Epidemiology of endovascular and open repair for abdominal aortic aneurysms in the United States from 2004 to 2015 and implications for screening

Kirsten D. Dansey, MD,[a] Rens R. B. Varkevisser, BS,[a] Nicholas J. Swerdlow, MD,[a] Chun Li, MD,[a] Livia E. V. M. de Guerre, BS,[b] Patric Liang, MD,[a] Christina Marcaccio, MD,[a] Thomas F. X. O'Donnell, MD,[a] Brett J. Carroll, MD,[c] *and* Marc L. Schermerhorn, MD,[a] *Boston Mass; and Utrecht, The Netherlands*

CME Activity

Purpose or Statement of Need The purpose of this journal-based CME activity is to enhance the vascular specialist's ability to diagnose and care for patients with the entire spectrum of circulatory disease through a comprehensive review of contemporary vascular surgical and endovascular literature.

Learning Objective

- Understand the current screening criteria for AAA and identify subgroups of men and women who should be screened due to their risk of AAA rupture.

Target Audience This activity is designed for vascular surgeons and individuals in related specialties.

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ABSTRACT

Background: Contemporary national trends in the repair of ruptured abdominal aortic aneurysms (AAAs) and intact AAAs are relatively unknown. Furthermore, screening is only covered by insurance for patients aged 65 to 75 years with a family history of AAAs and for men with a positive smoking history. It is unclear what proportion of patients who present with a ruptured AAA would have been candidates for screening.

Methods: Using the National Inpatient Sample from 2004 to 2015, we identified ruptured and intact AAA admissions and repairs using the International Classification of Diseases codes. We generated the screening-eligible cohort using previously identified proportions of male smokers (87%) and all patients with a family history of AAAs (10%) and applied these proportions to patients aged 65 to 75 years. We accounted for those who could have had a previous AAA diagnosis (17%), either from screening or an incidental detection in patients aged >75 years who had presented with AAA rupture. The primary outcomes were treatment and in-hospital mortality between patients meeting the criteria for screening vs those who did not.

From the Division of Vascular and Endovascular Surgery, Beth Israel Deaconess Medical Center, Boston[a]; the Department of Vascular Surgery, University Medical Center, Utrecht[b]; and the Division of Cardiovascular Medicine, Beth Israel Deaconess Medical Center, Boston.[c]

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Correspondence: Marc L. Schermerhorn, MD, FACS, Division of Vascular and Endovascular Surgery, Beth Israel Deaconess Medical Center, 110 Francis St, Ste 5B, Boston, MA 02215 (e-mail: mscherm@bidmc.harvard.edu).

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Results: We evaluated 65,125 admissions for ruptured AAAs and 461,191 repairs for intact AAAs. Overall, an estimated 45,037 admitted patients (68%) and 25,777 patients who had undergone repair for ruptured AAAs (59%) did not meet the criteria for screening. Of the patients who did not qualify, 27,653 (63%) were aged >75 years, 10,603 (24%) were aged <65 years, and 16,103 (36%) were women. Endovascular AAA repair (EVAR) increased for ruptured AAAs from 10% in 2004 to 55% in 2015 ($P < .001$), with operative mortality of 35%. EVAR increased for intact AAAs from 45% in 2004 to 83% in 2015 ($P < .001$), with operative mortality of 2.0%.

Conclusions: Most patients who had undergone repair for ruptured AAAs did not qualify for screening. EVAR was the primary treatment of both ruptured and intact AAAs with relatively low in-hospital mortality. Therefore, expansion of the screening criteria to include selected women and a wider age range should be considered. (J Vasc Surg 2021;74:414-24.)

Keywords: Abdominal aortic aneurysm outcomes; Endovascular; AAA screening

Abdominal aortic aneurysms (AAAs) are the 15th leading cause of death in the United States.[1] Mortality has remained high in the setting of a ruptured AAA despite the introduction of minimally invasive endovascular AAA repair (EVAR).[2] Prophylactic repair offers much lower mortality and complication rates compared with the repair of ruptured AAAs.[3,4] The U.S. Preventative Task Force (USPTF) has recommended screening men aged 65 to 75 years, with the caveat to only selectively screen men with a negative smoking history.[5] In 2007, the Screening Abdominal Aortic Aneurysms Very Efficiently (SAAVE) Act was implemented. Consequently, the Centers for Medicare and Medicaid Services initiated reimbursement for a one-time aortic ultrasound examination for men aged 65 to 75 years with a positive smoking history and for men and women in the same age group with a family history of AAAs.[6] Although the screening policy has likely contributed to the decrease in the incidence of ruptured AAAs, the proportion of ruptured AAAs occurring in patients currently excluded from screening is unknown.[7] The existing data have suggested that the excluded populations might also benefit from screening.[8,9]

We, therefore, analyzed data from the National (Nationwide) Inpatient Sample (NIS) database from 2004 to 2015 to identify the proportion of patients who had presented for AAA repair but were not eligible for screening. Additionally, we investigated the contemporary trends in admissions, treatment patterns, and outcomes for ruptured and intact AAA repair.

METHODS

Data source. We performed a retrospective cohort analysis of ruptured AAA diagnosis and repair and intact AAA repair using the NIS (formerly known as the Nationwide Inpatient Sample). The NIS was developed and maintained by the Healthcare Cost and Utilization Project and the Agency for Healthcare Research and Quality. NIS currently collects in-hospital diagnoses and procedures for 20% of all discharges of non—Veterans Affairs hospitals in participating states (48 of 50). Before 2012, the NIS collected all hospital discharges from 20% of hospitals. The NIS stratifies the hospitals and applies discharge weights to the sample using information from the National Census Bureau to generate the national estimate. (A list of participating states and more information is available at: www.hcup-us.ahrq.gov/nisoverview.jsp.) The present report was written in accordance with the STROBE (strengthening the reporting of observational studies in epidemiology) guidelines.[10]

Study population. We included the admissions from 2004 to 2015. Because the diagnosis codes in the International Classification of Diseases (ICD) changed from the 9th revision to the 10th revision at the end of 2015, we excluded the last quarter of 2015 to reduce coding variability. We defined the study cohort as admissions with both a diagnosis of AAA (ICD-9 codes, 441.3 [abdominal aneurysm with rupture] and 441.4 [abdominal aneurysm without rupture]) and procedure of AAA repair (ICD-9 codes, 38.34 [aorta resection and anastomosis], 39.25 [aorta-Iliac femoral bypass], 38.44 [replacement of abdominal aorta], 38.64 [excision of aorta], 39.52 [other repair of Aneurysm], and 39.71 [endovascular abdominal aorta repair]).

