index; open abdominal aortic aneurysm repair; endovascular abdominal aortic aneurysm repair; non-home discharge

Introduction

The introduction of endovascular techniques has allowed us to offer a wider array of interventions to patients who would have otherwise been considered poor candidates for open repair. Frailty is a biological syndrome reflecting limited reserve across a number of physiologic systems which culminates in decreased ability to withstand stressors and increased vulnerability to adverse outcomes.(1) Different methods to quantify frailty have been described, including multiple frailty scores, sarcopenia, and questionnaire-based scales. Regardless of the measure, frailty has been shown to be an independent risk factor for poor outcomes across surgical specialties, including vascular surgery.(2–13)

In 2014, in the United States alone, abdominal aortic aneurysms (AAA) were directly responsible for approximately 9,900 deaths and ~120,000 AAA repairs were performed to prevent subsequent rupture.(14) Independent of other co-morbidities, increased frailty has been found to predict higher 30-day mortality, morbidity, and failure to rescue following both open AAA repair (OAR) and endovascular AAA repair (EVAR); however, the impact of frailty on long-term survival after elective AAA repair has not been examined.(15)

The aim of our study is to determine the effect of frailty (as measured by an adaptation of the Risk Analysis Index (RAI) derived from variables contained within the Vascular Quality Initiative (VQI) database) on long-term mortality after elective AAA repair. We plan to investigate the distribution of frailty across centers performing AAA repair, and our hypothesis is that frailty will be a predictor of long-term survival following OAR and EVAR when adjusting for center-level variance.

Methods

Patients undergoing OAR and EVAR in the VQI database from 2003–2017 were identified. We elected to crosswalk a prospectively validated frailty screening tool, the RAI, to the VQI to create the VQI-derived RAI (VQI-RAI).(16) The instrument is an adaptation of the Minimum Data Set Mortality Risk Index-Revised and based on the deficit accumulation model of frailty by Rockwood et al.(10,17–20) The validity and utility of the original RAI has been discussed in depth previously, but in brief, the instrument was developed and validated in the veteran population and is associated with short and long-term mortality.(16,21) The RAI has two versions: 1) a prospective survey (RAI-C) administered pre-operatively by clinic staff or providers, and 2) a retrospective, objective calculation (RAI-A) of frailty based on chart review. The RAI-A (from which the VQI-RAI is derived) is used to test associations between frailty and surgical outcomes in larger databases and the RAI-C is intended for prospective screening with a high correlation between the two versions.(16)

Cohort Selection

This study was deemed exempt from review by Stanford University's Institutional Review Board. Patients undergoing both straightforward and complex infrarenal AAA repair were retrospectively identified in the de-identified VQI database (n=40,254) at a total of 246 different centers. Patients with "ruptured" or "symptomatic" AAA were excluded (n=7,180). Further exclusions included age <18 (n=7), incomplete VQI-RAI data (n=16,845), insufficient long-term mortality data (n=7), AAA diameters outside of the VQI's parameters (<20mm or > 150mm) or missing AAA diameter data (n=363). For patients listed with more than one discrete AAA operation (n=88), only the first AAA encounter was included. Similar to the Society for Vascular Surgery (SVS) Clinical Practice Guidelines, centers with very low case volume (< 10 total cases) were excluded (n=46 centers, n=163 patients).(22) The final cohort included 15,803 patients from 185 centers (Supplemental Figure 1). Supplemental Table I is a comparison of the included and excluded cohorts and confirms that our sample was an accurate representation of patients in the VQI.

Variables

The dependent variable, survival time, is defined as the difference between the procedure date and the last date of contact or death. Death is determined by the VQI using either procedural or follow-up data and is updated with the Social Security Death Index semiannually. The primary independent variable was frailty as measured by the VQI-RAI using the following characteristics: sex, age, body mass index (BMI), renal failure, congestive heart failure (CHF), dyspnea, residence other than independent living, preoperative ambulation, and functional status (Supplemental Figure 2). Renal failure was defined as Cr > 1.78 mg/dL or on dialysis, consistent with previous frailty research in the VQI.(17) An activities of daily living (ADL) score was determined by assessing a patient's preoperative ambulation and functional status. To adjust the nutritional domain of the RAI for the available VQI variables, we employed BMI as a measure of frailty. Literature from Hubbard et al. suggests frailty is increased among those with very low (underweight <20 kg/m2) and very high (morbidly obese ≥ 35 kg/m2) BMIs, and we chose to incorporate both extremes.(23) Previous studies using the RAI included three other variables, weight loss, cognitive status, and cancer diagnosis; however, these are not available within the VQI registry. Weighted indicator variables for each component were summed as a continuous composite VQI-RAI score (total scale range: 0–72). The cut-off to dichotomize frail versus non-frail patients was chosen as a VQI-RAI score ≥ 35 based on prior research.(16,21) Covariates included in the analysis for adjustment were procedure type, race, maximum AAA diameter, insurance provider, surgery year, and proportion of OAR cases by center.

