

## ORIGINAL ARTICLE

# Endovascular vs. Open Repair of Abdominal Aortic Aneurysms in the Medicare Population

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## ABSTRACT

**BACKGROUND**

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Randomized trials have shown reductions in perioperative mortality and morbidity with endovascular repair of abdominal aortic aneurysm, as compared with open surgical repair. Longer-term survival rates, however, were similar for the two procedures. There are currently no long-term, population-based data from the comparison of these strategies.

**METHODS**

We studied perioperative rates of death and complications, long-term survival, rupture, and reinterventions after open as compared with endovascular repair of abdominal aortic aneurysm in propensity-score-matched cohorts of Medicare beneficiaries undergoing repair during the 2001–2004 period, with follow-up until 2005.

**RESULTS**

There were 22,830 matched patients undergoing open repair of abdominal aortic aneurysm in each cohort. The average age of the patients was 76 years, and approximately 20% were women. Perioperative mortality was lower after endovascular repair than after open repair (1.2% vs. 4.8%,  $P<0.001$ ), and the reduction in mortality increased with age (2.1% difference for those 67 to 69 years old vs. 8.5% for those 85 years or older,  $P<0.001$ ). Late survival was similar in the two cohorts, although the survival curves did not converge until after 3 years. By 4 years, rupture was more likely in the endovascular-repair cohort than in the open-repair cohort (1.8% vs. 0.5%,  $P<0.001$ ), as was reintervention related to abdominal aortic aneurysm (9.0% vs. 1.7%,  $P<0.001$ ), although most reinterventions were minor. In contrast, by 4 years, surgery for laparotomy-related complications was more likely among patients who had undergone open repair (9.7% vs. 4.1% among those who had undergone endovascular repair;  $P<0.001$ ), as was hospitalization without surgery for bowel obstruction or abdominal-wall hernia (14.2% vs. 8.1%,  $P<0.001$ ).

**CONCLUSIONS**

As compared with open repair, endovascular repair of abdominal aortic aneurysm is associated with lower short-term rates of death and complications. The survival advantage is more durable among older patients. Late reinterventions related to abdominal aortic aneurysm are more common after endovascular repair but are balanced by an increase in laparotomy-related reinterventions and hospitalizations after open surgery.

N Engl J Med 2008;358:464-74.

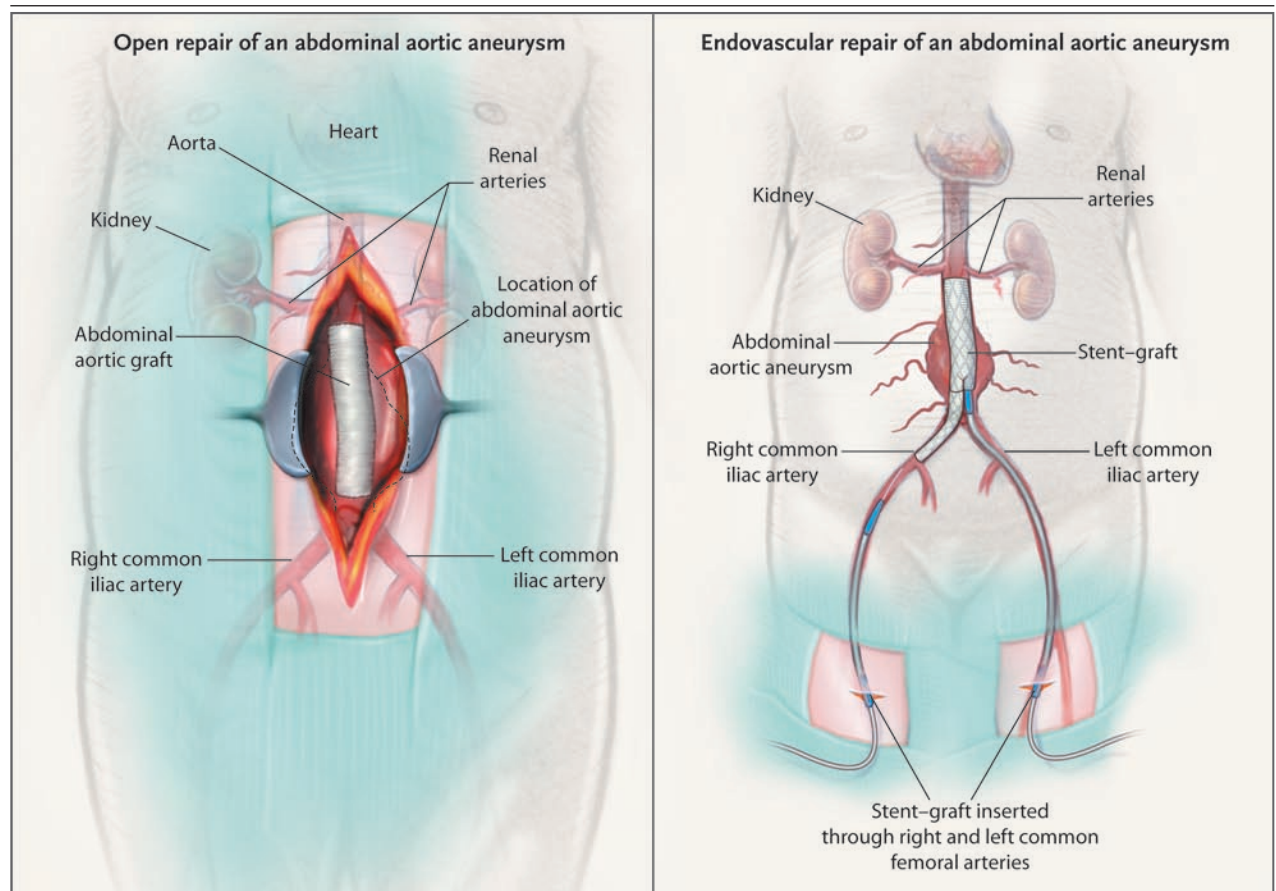
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SINCE THE FIRST REPORT OF ENDOVASCULAR repair of abdominal aortic aneurysm in 1991, the technique has become a mainstay in the repair of abdominal aortic aneurysm, accounting for over 40% of elective repairs of abdominal aortic aneurysm in 2003 (Fig. 1).<sup>1-3</sup> Randomized trials have shown a perioperative survival benefit of endovascular repair over open repair, with fewer complications and a shorter recovery.<sup>4,5</sup>