Clinical and outcome variables. For all patients, we collected age and sex and used the predefined Elixhauser covariates to identify comorbidities.[11] The primary outcomes were admission, treatment, and in-hospital mortality for patients eligible for screening compared with those ineligible for screening. The secondary outcomes included trends in the proportion of EVAR and open repair performed annually for both intact and ruptured AAAs and trends in mortality. The outcomes were compared between EVAR and open repair for intact and ruptured AAAs separately. We performed an additional analysis to evaluate patients aged >65 years and patients with the primary payer as Medicare to directly assess the number and proportion of patients covered by Medicare.

Study population. For the ruptured AAAs, we estimated a screening-eligible and not-eligible cohort using the national estimates, because the NIS does not collect information on smoking status or family history. Reported data from the Vascular Quality Initiative (representing >550 institutions from the United States and Canada) registry reported that 10% of both men and women who had undergone AAA repair had had a family history of AAA and that 87% of male patients who had undergone AAA repair had had a positive smoking history.[12,13] To estimate the number of male patients who would qualify for screening, we used the proportion of 87% of the number of male patients aged 65 to 75 years, based on a presumed positive smoking history. Of the remaining 13% of men, we estimated that 10% would qualify owing to a presumed family history of AAA, because a previous analysis had shown that the smoking rates were similar for those with familial and sporadic AAAs.[12] We assumed that 10% of female patients aged 65 to 75 years would have had a family history of AAA and would, thus, have been eligible for screening. We summed these populations to create the estimated screening-eligible cohort for ruptured AAAs. According to a previous Medicare analysis, 17% of patients who had presented with a ruptured AAA had had a previous diagnosis of an AAA.[14] We, therefore, also included 17% of patients aged >75 years to account for those with a previous diagnosis that could have resulted from a screening study. This assumption that 17% of the patients would have had a previous diagnosis from screening was almost certainly an overestimation, because it is likely that many of these patients had had their AAA detected incidentally. However, given the lack of definitive data, we sought to show the best-case scenario.

Statistical analysis. The categorical variables are presented as percentages and were compared using the Pearson χ^2 test. We performed a Wald test to assess for differences in the mean value for continuous variables. We performed univariate regression analysis with time as a continuous dependent variable and the outcomes as independent variables to test for trends in the outcomes over time. For the graphs reporting absolute numbers stratified by year, we extrapolated the numbers for 2015 using the estimates from the first three quarters of that year. All variables had <3% of missing data.

The NIS uses de-identified data; therefore, the institutional review board of the Beth Israel Deaconess Medical Center waived the requirement for patient informed consent. All statistical analyses were performed using Stata, version 15.1 (StataCorp, College Station, Tex).

RESULTS

Ruptured AAA repair. From 2004 to 2015, 65,125 patients had been admitted with a diagnosis of ruptured AAAs, of whom 69% had undergone repair. A significant decrease was found in the number of admissions (from 6461 in 2004 to 4848 in 2015; $P < .001$), surgery for ruptured AAAs (from 4445 in 2004 to 3283 in 2015; $P < .001$), and proportion of patients undergoing repair (from 71% to 67%; $P < .001$) during the study period (Fig 1, *A*). Of the patients who had undergone repair, 14,012 (31%) had undergone EVAR and 31,693 (69%) had undergone open repair (Table I). In 2004, 10% of all ruptured AAA repairs had been performed with EVAR; however, EVAR had surpassed open repair by 2014, and 55% of all repairs were performed using EVAR in 2015 ($P < .001$; Fig 1, *A*).

ARTICLE HIGHLIGHTS

- **Type of Research:** A retrospective analysis of prospectively collected data from a national administrative database
- **Key Findings:** We identified 65,125 admissions for ruptured abdominal aortic aneurysms (AAAs) and 461,191 repairs for intact AAAs. Of the patients who had presented with ruptured AAAs and those who had undergone repair of ruptured AAAs, 68% and 59% had not qualified for screening, even after accounting for patients with a previous diagnosis.
- **Take Home Message:** The majority of patients who were admitted and underwent repair for ruptured AAA did not meet criteria for screening. Endovascular repair overtook open repair as the primary treatment for ruptured and intact AAA and mortality of ruptured AAA decreased over the study time period.

Ruptured AAA outcomes. The overall in-hospital mortality after repair of ruptured AAAs was 35%. However, a decrease occurred in mortality during the study period, from 42% in 2004 to 28% in 2015 ($P < .001$). For the entire study period, the patients who had undergone EVAR had had lower rates of in-hospital mortality compared with those who had undergone open repair (25% vs 40%; $P < .001$; Table I). The mortality after EVAR had also decreased during the study period time (from 30% to 21%; $P = .05$). A decrease was also seen in the mortality after open repair during the study period (44% vs 36%; $P < .001$; Fig 1, *B*).