Statistics

Frail and non-frail patients in each procedure subtype were compared by t-test or chi-square test for differences in VQI-RAI characteristics and covariates. The average VQI-RAI per center was used to create center-level quintiles. These were then evaluated for trends in VQI-RAI characteristics, frailty, and OAR case proportion using nonparametric Spearman rank correlation. Center-level VQI-RAI differences were assessed by global F test of center ID fixed effects in ANOVA. Relationships between frailty and survival were compared by Kaplan-Meier analysis for OAR and EVAR until 10% of the cohort remained in the sample (four years). A multivariable Cox proportional hazard center-level random intercept model was calculated to evaluate differences in survival time by frailty status adjusted for the aforementioned covariates. Differences in postoperative discharge destination were evaluated with Fisher's exact tests. Statistical significance was assessed at an alpha level of 0.05. All statistical analyses were performed using SAS version 9.4 (Cary, NC, USA).

Results

VQI-derived RAI scores were calculated for each of the 15,803 patients that received either elective OAR or EVAR. The overall mean VQI-RAI score was 27.6 (SD 5.9, range 4 – 56), the mean EVAR VQI-RAI score was 28.3 (SD 5.9, range 4–54), and the mean OAR VQI-RAI score was 25.6 (SD 5.4, range 4 – 56) [p<0.001]. The majority of patients (74.0%) underwent EVAR, and a greater proportion of frail patients received EVAR (85.4%) compared to non-frail patients (72.3%, p<0.001).

In both procedure groups, there were significant differences between frail and non-frail patients [Table I]. For OAR, there were statistically significant differences (p<0.05) between frail and non-frail patients for all VQI-RAI components, in addition to insurance and AAA diameter (p<0.001). For EVAR, there were significant differences for all VQI-RAI components with the exception of gender (0.091), and for race, insurance, and AAA diameter.

Variable components of the VQI-RAI significantly differed between frail OAR and frail EVAR patients, with the exception of CHF ($p = 0.11$) and gender ($p=0.36$). Frail EVAR patients were significantly older than frail OAR patients (mean age 80.1 vs. 76.1, $p < 0.001$) and experienced dyspnea (14.7% vs. 9.6%, $p = 0.018$). In contrast, a larger percentage of frail OAR patients had renal failure compared to the frail EVAR subgroup (41.0% vs. 27.8%, $p < 0.001$) and had an extremely low or high BMI (54.3% vs. 46.9%, $p=0.020$). There was also significantly greater functional dependence among frail patients who underwent EVAR (partially dependent 36.7% and totally dependent 1.1%) compared to OAR (partially dependent 34.8% and totally dependent 0.3%, $p=0.007$).

Frail patients undergoing OAR tended to have proportionately larger aneurysms at the time of repair; 34.8% frail OAR patients compared to 21.0% frail EVAR patients had AAA diameters > 6.5cm ($p<0.001$). Overall, 45.0% of patients underwent elective AAA repair for aneurysms measuring less than 5.5cm, with the overwhelming majority (84.5%) of those repairs being EVARs. Of those patients who had their aneurysms repaired at a diameter < 5.5cm, 9.5% of those patients were frail. Overall, 5.2% of EVARs and 1.6% of OARs were performed on frail patients with aneurysms measuring < 5.5cm.

The mean VQI-RAI score varied significantly across centers, with mean scores ranging from 21.9 in the lowest quintile to 31.8 in the highest quintile ($F=2.41$, $p<0.001$, [Figure 1]). Table II evaluates in greater granularity how the components of the VQI-RAI vary across the center-level quintiles. In the highest quintile with the largest frailty burden (quintile 5), 20.1% were frail whereas in the lowest quintile with the smallest frailty burden (quintile 1) only 7.8% of patients were frail. The percentage of patients who were partially or totally dependent more than tripled for quintile 5 (14.5%) compared to quintile 1 (4.5%). Interestingly, there was an inverse relationship across the quintiles between the proportion of OAR cases and the percentage of frail patients; quintile 5 had 12% OAR cases per center while quintile 1 had on average 40.7% OARs per center.