There are concerns, however, that longer-term outcomes of endovascular repair may not be as durable as those of open repair, with endovascular repair increasing the risk of late rupture of the abdominal aortic aneurysm and necessitating more frequent reinterventions — including conversion to open repair — to preserve the integrity of the aneurysm repair.<sup>6</sup> The risks of complications and death, as well as the expense,

associated with these additional procedures may offset the initial survival benefit observed with endovascular repair.<sup>7-9</sup> In addition, patients enrolled in the clinical trials were highly selected and were generally treated at high-volume referral institutions. Therefore, the experience in those trials may not reflect that in actual practice.

Currently, there are limited data regarding long-term reintervention and rupture after open repair<sup>10,11</sup> or endovascular repair.<sup>6,7,12,13</sup> In addition, there are few data on laparotomy-related reinterventions for problems such as bowel obstruction and abdominal-wall hernia that arise as late complications of open repair. In this study, we used data from the Medicare program to compare short-term and long-term outcomes among matched cohorts of patients with abdominal aortic aneurysm who underwent open or endovascular repair during the 2001-2004 period.



**Figure 1. Open Repair and Endovascular Repair of an Infrarenal Abdominal Aortic Aneurysm.**  
 In endovascular repair, a stent-graft inserted through the right groin is placed just below the renal arteries, and the left limb of the bifurcated device is inserted through the left groin to overlap with the main body of the stent-graft.

## METHODS

## PATIENTS

We identified all Medicare beneficiaries who had undergone elective repair of an abdominal aortic aneurysm during the 2001–2004 period for whom we had at least 2 years of claims data from before the procedure. Patients 67 years of age or older with a discharge diagnosis of abdominal aortic aneurysm without rupture (code 441.4 in the *International Classification of Diseases, 9th Revision, Clinical Modification* [ICD-9-CM]) who also had a procedural code for open surgical repair (38.44 [resection of abdominal aorta with replacement] or 39.25 [aortoiliac–femoral bypass]) or for endovascular repair (39.71 [endovascular implantation of graft]) were included. The codes identifying endovascular repair were introduced in October 2000. We excluded all patients with diagnostic codes for ruptured abdominal aortic aneurysm (441.3), thoracic aneurysm (441.1 or 441.2), thoracoabdominal aortic aneurysm (441.6 or 441.7), or aortic dissection (441.00–441.03). We also excluded those with procedural codes for repair of the thoracic aorta (38.35, 38.45, or 39.73) or visceral or renal bypass (38.46, 39.24, or 39.26).

Beneficiaries enrolled in health maintenance organizations were excluded from the analyses. Only beneficiaries with coverage from both Medicare Part A and Part B were included. Data for all beneficiaries were censored at the end of the 2005 calendar year.

To improve the coding accuracy for endovascular repair and for open repair, we examined physicians' claims corresponding to the period of the hospitalization. In cases in which the codes from the hospital and the physician were in conflict (<5.5% of the sample), we assigned patients to a procedural group on the basis of the physicians' claims, because we thought it most likely that physicians would accurately identify the procedure they performed.