Ruptured AAAs stratified by screening eligibility. Of the 65,125 patients admitted with a diagnosis of a ruptured AAA, 44,155 (68%) would have been ineligible for screening. A flowchart of the screening eligibility cohort is shown in Fig 2. A total of 18,755 women had been admitted with a ruptured AAA; 16,103 (86%) of whom would have been ineligible for screening by their age or the absence of a presumed family history or previous diagnosis. For the 4623 women aged 65 to 75 years, we would expect 10% to have had a family history of AAAs, resulting in 462 women who could be included in

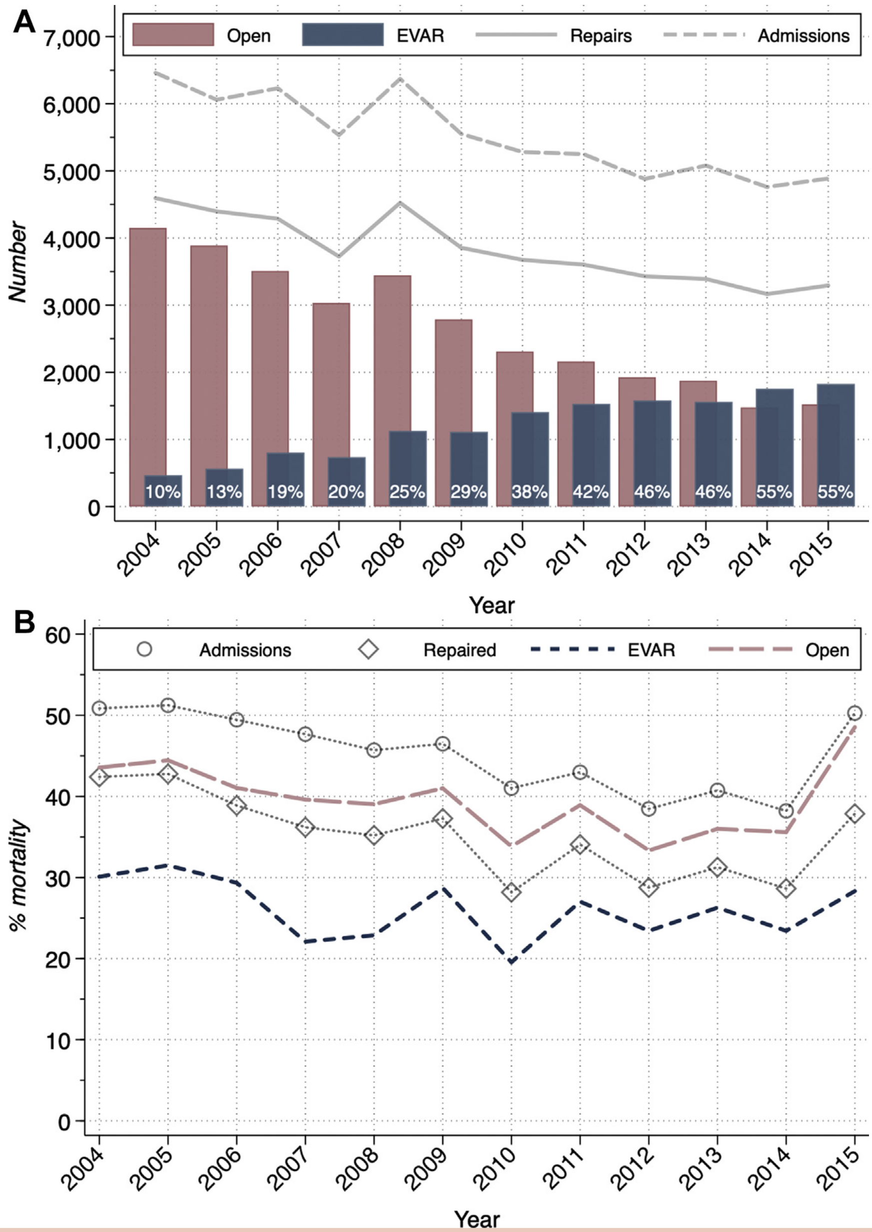

Fig 1. **A,** Proportion of ruptured abdominal aortic aneurysms stratified by treatment annually. **B,** Mortality of those with ruptured abdominal aortic aneurysms who were admitted, underwent repair, and stratified by repair each year. *EVAR,* Endovascular abdominal aortic aneurysm repair.

the screening-eligible cohort. Furthermore, to account for those patients with a previous diagnosis, we included 17% of women aged >75 years (ie, 2147 women) in the screening-eligible cohort. Thus, the vast majority (86%) of women with an AAA rupture were in the screening-ineligible cohort. A total of 46,371 men had been admitted with a ruptured AAA; 29,715 (64%) of whom would have been ineligible for screening by their age. Of the 16,655 men aged 65 to 75 years, we predicted that 14,490 (87%) would have been eligible for screening because of a positive smoking history. Of the remaining 2165 men (13%), we estimated that 217 (10%) would have been eligible for screening owing to a positive family history for AAAs. To estimate the total number of patients with a previous diagnosis, we included 17% of all patients aged >75 years (ie, 33,455 men) for a total of 5802 patients. We then summed the estimates, for a total of 20,971 patients (32%) who would have qualified for screening (Fig 2).

Patients aged >75 years constituted 63% of the screening-ineligible population, patients aged <65 years accounted for 24% of the cohort, women comprised 36% (some of whom were also aged <65 years or >75 years) of the cohort, and women aged 65 to 75 years constituted 13% of the

Table I. Baseline demographics and outcomes for ruptured abdominal aortic aneurysm (AAA) stratified by repair type

Variable	Overall	EVAR	Open	*P* value
Total, No.	45,117	14,011	31,693	NA
Mean age, years	73.1 ± 0.11	73.8 ± 0.19	72.7 ± 0.13	<.001
Female sex, %	23	21	24	.02
White race, %	86	86	86	.50
Congestive heart failure, %	2.0	1.6	2.1	.08
Diabetes mellitus, %	13	15	12	<.001
Renal failure, %	17	20	15	<.001
Obesity, %	8.7	10	8.0	<.001
Income <50% of median household, %	52	52	51	.62
Insurance, %				
Medicare	72	74	72	.07
Medicaid	3.0	2.7	3.1	.25
Private insurance	19	18	20	.15
Self-pay	3.3	2.7	3.5	.10
No charge	0.3	0.4	0.2	.13
Other	2.3	2.5	2.2	.26
In-hospital mortality, %	35	25	40	<.001

EVAR, Endovascular abdominal aortic aneurysm repair.