In Kaplan-Meier analysis, significant differences were observed in survival curves by frailty and procedure groups ($p<0.001$, [Figure 2]). Most of the mortality risk varied during the first postoperative year as the curves plateaued over time. As expected, non-frail EVAR patients had the best initial survival outcomes with 98.6% alive at 3 months, 97.7% at 6 months, 95.9% at 1 year, and 92.9% at 2 years post-operatively. Non-frail OAR patients had similar long-term outcomes with 96.4% survival to 3 months, 95.6% to 6 months, 94.6% to 1 year, and 93.6% to 2 years post-operatively. Survival in the frail subgroups was markedly worse. In the frail OAR subgroup 85.6% survived to 3 months and 83.4% to 6 months, but this proportion dropped to 78.2% alive at 1 year and 74.3% at 2 years post-operatively. The frail EVAR subgroup experienced a similar decline but to a lesser degree with 93.6% alive at 3 months, 90.8% at 6 months, 86.0% at 1 year, and 80.0% alive at 2 years post-operatively.

Frailty was associated with increased hazard of long-term mortality (HR 2.88, 95% CI 2.57–3.21, $p < 0.001$) after adjusting for center-level variance and covariates [Table III]. Notably, there was no increased hazard of mortality in patients who underwent OAR compared to EVAR (HR 0.98, 95% CI 0.86–1.13, p=0.780), and there were no differences in mortality hazard among centers when stratified by percentage of OARs performed. Patients of Hispanic background had significantly lower mortality risk than Caucasian patients (HR 0.54, 95% CI 0.35–0.83, p = 0.006). Compared to commercial insurance, Medicare was associated with increased mortality hazard (HR 1.37, 95% CI 1.21–1.54, p < 0.001); however, Medicaid was not (HR 1.35, 95% CI 0.93–1.95). AAA diameter greater than 5.5 cm was associated with increased long-term mortality (p<0.0001).

In a post-hoc analysis of discharge destination, there were significant differences in the percentage of prior home-dwelling frail patients discharged to either a rehabilitation facility or nursing home following both OAR (40.5% vs. 17.8%, p<0.0001) and EVAR (17.7% vs. 4.6%, p<0.0001) [Table IV]. Overall, just under a fifth (19.3%) of elective OAR patients were discharged to a rehab or nursing facility as were 6.5% of elective EVAR patients. Amongst patients with non-home discharge, long-term mortality was twice that of patients who were discharged home (17.64% vs. 8.37%, p<0.0001).

Discussion

This is the first study to use the VQI-derived RAI to look at the distribution of frailty across VQI centers and evaluate its impact on survival in elective AAA patients. We found that frailty in patients undergoing elective AAA repair varied significantly across centers. Increased long-term mortality following AAA repair was significantly associated with patient frailty (HR 2.88), and although procedure type did not impact long-term mortality, both procedure type and frailty were associated with increased non-home discharge.

Prior studies in AAA patients have demonstrated frailty to be associated with short-term mortality, but this is the first study to examine the impact of frailty on long-term mortality following elective AAA repair.(15) Mortality diverged significantly in frail and non-frail patients within the first year of surgery. EVAR in frail patients did not confer survival advantage beyond the post-operative period. The frail OAR survival curve plateaus beyond two years while the frail EVAR survival curve continues its downward slope to result in the poorest long-term survival outcomes, potentially reflecting the inherent lack of physiologic reserve that may have influenced initial selection of operative approach. Interestingly, non-frail patients who underwent either OAR or EVAR had similar long-term survival. Around the 1.5-year mark the survival curves cross, and the non-frail OAR curve plateaus while the non-frail EVAR curve continues to have a slightly downward slope. These findings echo randomized control trial data from the DREAM, EVAR-1, and OVER trials where there was an early survival advantage of EVAR compared to OAR, but this advantage was not sustained long-term and EVAR was ultimately associated with increased secondary interventions.(24–27) There has been a rapid uptake of EVAR in elective and emergency surgeries in the United States, so it is not surprising that a larger percentage of frail patients underwent EVAR compared to OAR.(28) However, open surgery had equivalent long-term survival results for non-frail patients, and thus OAR should remain an option for patients based on quality of life preferences and need for surveillance and secondary interventions.(24) In our analysis, 1-year mortality for frail patients undergoing EVAR and OAR was high

(~15–20%). The EVAR-2 trial randomly assigned patients physically ineligible for OAR to either EVAR or no repair. Although aneurysm-related mortality was lower following EVAR, overall mortality was the same and EVAR provided no additional mortality benefit.(29) Given these results, it is of utmost importance that long-term survival data be included as part of the shared-decision making process when offering patients elective AAA repair.