Our study was approved by the institutional review board at Harvard Medical School. All data from patients were rendered anonymous and were held at the Centers for Medicare and Medicaid Services (CMS); the requirement of obtaining informed consent was waived.

## CREATING MATCHED COHORTS

To control for the nonrandom assignment of patients to one of the two procedural groups, we

created matched cohorts of patients after constructing logistic-regression models that predicted the likelihood of endovascular repair (the propensity score). We used all available demographic and clinical characteristics for beneficiaries at baseline as explanatory variables. These data were obtained from claims during the 2-year period before the repair was performed, not including the index admission. We measured the rates of coexisting conditions using a version of the Elixhauser algorithm that was adapted to also include diagnoses made in the outpatient setting.<sup>14,15</sup> We matched each beneficiary who underwent endovascular repair to the beneficiary who underwent open repair with the closest estimated propensity score. To ensure close matches, we required that the estimated log-odds scores for endovascular repair of a patient who underwent endovascular repair and one who underwent open repair be within 0.60 SD of one another. This requirement ensures the removal of approximately 90% of the bias in estimates of effects due to differences in covariate distributions between the endovascular-repair group and the open-repair group.<sup>16,17</sup>

## OUTCOMES

*Mortality*

Perioperative mortality was defined as the percentage of patients who died during the index admission or within 30 days after surgery. Long-term mortality included all deaths during the available follow-up period. Dates of death were obtained from the denominator file of the CMS.

*Perioperative Outcomes and Complications*

We examined length of stay and discharge disposition for each patient. The discharge disposition was classified as discharge to either home or an institutional facility. We identified perioperative complications of several types: those related to abdominal aortic aneurysm (i.e., conversion from endovascular repair to open repair, removal of an infected graft, or return to the operating room for bleeding), those related to the vasculature or abdomen (i.e., bowel ischemia, ileus, bowel resection, thromboembolism, or amputation of the lower leg [above or below the knee]), and medical (i.e., postoperative myocardial infarction, pneumonia, tracheostomy, or renal failure). We examined perioperative complications by using ICD-9-CM diagnostic and complication codes, as well as physicians' current-procedural-terminology (CPT) codes.

*Late Outcomes and Reinterventions*

We identified all hospitalizations occurring after repair that were related to abdominal aortic aneurysm, including hospitalizations for rupture, major reintervention (i.e., open repair of the aneurysm, conversion from endovascular to open repair, repair of a graft–enteric fistula or graft infection, or axillobifemoral bypass), and minor reintervention (i.e., stent–graft extension, repeat endovascular repair, embolization, aortic or iliac angioplasty, graft thrombectomy, or femoral–femoral bypass). We also identified late-onset laparotomy-related complications requiring procedures, including lysis of adhesions, bowel resection, and repair of an abdominal-wall hernia. Finally, we identified readmissions for bowel obstruction without operation.

**STATISTICAL ANALYSIS**

We compared the characteristics of the cohorts on admission by using chi-square tests for categorical variables and t-tests for continuous variables. To account for the dependence of the matched pairs, postmatching differences between the two groups were tested, with the use of McNemar's test for categorical variables and paired t-tests for continuous variables. We estimated the association between the initial treatment strategies and the rates of in-hospital death, reinterventions, perioperative complications, and long-term complications for the matched pairs and determined the significance of the differences by using McNemar's test. Rates of survival, freedom from rupture, and reintervention related to abdominal aortic aneurysm were estimated with the use of Kaplan–Meier life-table methods, and comparisons were made with the use of log-rank analysis. P values of less than 0.05 were considered to indicate statistical significance.

**RESULTS****PROPENSITY-SCORE–MATCHED COHORTS**

We identified all 61,598 patients 67 years of age or older who underwent elective abdominal aortic aneurysm repair during the 2001–2004 period. Endovascular repair was performed in 29,542 patients, and open repair was performed in 32,056. Baseline characteristics of the patients and coexisting conditions are shown in Table 1. More detailed data, according to the year of enrollment, are shown in the Supplementary Appen-

dix, available with the full text of this article at [www.nejm.org](http://www.nejm.org). Patients who underwent endovascular repair were older and more likely to have a major coexisting condition than were those who underwent open repair. Patients in the endovascular-repair group were also more likely to have a previous diagnosis of abdominal aortic aneurysm and accordingly were less likely to be admitted urgently.

After matching, there were 45,660 patients, with 22,830 in each cohort. The average age was 76 years. Approximately 20% were women. Approximately 10% had had a myocardial infarction within the previous 2 years.