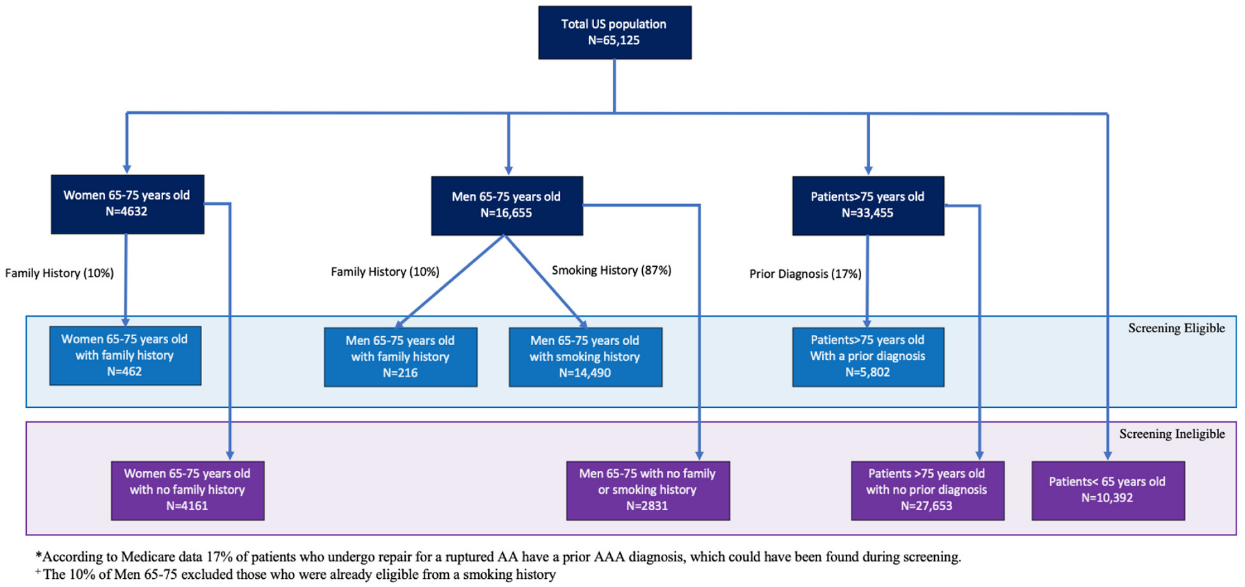

Fig 2. Flow chart showing inclusion criteria for patients who met the screening criteria for ruptured abdominal aortic aneurysms (AA, AAA).

cohort. Of those patients admitted with a ruptured AAA who had died, 70% were screening ineligible. Among the patients admitted with a ruptured AAA, those who were ineligible for screening had had higher hospital mortality compared with the screening-eligible patients (45% vs 34%; $P < .001$). The perioperative mortality for the screening-eligible cohort was 39% compared with 30% for the screening-ineligible cohort ($P < .001$). However, because most (59%) of the patients taken to the operating room for repair had not been eligible for screening, the ineligible patients comprised most of the postoperative deaths (65%; Fig 3).

Ruptured AAAs in women. A total of 65,125 patients had been admitted for a ruptured AAA, of whom 18,755 were women (29%). Of the 45,117 patients (69%)

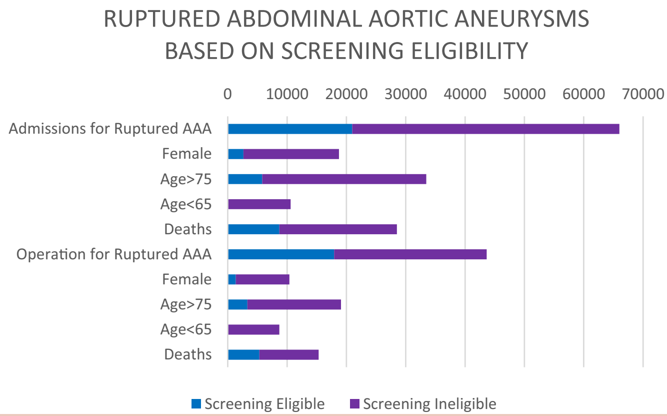

Fig 3. Graph showing ruptured abdominal aortic aneurysms (*AAAs*) stratified by screening eligibility.

Table II. Baseline demographics and outcomes for intact abdominal aortic aneurysm (AAA) stratified by repair type

Variable	Overall	EVAR	Open	*P* value
Total, No.	461,191	322,111	143,538	NA
Mean age, years	72.6 ± 0.05	73.6 ± 0.05	70.3 ± 0.08	<.001
Female sex, %	21	19	27	<.001
White race, %	88	88	88	.15
Congestive heart failure, %	0.4	0.3	0.7	<.001
Diabetes mellitus, %	16	17	14	<.001
Renal failure, %	12	11	12	.58
Obesity, %	7.9	8.3	7.0	<.001
Income <50% of median household, %	51	51	52	.49
Insurance, %				
Medicare	77	80	70	<.001
Medicaid	2.0	1.6	2.5	<.001
Private insurance	19	16	24	<.001
Self-pay	0.9	0.7	1.4	<.001
No charge	0.1	0.1	0.2	<.001
Other	1.5	1.4	1.7	<.001
In-hospital mortality, %	2.0	0.9	4.7	<.001

EVAR, Endovascular abdominal aortic aneurysm repair.

admitted with a ruptured AAA who had undergone repair, 10,388 were women (23%), of whom 29% had undergone EVAR. Female patients accounted for disproportionately high percentages of in-hospital mortality, comprising 35% of deaths for all patients with AAA ruptured and 27% of deaths after repair. After repair, women had had postoperative mortality of 41% (31% EVAR vs 45% open; $P < .001$).

Ruptured AAAs in patients aged <65 years. Patients aged <65 years represented 16% of all ruptured AAA admissions and 11% of all deaths for those admitted with a ruptured AAA. Younger patients represented 19% of those who had undergone surgery for a ruptured AAA (30% EVAR) and 11% of the postoperative deaths. The postoperative mortality for these patients was 20% (13% EVAR vs 23% open; $P < .001$), and 13% of these younger patients were women.