Our analysis revealed that 45.0% of patients underwent elective AAA repair below the 5.5cm diameter threshold. In frail patients, 35.6% underwent EVAR and 22.2% underwent OAR with aneurysms measuring less than 5.5cm. The SVS Clinical Practice Guidelines recommend elective repair for patients at low or acceptable surgical risk with a fusiform AAA that is > 5.5cm.(22) This recommendation is based on trials such as the Aneurysm Detection and Management (ADAM) trial where the rupture risk for those unfit for repair was less than 1.0% per year for patients with aortic diameters less than 5.5cm, 9.4% between 5.5 and 5.9 cm, 10.2% between 6.0 and 6.9 cm, and 32.5% for those >7.0 cm.(30,31) A more recent pooled analysis suggested that the current rupture risk may be much lower: 5.3% per year for AAAs between 5.5 and 7.0 cm in diameter and 6.3% per year for AAAs >7.0 cm.(32) Similar to the EVAR-2 trial, the risk of death from causes other than AAA was higher than the risk of death from aneurysm rupture.(29,32)

This raises the important question whether there should be a different size threshold for AAA repair in frail patients. Comparing published data to our Kaplan-Meier survival curves, we suggest that elective aneurysm repair in frail patients be performed only for AAA diameters > 7.0cm as 1-year survival following surgery in frail patients was 86.0% for EVAR and 78.2% for OAR. Future research is required to substantiate the need and threshold for repair as AAA repair clearly sends frail patients down a very different survival trajectory than what may have befallen them without intervention(33). Development of medical therapies for slowing AAA growth, such as the ongoing work in doxycycline and metformin, also has the potential to produce a paradigm shift in our management of AAAs, especially for frail patients.(34,35)

Although age and co-morbidities are associated with poor outcomes, they are not useful as tools for determining candidacy for surgery given the heterogeneity of outcomes.(36,37) Frailty, however, has consistently been shown to predict poor outcomes and more evidence continues to accumulate that frailty is multidimensional and goes beyond merely comorbidities and functional status. The advantage of the RAI is the capture of five domains of frailty; namely, functional, physical, social, cognitive, and nutritional. A prospective version of the RAI has been developed and validated in surgical populations [Supplemental Figure 3].(16) The ease of administration and granular detail provided by the RAI makes it an ideal tool for frailty screening in the vascular surgical population to identify high-risk patients and improve patient selection.(38) It also provides a structured opportunity to elicit patient preferences and incorporate quality of life considerations into the treatment plan.

In the context of AAA repair, frailty could influence the decision between elective surgery versus ongoing surveillance and between possible versus no intervention in case of aneurysm size progression or rupture. Furthermore, we found 40.5% of frail OAR patients and 17.7% of frail EVAR patients were discharged to either a rehab facility or nursing home.

Frail home-dwelling patients undergoing elective vascular procedures are at high risk of not returning home after surgery.(39) However, even in the absence of frailty, discussions regarding post-surgery discharge expectations are important because overall 1 in 5 elective OAR and 1 in 15 elective EVAR patients were discharged to locations other than home. In a study by Edgerton et al., only half of the cardiac surgery patients discharged to an extended care facility return to independent living, thus highlighting that discharge to a rehabilitation facility is not a “benign” event and can lead to prolonged or permanent stay away from home.(40)

There is considerable variability of preoperative frailty among centers performing AAA repair. For some centers, almost a third of their patients qualified as being frail. Establishing a screening program to identify potentially frail patients may allow them to decrease procedural and long-term morbidity and mortality through the implementation of preoperative interventions such as pre-habilitation with exercise. (41) Furthermore, it can help hospitals direct their resources to the highest risk strata to anticipate rehabilitation and discharge needs and include families/caregivers in the process. process. The variability of patient frailty could have a dramatic impact on an individual center’s reporting of surgical outcomes and has implications for ensuring proper hospital quality comparisons. Over the past two decades, authorities such as the Centers for Medicare and Medicaid Services have increased the transparency of reporting hospital quality of care. Understanding that different centers will bear a higher burden of frailty over time will help develop better normalizing methodologies for more appropriate head-to-head hospital comparisons.

There are several limitations to our study, some of which are inherent to the VQI dataset. First, there is a selection bias manifest in the data collection itself as institutions and providers voluntarily submit self-reported data and not all institutions or providers participate in all aspects of the registry. Second, this is a retrospective analysis of prospectively collected data and we are therefore limited in our ability to draw conclusions about causality and the analyses may be subject to residual confounding. Third, variables such as ambulation and functional status are prone to individual interpretation and as a result may introduce unintentional bias. Finally, the VQI database differs from the original RAI dataset, notably missing data on cognition and malignancy. Functional status and cognition are typically recorded in the original RAI as a composite sub-score (ADL*cognition) as cognitive and physical decline often go hand in hand.(42) Since there is no variable available for capturing cognition in the VQI, we assumed the absence of cognitive deficits or dementia and ascribed all the weight for the original ADL*cognition sub-score to the ADL domain in the VQI-RAI. Similarly, the cancer variable is part of a composite sub-score (age*cancer) in the original RAI due to an interaction between age and cancer. In younger patients, frailty is mostly due to the presence of disseminated or poor prognosis malignancies. Since our population’s mean age is > 65 years old, we ascribed all the weight for the original age*cancer sub-score to the age criteria and assumed no active malignancy in VQI patients. Statistically speaking, these assumptions will bias our association results towards the null. If the VQI were to capture the presence of cognitive decline or cancer, we hypothesize more patients would be classified as frail.