Ruptured AAAs in patients aged >75 years. Patients aged >75 years represented 51% of the patients admitted with a ruptured AAA but 64% of the deaths. These older

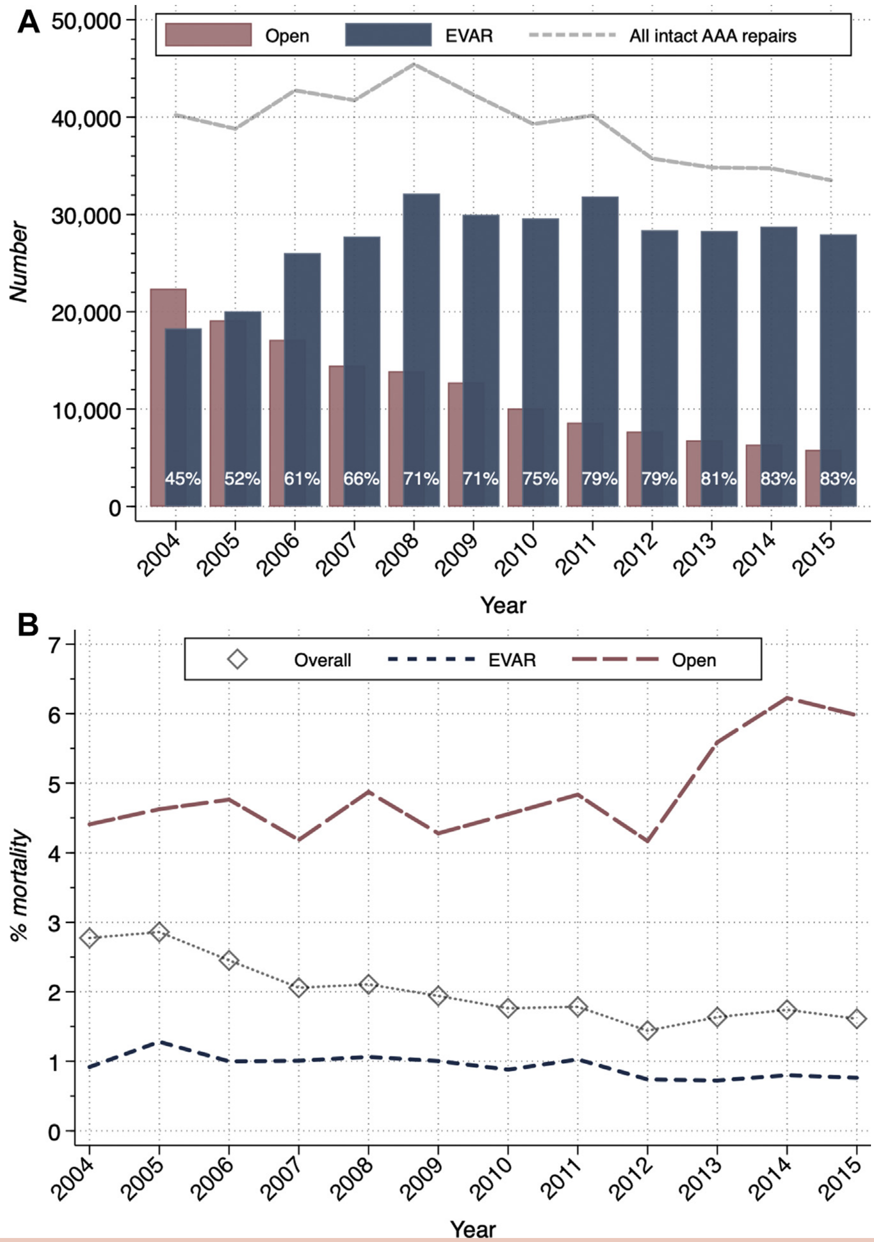

Fig 4. A, Proportion of intact abdominal aortic aneurysms (*AAAs*) treated annually. **B,** Mortality of those admitted for intact AAA repair. *EVAR,* Endovascular abdominal aortic aneurysm repair.

patients constituted 42% of those who had undergone surgery (33% EVAR) and 55% of the postoperative deaths. The postoperative in-hospital mortality for the older patients who had been taken to the operating room was 45% (33% EVAR vs 51% open), and 29% were women.

Intact AAA repair. We identified 461,191 patients who had undergone repair of an intact AAA. Of these repairs, 70% were EVAR and 30% were open (Table II). A significant decrease was found in the number of operations performed for intact AAA repair during the study period (from 40,225 in 2004 to 33,488 in 2015; $P < .001$; Fig 4, *A*).

Of all patients undergoing repair of intact AAAs, 322,111 (73%) had undergone EVAR and 143,538 (27%) had undergone open repair (Table II). In 2005, EVAR had surpassed the number of open repairs for intact AAA repair, and the proportion of EVAR had reached 85% by 2015 (Fig 4, *A*).

Intact AAA repair outcomes. The in-hospital mortality rate for all admissions after intact repair using either EVAR or open repair was 2.0%, representing a decrease from 2.8% in 2004 to 1.6% in 2015 ($P < .001$; Fig 4, *B*). The overall mortality after EVAR was 0.9%, which was lower than the

4.7% after open repair ($P < .001$; Table II). The mortality after EVAR decreased during the study period from 0.9% to 0.8% ($P < .001$). However, the mortality after elective open repair had increased from 4.4% to 6.0% ($P = .02$; Fig 4, *B*).

Intact AAAs in women. Women comprised 21% (n = 96,815) of all patients treated for an intact AAA (62% EVAR vs 38% open repair) but constituted 37% of all patients who had died after intact repair, with a perioperative mortality of 3.6% (2.0% EVAR vs 6.6% open repair). The average age of the women who had undergone repair of intact AAAs was 74 years compared with 72 years for the men.

Intact AAAs in patients aged <65 years. Patients aged <65 years comprised 17% of the patients treated for an intact AAA (58% EVAR vs 42% open repair), with a lower proportion of women (15% vs 22%; $P < .001$). Of the patients who had died after intact repair, younger patients comprised ∼11%, with a perioperative mortality of 1.3% (0.5% EVAR vs 2.4% open).

Intact AAAs in patients aged >75 years. Patients aged >75 years represented 40% (n = 184,258) of those who had undergone repair for an intact AAA (77% EVAR vs 23% open) but constituted 53% of those who had died postoperatively. Of the patients in this age cohort, 25% were women. Overall, patients aged >75 years had had postoperative mortality of 2.7% (1.3% EVAR vs 7.5% open).