The prevalence of cognitive impairment among older patients presenting for vascular surgery is high; 68% in one study and previously unrecognized in 88.3% of those patients.(43) In a recent systematic review, patients deemed frail with cognitive deficits were at higher risk for mortality, morbidity, functional decline, and major adverse events following cardiac surgery.(44,45) Patients with mild cognitive impairment or dementia are at two-fold higher risk of developing postoperative delirium as well as other adverse outcomes.(42,46) Therefore, we believe cognitive status to be a critical component of any preoperative evaluation, and based on our analysis we recommend more granular data regarding cognition be included in VQI data collection to help preoperative assessment and future quality improvement efforts.

Conclusion

Frailty has a significant association with long-term mortality after AAA repair after adjusting for operative approach and variance across centers while operative approach did not influence long-term mortality. There is considerable variability of preoperative frailty among centers, and this may have implications for making accurate hospital comparisons regarding surgical outcomes. Routine measurement of frailty preoperatively by centers to identify high-risk patients and implementation of perioperative interventions may help improve shared-decision making regarding AAA repair and possibly mitigate procedural and long-term mortality.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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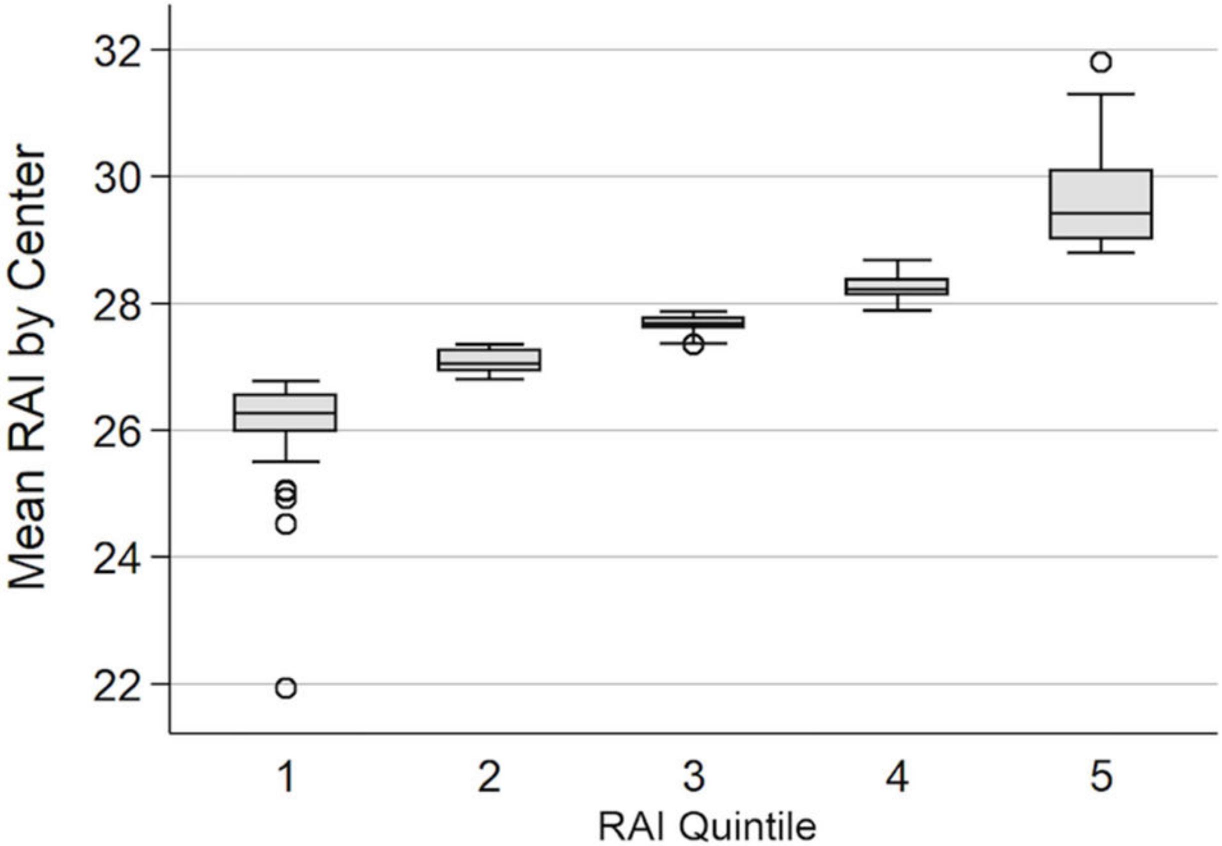
Highlights:

Type of Research:

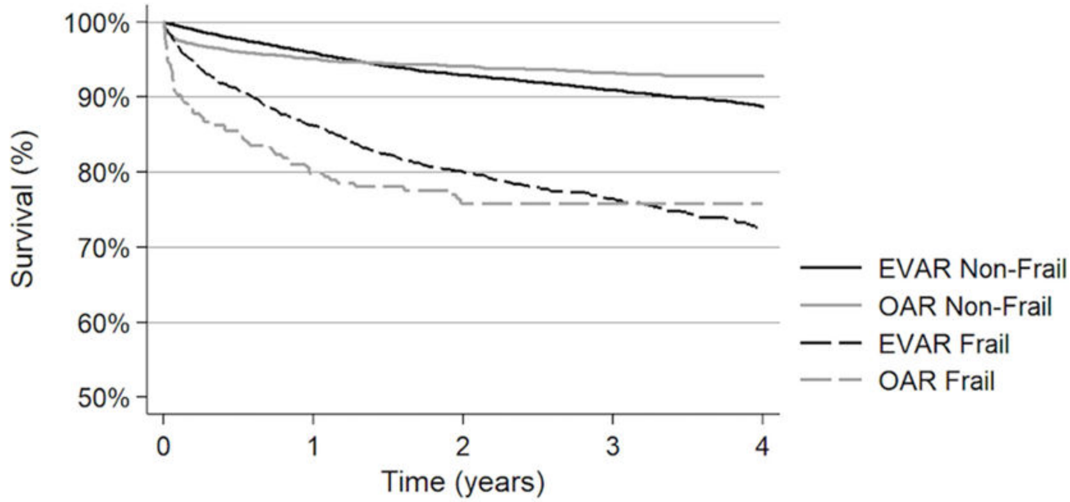
Retrospective review of prospectively collected Vascular Quality Initiative (VQI) data Key Findings: In 15,803 patients undergoing elective open abdominal aortic aneurysm repair (OAR) or endovascular abdominal aortic aneurysm repair (EVAR) frailty, as measured by the VQI-derived Risk Analysis Index (VQI-RAI), was independently associated with long-term mortality [HR 2.88, (2.6, 3.2)] and non-home discharge. OAR was associated with non-home discharge. Frailty varied significantly across centers (F=2.41, p<0.001). Take Home Message: Routine measurement of frailty preoperatively to identify high-risk patients and implementation of perioperative interventions may help mitigate procedural and long-term outcomes and improve shared-decision making regarding AAA repair.



min	21.93	26.79	27.35	27.88	28.80
25th %	25.97	26.93	27.60	28.13	29.02
median	26.27	27.05	27.68	28.22	29.41
75th %	26.55	27.26	27.76	28.38	30.09
max	26.77	27.35	27.87	28.67	31.80

Figure 1.

Variation in center-level frailty burden arranged by quintile based on the average Vascular Quality Initiative-derived Risk Analysis Index (VQI-RAI) score of patients treated at those centers from smallest to largest (N=185 centers). Center-level VQI-RAI differences were assessed by Analysis of Variance (ANOVA) test.



Number at Risk:					
EVAR Non-Frail	9973	8904	7886	5451	2211
OAR Non-Frail	3797	2940	2102	1207	460
EVAR Frail	1715	1324	1079	665	265
OAR Frail	287	187	131	68	28

Figure 2.

Kaplan-Meier adjusted analysis of the impact of frailty (Vascular Quality Initiative-derived Risk Analysis Index (VQI-RAI) score > 35) on long-term survival of patients undergoing open or endovascular AAA repair in the VQI database from 2003–2017. Subgroup survival differences were plotted until 10% of the cohort remained in the sample, which was at four years follow-up.

Table I.

Baseline demographic, Vascular Quality Initiative-derived Risk Analysis Index (VQI-RAI) characteristics, and model covariates of patients undergoing elective abdominal aortic aneurysm repair stratified first by type of repair [open (OAR) versus endovascular (EVAR)] and then by frailty status [frail (VQI-RAI score > 35) versus non-frail)]. Continuous variables are expressed as mean ± standard deviation and categorical variables are reported in total number of observations with associated percentage (%). [N=15,803]