DISCUSSION

We found that 68% of patients admitted for a ruptured AAA were not candidates for screening. Most (61%) of the patients who had not qualified for screening were aged >75 years. In addition, 24% were aged <65 years, 9% were women without a family history of an AAA and aged 65 to 75 years, and 6% were men aged 65 to 75 years without a positive smoking history or family history of AAAs. We confirmed the increasing dominance of EVAR, the decreasing overall mortality after repair, and the consistent lower mortality after EVAR compared with that after open repair. The overall mortality after repair of intact AAAs has remained low, even for the elderly when using EVAR, although the mortality after open repair has been increasing.

When Congress passed the SAAVE Act, the USPTF also issued their first recommendations for AAA screening. The USPTF recommended a one-time ultrasound examination for men aged 65 to 75 years with a positive smoking history.[15,16] However, the current USPTF guidelines, updated in 2019 to include men aged 65 to 75 years with a family history of AAAs, have continued to recommend against screening for women.[5] Furthermore, both sets of guidelines were based primarily on the results from four randomized clinical trials, which had studied almost exclusively open repair for men, most of whom were aged 65 to 75 years.[17-20] We found that EVAR had become the primary treatment modality for ruptured AAAs in 2014 and for intact AAA repair in 2005, with 85% of all intact AAAs repaired by EVAR by 2015.

In the guidelines, which are not representative of current experience, the advantage of using EVAR is missed when calculating which patients would benefit from this low-risk procedure. Patients aged >75 years constituted more than one half of the patients admitted with AAA rupture and represent a critical and increasing screening-ineligible population. This population will realize an especially high benefit of undergoing repair of intact AAAs, given the difference in mortality of 45% after repair of ruptured AAAs vs 1.3% after repair of intact AAAs. Although certain high-risk patients might not benefit from EVAR, validated risk prediction models can be used to aid in the preoperative clinical decision-making.[21] A recent study evaluating elective EVAR for patients aged ≥75 years found perioperative mortality of 1.4% and 5-year survival of 88%.[8] With the increasing use of EVAR, formerly higher risk patients now have a robust option for repair, and we believe that the screening guidelines should be expanded to reflect this possibility. Given the life expectancy of 12 years for those patients who live to 75 years and the low operative mortality with EVAR, it might be inappropriate to withhold AAA screening for these patients.[22]

Our data have corroborated the reported data that ∼20% of the patients with a ruptured AAA will be aged <65 years.[23] Younger patients have had excellent 1-year survival of 97% when the AAA was repaired in an elective setting.[24] Furthermore, cost prediction models have demonstrated an improvement in quality-adjusted life years and suggested a potential costs saving by performing the repair in younger patients.[25] Discerning which patients aged <65 years should qualify for screening is complex. Patients with a family history of AAA have had greater rates of rupture, and some have questioned whether these patients would benefit from earlier screening because their pathology appears to be more aggressive.[26,27] Other studies have identified modifiable risk factors that increase the odds of AAAs, which might help further identify which of these patients would benefit from earlier screening.[28] This question should be an area of further investigation.

Few studies have assessed the clinical and cost benefit of screening women and those who have significant limitations. The single randomized controlled trial was underpowered, and the most recent cost analysis used data composed of disproportionate numbers of open repairs, resulting in high operative mortality.[29,30] These data led to the current screening guidelines. Medicare only reimburses screening for women with a family history of AAAs, which, according to the present data, will only be 2% of those women whose AAA will rupture. The USPTF guidelines, which have recommended against screening women entirely, thus exclude ~30% of the patients presenting with a ruptured AAA, according to our study.[31]

Because the clinical scenario and decision-making differs between the sexes, the same criteria used to justify screening for men might not be appropriate for women. However, the United Kingdom's National Institute for Health Care and Excellence guidelines for AAA diagnosis and management found benefit for AAA screening for a prevalence as low as 0.35%.[32] It would, therefore, be reasonable to conclude that screening women, who have a prevalence of AAA of 1.7% (reported for women with a positive smoking history) would be cost-effective, as was recommended in the National Institute for Health Care and Excellence guidelines.[33-35] Furthermore, evidence has shown that women with ectatic infrarenal aortas might benefit from ≤5 years of follow-up with ultrasound examinations.[36] Although data have shown that AAAs in women will not only rupture at smaller diameters but that these women will also experience greater mortality when repaired in the urgent setting, the disproportionate outcomes are mitigated when AAAs are repaired in the elective setting.[37,38] Thus, the use of elective repair will optimize outcomes and reduce the disparity between the sexes.

The mortality after intact open AAA repair has increased over time, from 4.3% in 2004 to 5.5% in 2015. This might have been an aggregate effect of the increased use of EVAR and selection bias, because patients with more complex anatomy unsuited for EVAR will be more likely to undergo open repair. Although the endovascular options for patients with more complex anatomy have been increasing, not all hospitals perform complex endovascular repair, leaving patients with open repair as their only option.[39] It is not clear whether endovascular repair of complex aneurysms is superior to open repair because long-term data are lacking. In addition, the association of higher volume centers and surgeons with lower operative mortality after open repair is well-established.[40] These data support the Society for Vascular Surgery guidelines that open repair should be limited to centers performing ≥10 procedures annually.[41] Additionally, with only 15% of intact AAA repairs performed using open surgery, concern exists that trainees will not be prepared to perform open aneurysm repairs in practice.[42] Further research is required to explore methods to supplement the education of trainees.

The numbers of ruptured AAA admissions decreased overtime (from 6461 in 2004 to 4848 in 2015; $P < .001$). We hypothesized that screening and the evolution of EVAR were partly responsible for this reduction, in addition to the decreased rates of smoking.[43,44] However, the number of repairs for ruptured AAAs remained largely unchanged, calling into question whether screening has been fully utilized. Other studies have demonstrated that screening rates have remained low even after enacting the SAAVE act.[45] European countries have effectively expanded their screening programs, with a 90% inclusion rate.[46] If the United States were able to improve adherence to screening criteria, expanding the criteria to include patients aged >75 years would be superfluous.

The present study had some limitations, which must be interpreted in the context of the design and source of the data. The NIS does not include information about family history, smoking status, or previous AAA diagnosis. We applied previously described proportions to this population to estimate those patients who would have been eligible for screening. Furthermore, we were unable to determine which patients aged >75 years would have undergone a screening ultrasound scan but who were considered unfit for elective repair.

CONCLUSIONS

Most patients with a ruptured AAA did not meet the criteria for screening, suggesting a need for reconsideration of the current screening paradigm. Of those admitted with a ruptured AAA, more than one half were aged >75 years and almost one quarter were aged <65 years, with women constituting a significant portion of the population. Using previously established risk factors such as age, cardiovascular disease, and tobacco use, further studies are needed to design a more sensitive screening algorithm to capture the high-risk patients in these excluded populations. In addition, the current guidelines should reflect the current management of AAAs for which EVAR is the predominant treatment and is associated with low postoperative mortality.

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AUTHOR CONTRIBUTIONS

Conception and design: KD, RV, MS
Analysis and interpretation: NS, CL, LdG, PL, CM, TO, BC, MS
Data collection:
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REFERENCES

1. Centers for Disease Control and Prevention. Deaths, percent of total deaths, and death rates for the 15 leading causes of death in 5-year age groups, by race, and sex: United States, 2015. Available at: https://www.cdc.gov/nchs/data/dvs/lcwk/lcwk1_hr_2015.pdf. Accessed December 2019.