	OAR* (n=4109)		EVAR^ (n=11694)		OAR Frail vs. EVAR Frail
Characteristic	**Frail (n=293)**	**Non-Frail (n=3816)**	**Frail (n=1717)**	**Non-Frail (n=9977)**	**p-value**
VQI-RAI components					
Age, Mean (SD)	76.1 (6.4)	68.9 (8.1)	80.1 (6.6)	73.0 (8.4)	<0.0001
Age, Range	54.−90.0	21.0−90.0	56.0−90.0	20.0–90.0	
Nutrition Score – underweight or morbidly obese, n (%)	159 (54.3)	407 (10.7)	806 (46.9)	1007 (10.1)	0.0204
Renal Failure - Cr > 1.78 or on dialysis, n (%)	120 (41.0)	104 (2.7)	477 (27.8)	198 (2.0)	<0.0001
Congestive Heart Failure, n (%)	90 (30.7)	230 (6.0)	611 (35.6)	821 (8.2)	0.1061
Dyspnea, n (%)	28 (9.6)	71 (1.9)	253 (14.7)	368 (3.7)	0.0181
Living status – not living independently, n (%)	5 (1.7)	19 (0.5)	128 (7.5)	88 (0.9)	<0.0001#
ADL score, n (%)					0.0067#
Totally Independent	190 (64.9)	3685 (96.6)	1069 (62.3)	9657 (96.8)	
Partially Dependent	102 (34.8)	131 (3.4)	630 (36.7)	320 (3.2)	
Totally Dependent	1 (0.3)	0 (0.0)	18 (1.1)	0 (0.0)	
Male sex, n (%)	235 (80.2)	2819 (73.9)	1415 (82.4)	8049 (80.7)	0.3626
Covariates					
Race, n (%)					0.0002#
Caucasian	252 (86.0)	3372 (88.4)	1519 (88.5)	8998 (90.2)	
African American	22 (7.5)	160 (4.2)	99 (5.8)	411 (4.1)	
Hispanic	6 (2.1)	98 (2.6)	41 (2.4)	253 (2.5)	
Asian	4 (1.4)	52 (1.4)	18 (1.1)	130 (1.3)	
Not reported/Other	9 (3.1)	134 (3.5)	40 (2.3)	185 (1.9)	
Insurance, n (%)					<0.0001#
Medicare	206 (70.3)	1998 (52.4)	1241 (72.3)	6312 (63.3)	
Medicaid	9 (3.1)	124 (3.3)	20 (1.2)	169 (1.7)	
Commercial	63 (21.5)	1395 (36.6)	390 (22.7)	3106 (31.1)	
Not reported/Other	15 (5.1)	299 (7.8)	66 (3.8)	390 (3.9)	
AAA diameter, n (%)					<0.0001
Less than 4.50cm	14 (4.8)	263 (6.9)	110 (6.4)	834 (8.4)	
4.50 – 5.49cm	51 (17.4)	1133 (29.7)	501 (29.2)	4203 (42.1)	
5.50 – 6.49cm	126 (43.0)	1492 (39.1)	746 (43.5)	3576 (35.8)	

	OAR* (n=4109)		EVAR^ (n=11694)		OAR Frail vs. EVAR Frail
Characteristic	**Frail (n=293)**	**Non-Frail (n=3816)**	**Frail (n=1717)**	**Non-Frail (n=9977)**	**p-value**
6.50 – 7.49cm	61 (20.8)	490 (12.8)	223 (13.0)	865 (8.7)	
7.50cm or larger	41 (14.0)	438 (11.5)	137 (8.0)	499 (5.0)	

*OAR: All comparisons between frail and non-frail groups showed statistically significant differences ($p < 0.05$) between the groups with the exception of race, p=0.118.

^EVAR: All comparisons between frail and non-frail groups showed statistically significant differences ($p < 0.05$) between the groups with the exception of sex, p = 0.091.

#p-values were calculated with Fisher's exact test

AAA: Abdominal aortic aneurysm; ADL: Activities of Daily Living; EVAR: Endovascular aortic aneurysm repair; OAR: Open aortic aneurysm repair; RAI: Risk Analysis Index; VQI: Vascular Quality Initiative

Table II.

Comparison of individual Vascular Quality Initiative-derived Risk Analysis Index (VQI-RAI) components, percentage of frail patients, and average proportion of open abdominal aortic aneurysm repairs (OAR) across quintiles grouped by mean VQI-RAI score. Note the inverse relationship between frailty burden and proportion of OAR performed within each quintile. [N=185 centers and 15,803 patients]