2. Abdulameer H, Al Taii H, Al-Kindi SG, Milner R. Epidemiology of fatal ruptured aortic aneurysms in the United States (1999-2016). J Vasc Surg 2019;69:378-384.e2.
3. Mani K, Bjorck M, Lundkvist J, Wanhainen A. Improved long-term survival after abdominal aortic aneurysm repair. Circulation 2009;120:201-11.
4. Dua A, Kuy S, Lee CJ, Upchurch GR Jr, Desai SS. Epidemiology of aortic aneurysm repair in the United States from 2000 to 2010. J Vasc Surg 2014;59:1512-7.
5. Guirguis-Blake JM, Beil TL, Senger CA, Coppola EL. Primary care screening for abdominal aortic aneurysm: updated evidence report and systematic review for the US Preventive Services Task Force. JAMA 2019;322:2219-38.
6. U.S. Centers for Medicare and Medicaid services. Abdominal aortic aneurysm screenings, 2019. Available at: https://www.medicare.gov/coverage/abdominal-aortic-aneurysm-screenings. Accessed December 2019.
7. Ali MU, Fitzpatrick-Lewis D, Miller J, Warren R, Kenny M, Sherifali D, et al. Screening for abdominal aortic aneurysm in asymptomatic adults. J Vasc Surg 2016;64:1855-68.
8. O'Donnell TFX, Wade JE, Liang P, Li C, Swerdlow NJ, DeMartino RR, et al. Endovascular aneurysm repair in patients over 75 is associated with excellent 5-year survival, which suggests benefit from expanded screening into this cohort. J Vasc Surg 2019;69:728-37.
9. Lo RC, Bensley RP, Hamdan AD, Wyers M, Adams JE, Schermerhorn ML, et al. Gender differences in abdominal aortic aneurysm presentation, repair, and mortality in the Vascular Study Group of New England. J Vasc Surg 2013;57:1261-8. e1-5.
10. von Elm E, Altman DG, Egger M, Pocock SJ, Gotzsche PC, Vandenbroucke JP. Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies. BMJ 2007;335:806-8.
11. Elixhauser A, Steiner C, Harris DR, Coffey RM. Comorbidity measures for use with administrative data. Med Care 1998;36:8-27.
12. Ryer EJ, Garvin RP, Zhou Y, Sun H, Pham A, Orlova K, et al. Outcomes of familial abdominal aortic aneurysm repair in the Vascular Quality Initiative. J Vasc Surg 2019;69:717-727.e1.
13. Zettervall SL, Buck DB, Soden PA, Cronenwett JL, Goodney PP, Eslami MH, et al. Regional variation exists in patient selection and treatment of abdominal aortic aneurysms. J Vasc Surg 2016;64:921-927.e1.
14. Edwards ST, Schermerhorn ML, O'Malley AJ, Bensley RP, Hurks R, Cotterill P, et al. Comparative effectiveness of endovascular versus open repair of ruptured abdominal aortic aneurysm in the Medicare population. J Vasc Surg 2014;59:575-82.
15. Deficit Reduction Act of 2005. Available at: https://www.congress.gov/bill/109th-congress/senate-bill/1932. Accessed December 2019.
16. Fleming C, Whitlock EP, Beil TL, Lederle FA. Screening for abdominal aortic aneurysm: a best-evidence systematic review for the U.S. Preventive Services Task Force. Ann Intern Med 2005;142:203-11.
17. Ashton HA, Buxton MJ, Day NE, Kim LG, Marteau TM, Scott RA, et al. The Multicentre Aneurysm Screening Study (MASS) into the effect of abdominal aortic aneurysm screening on mortality in men: a randomised controlled trial. Lancet 2002;360:1531-9.
18. Scott RA, Wilson NM, Ashton HA, Kay DN. Influence of screening on the incidence of ruptured abdominal aortic aneurysm: 5-year results of a randomized controlled study. Br J Surg 1995;82:1066-70.
19. Norman PE, Jamrozik K, Lawrence-Brown MM, Le MT, Spencer CA, Tuohy RJ, et al. Population based randomised controlled trial on impact of screening on mortality from abdominal aortic aneurysm. BMJ 2004;329:1259.
20. Lindholt JS, Sorensen J, Sogaard R, Henneberg EW. Long-term benefit and cost-effectiveness analysis of screening for abdominal aortic aneurysms from a randomized controlled trial. Br J Surg 2010;97:826-34.
21. Neal D, Beck AW, Eslami M, Schermerhorn ML, Cronenwett JL, Giles KA, et al. Validation of a preoperative prediction model for mortality within 1 year after endovascular aortic aneurysm repair of intact aneurysms. J Vasc Surg 2019;70:449-461.e3.
22. Administration for Community Living. Profile of Older Americans. Administration on Aging, U.S. Department of Health and Human Services. Available at: https://acl.gov/about-community-living. Accessed December 2019.
23. Laine MT, Vanttinen T, Kantonen I, Halmesmaki K, Weselius EM, Laukontaus S, et al. Rupture of abdominal aortic aneurysms in patients under screening age and elective repair threshold. Eur J Vasc Endovasc Surg 2016;51:511-6.
24. Liang NL, Reitz KM, Makaroun MS, Malas MB, Tzeng E. Comparable perioperative mortality outcomes in younger patients undergoing elective open and endovascular abdominal aortic aneurysm repair. J Vasc Surg 2018;67:1404-1409.e2.
25. Grant SW, Sperrin M, Carlson E, Chinai N, Ntais D, Hamilton M, et al. Calculating when elective abdominal aortic aneurysm repair improves survival for individual patients: development of the Aneurysm Repair Decision Aid and economic evaluation. Health Technol Assess 2015;19:1-154. v-vi.
26. van de Luijtgaarden KM, Verhagen HJ. What a vascular surgeon should know about familial abdominal aortic aneurysm. Eur J Vasc Endovasc Surg 2015;50:137-8.
27. Sakalihasan N, Defraigne JO, Kerstenne MA, Cheramy-Bien JP, Smelser DT, Tromp G, et al. Family members of patients with abdominal aortic aneurysms are at increased risk for aneurysms: analysis of 618 probands and their families from the Liege AAA Family Study. Ann Vasc Surg 2014;28:787-97.
28. Kent KC, Zwolak RM, Egorova NN, Riles TS, Manganaro A, Moskowitz AJ, et al. Analysis of risk factors for abdominal aortic aneurysm in a cohort of more than 3 million individuals. J Vasc Surg 2010;52:539-48.
29. Sweeting MJ, Masconi KL, Jones E, Ulug P, Glover MJ, Michaels JA, et al. Analysis of clinical benefit, harms, and cost-effectiveness of screening women for abdominal aortic aneurysm. Lancet 2018;392:487-95.
30. Scott RA, Bridgewater SG, Ashton HA. Randomized clinical trial of screening for abdominal aortic aneurysm in women. Br J Surg 2002;89:283-5.
31. Agency for Healthcare Research and Quality. Guide to Clinical Preventive Services, 2014. Available at: https://www.uspreventiveservicestaskforce.org/Page/Document/UpdateSummaryFinal/abdominal-aortic-aneurysm-screening. Accessed December 2019.
32. NICE Guideline Updates Team (UK). Risk factors for predicting presence of an abdominal aortic aneurysm. Abdominal aortic aneurysm: diagnosis and management. Evidence review A. NICE Guideline, No. 156. London, UK: National Institute for Health and Care Excellence; 2020.
33. Berger JS, Hochman J, Lobach I, Adelman MA, Riles TS, Rockman CB. Modifiable risk factor burden and the prevalence of peripheral artery disease in different vascular territories. J Vasc Surg 2013;58:673-681.e1.
34. O'Donnell TFX, Landon BE, Schermerhorn ML. AAA screening should be expanded. Circulation 2019;140:889-90.
35. Derubertis BG, Trocciola SM, Ryer EJ, Pieracci FM, McKinsey JF, Faries PL, et al. Abdominal aortic aneurysm in women: prevalence, risk factors, and implications for screening. J Vasc Surg 2007;46:630-5.
36. Söderberg P, Wanhainen A, Svensjö S. Five year natural history of screening detected sub-aneurysms and abdominal aortic aneurysms in 70 year old women and systematic review of repair rate in women. Eur J Vasc Endovasc Surg 2017;53:802-9.
37. O'Donnell TFX, Verhagen HJ, Pratesi G, Pratesi C, Teijink JAW, Vermassen FEG, et al. Female sex is associated with comparable 5-year outcomes after contemporary endovascular aneurysm repair despite more challenging anatomy. J Vasc Surg 2020;71:1179-89.
38. Lo RC, Lu B, Fokkema MT, Conrad M, Patel VI, Fillinger M, et al. Relative importance of aneurysm diameter and body size for predicting abdominal aortic aneurysm rupture in men and women. J Vasc Surg 2014;59:1209-16.
39. Suckow BD, Goodney PP, Columbo JA, Kang R, Stone DH, Sedrakyan A, et al. National trends in open surgical, endovascular, and branched-fenestrated endovascular aortic aneurysm repair in Medicare patients. J Vasc Surg 2018;67:1690-1697.e1.
40. Zettervall SL, Schermerhorn ML, Soden PA, McCallum JC, Shean KE, Deery SE, et al. The effect of surgeon and hospital volume on mortality after open and endovascular repair of abdominal aortic aneurysms. J Vasc Surg 2017;65:626-34.
41. Chaikof EL, Dalman RL, Eskandari MK, Jackson BM, Lee WA, Mansour MA, et al. The Society for Vascular Surgery practice

guidelines on the care of patients with an abdominal aortic aneurysm. J Vasc Surg 2018;67:2-77.e2.

42. Sutzko DC, Andraska E, Boniakowski A, Coleman DM, Osborne NH. Decline of open abdominal aortic aneurysm repair among vascular surgery training programs in the United States. J Am Coll Surg 2017;225:e114-5.
43. Anjum A, Powell JT. Is the incidence of abdominal aortic aneurysm declining in the 21st century? Mortality and hospital admissions for England & Wales and Scotland. Eur J Vasc Endovasc Surg 2012;43:161-6.
44. Schermerhorn ML, Bensley RP, Giles KA, Hurks R, O'Malley AJ, Cotterill P, et al. Changes in abdominal aortic aneurysm rupture and short-term mortality, 1995-2008: a retrospective observational study. Ann Surg 2012;256:651-8.
45. Herb J, Strassle PD, Kalbaugh CA, Crowner JR, Farber MA, McGinigle KL. Limited adoption of abdominal aortic aneurysm screening guidelines associated with no improvement in aneurysm rupture rate. Surgery 2018;164:359-64.
46. Wanhainen A, Björck M. The Swedish experience of screening for abdominal aortic aneurysm. J Vasc Surg 2011;53:1164-5.

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