Center-level Quintile	**1**	**2**	**3**	**4**	**5**	**p-value***
Number of Centers within each Quantile	**37**	**37**	**37**	**37**	**37**	
Patients within Center-level Quantile, n (% total patients)	**n=2642 (16.7)**	**n=3347 (21.2)**	**n=4342 (27.5)**	**n=3668 (23.2)**	**n=1804 (11.4)**	
VQI-RAI components						
Age, mean (SD)	70.9 (8.6)	72.3 (8.4)	72.9 (8.7)	73.9 (8.6)	74.4 (8.8)	<0.001
Underweight or morbidly obese, n (%)	343 (13.0)	486 (14.5)	637 (14.7)	597 (16.3)	316 (17.5)	<0.001
Renal Failure - Cr > 1.78 or on dialysis, n (%)	139 (5.3)	158 (4.7)	241 (5.6)	229 (6.2)	132 (7.3)	<0.001
Congestive Heart Failure, n (%)	196 (7.4)	339 (10.1)	539 (12.4)	373 (10.2)	305 (16.9)	<0.001
Dyspnea, n (%)	93 (3.5)	163 (4.9)	172 (4.0)	198 (5.4)	94 (5.2)	0.003
Residence other than independent living, n (%)	26 (1.0)	45 (1.3)	56 (1.3)	65 (1.8)	48 (2.7)	<0.001
ADL Partially/Totally Dependent, n (%)	118 (4.5)	182 (5.4)	341 (7.9)	299 (8.2)	262 (14.5)	<0.001
Male sex, n (%)	2098	2630	3487	2910	1393	0.431
	(79.4)	(78.6)	(80.3)	(79.3)	(77.2)	
Frail, n (%)	205 (7.8)	345 (10.3)	551 (12.7)	546 (14.9)	363 (20.1)	<0.001
Proportion OAR, n (%)	1075 (40.7)	1036 (31.0)	1046 (24.1)	735 (20.0)	217 (12.0)	<0.001

*p-values were calculated by Spearman nonparametric tests for trend

OAR: Open abdominal aortic aneurysm repair; RAI: Risk Analysis Index; VQI: Vascular Quality Initiative

Table III.

Multivariable Cox proportional hazard center-level random intercept model to evaluate differences in survival time by frailty status and procedure type [open (OAR) versus endovascular (EVAR) abdominal aortic aneurysm (AAA) repair]. The model was adjusted for procedure type, race, insurance, AAA diameter, surgery year, and proportion of open cases by center [N=15,772].

	Hazard Ratio (95% CI)	p-value
Frailty	2.88 (2.57, 3.21)	< 0.0001
Procedure Type		
EVAR	Referent	
OAR	0.98 (0.86, 1.13)	0.780
Race		
Caucasian	Reference	
African American	0.94 (0.74, 1.20)	0.633
Hispanic	0.54 (0.35, 1.37)	0.006
Asian	0.84 (0.52, 1.37)	0.478
Not reported/Other	0.65 (0.43, 0.98)	0.041
Insurance		
Commercial	Referent	
Medicaid	1.35 (0.93, 1.95)	0.117
Medicare	1.37 (1.21, 1.54)	<0.0001
Not reported/Other	1.14 (0.81, 1.62)	0.447
AAA Diameter		
Less than 4.50cm	1.05 (0.84, 1.30)	0.684
4.50 − 5.49cm	Referent	
5.50 − 6.49cm	1.35 (1.20, 1.53)	<0.0001
6.50 − 7.40cm	1.95 (1.67, 2.27)	<0.0001
7.50cm or larger	1.88 (1.56, 2.25)	<0.0001
Proportion OAR Quartile		
0 − 9.31%	Referent	
9.32 − 0 20.94%	1.08 (0.83, 1.41)	0.572
20.95 − 33.89%	1.04 (0.79, 1.35)	0.798
33.90 − 100%	0.81 (0.61, 1.08)	0.149
Surgery Year		
2003 − 2011	Referent	
2012	1.08 (0.73, 1.58)	0.713
2013	1.12 (0.76, 1.64)	0.562
2014	0.92 (0.63, 1.36)	0.685
2015	1.09 (0.72, 1.63)	0.696
2016	0.80 (0.52, 1.25)	0.334
2017	1.04 (0.50, 2.17)	0.911

Table IV.

Post-hoc analysis examining the discharge destination of patients undergoing elective abdominal aortic aneurysm repair stratified by frailty status and procedure type. Discharges to an acute/subacute rehab facility or skilled/regular nursing home reported in the Vascular Quality Initiative (VQI) are new following surgery as the VQI defines discharge "home" as inclusive of patients who returned to their pre-operative level of care [N=15,064].

	Discharge Destination				
	Home	**Rehab facility**	**Nursing home**	**Transfer to another hospital**	**p-value***
EVAR Non-Frail, n (%)	9453 (95.1)	249 (2.5)	204 (2.1)	29 (0.3)	<0.0001
OAR Non-Frail, n (%)	3014 (81.2)	427 (11.5)	232 (6.3)	38 (1.0)	
EVAR Frail, n (%)	1383 (81.6)	139 (8.2)	161 (9.5)	11 (0.6)	<0.0001
OAR Frail, n (%)	148 (56.1)	63 (23.9)	44 (16.7)	9 (3.4)	

*p-value calculated by Fisher's exact test

EVAR: Endovascular abdominal aortic aneurysm repair; OAR: open abdominal aortic aneurysm repair