**PERIOPERATIVE OUTCOMES***Perioperative Mortality*

Perioperative mortality was 1.2% after endovascular repair and 4.8% after open repair (relative risk for the open-repair group, 4.00; 95% confidence interval [CI], 3.51 to 4.56;  $P < 0.001$ ) for an absolute difference of 3.6%, which did not vary substantially on the basis of the year of the procedure (Table 2). After stratification according to age, the absolute differences in mortality between the two groups ranged from 2.1% for patients 67 to 69 years of age (relative risk, 6.21; 95% CI, 4.98 to 7.73) to 8.5% for those 85 years of age or older (relative risk, 4.14; 95% CI, 3.80 to 4.52). Although the relative risk was fairly consistent across the age groups, the absolute risk reduction associated with endovascular repair increased with increasing age.

For purposes of comparison, perioperative mortality in the unmatched cohort (61,598 patients) was 1.7% after endovascular repair and 4.6% after open repair.

*Perioperative Complications and Course*

All major medical complications were less likely after endovascular repair than after open repair (Table 2): for instance, myocardial infarction (7.0% vs. 9.4%,  $P < 0.001$ ), pneumonia (9.3% vs. 17.4%,  $P < 0.001$ ), acute renal failure (5.5% vs. 10.9%,  $P < 0.001$ ) and need for dialysis (0.4% vs. 0.5%,  $P = 0.047$ ). Conversion from endovascular repair to open repair occurred in 1.6% of patients. Some vascular and abdominal surgical complications were more likely after open repair than after endovascular repair, although the absolute differences were not large: acute mesenteric ischemia (2.1% vs. 1.0%,  $P < 0.001$ ), reintervention for bleed-

**Table 1. Baseline Characteristics of Medicare Beneficiaries Undergoing Endovascular Repair or Open Repair of Abdominal Aortic Aneurysms in the 2001–2004 Period, before and after Matching for Propensity Score.**

Variable	Unmatched Cohort			Matched Cohort		
	Endovascular Repair (N=29,542)	Open Repair (N=32,056)	P Value	Endovascular Repair (N=22,830)	Open Repair (N=22,830)	P Value
	% of patients			% of patients		
Male sex	83.2	74.6	<0.001	80.3	80.6	0.38
Age						
67–69 yr	11.9	15.6	<0.001	13.9	13.9	0.94
70–74 yr	26.8	32.0	<0.001	29.7	29.7	1.00
75–79 yr	35.7	35.3	0.41	36.4	36.5	0.85
80–84 yr	15.8	12.2	<0.001	13.9	14.0	0.71
≥85 yr	9.8	4.9	<0.001	6.2	6.0	0.30
Race or ethnic group*						
White	95.8	95.6	0.16	95.8	95.9	0.67
Black	2.6	2.8	0.22	2.7	2.5	0.32
Hispanic	0.5	0.5	0.99	0.5	0.5	0.28
Other	1.1	1.1	0.40	1.1	1.1	1.00
Urgent admission	2.5	6.5	<0.001	3.1	2.9	0.37
Previous diagnosis of abdominal aortic aneurysm without rupture	76.3	61.7	<0.001	71.8	71.5	0.40
Coexisting conditions						
Myocardial infarction within the past 6 mo	1.9	1.8	0.73	1.9	1.8	0.48
Myocardial infarction within the past 7–24 mo	9.1	7.1	<0.001	8.0	8.0	0.96
Valvular heart disease	12.2	9.6	<0.001	10.9	10.5	0.17
Congestive heart failure	16.1	11.6	<0.001	13.3	13.1	0.58
Peripheral vascular disease	21.2	21.4	0.53	21.3	20.8	0.22
Cerebrovascular disease	16.1	16.8	0.02	16.4	16.3	0.86
Hypertension	67.1	65.0	<0.001	66.2	65.8	0.40
Diabetes mellitus	17.8	14.3	<0.001	15.7	15.7	1.00
Chronic obstructive pulmonary disease	30.8	28.9	<0.001	29.7	29.7	0.98
Renal disease	5.1	4.1	<0.001	4.6	4.4	0.28
End-stage renal disease	0.6	0.3	<0.001	0.3	0.3	1.00
History of cancer	23.6	18.2	<0.001	20.7	20.9	0.61
Obesity	2.4	1.6	<0.001	2.0	2.0	0.87

\* Race or ethnic group was self-reported.

ing (1.2% vs. 0.8%,  $P<0.001$ ), and embolectomy (1.7% vs. 1.3%,  $P<0.001$ ). Complications related to laparotomy were more common in the open-repair group than in the endovascular-repair group (e.g., bowel resection [1.3% vs. 0.6%,  $P<0.001$ ]

and obstruction or ileus without operative intervention [16.7% vs. 5.1%,  $P<0.001$ ]).

The mean length of stay was 3.4 days after endovascular repair, as compared with 9.3 days after open repair ( $P<0.001$ ). Of the patients who

**Table 2. Perioperative Outcomes after Endovascular Repair or Open Repair.\***

Perioperative Outcome	Endovascular Repair (N=22,830)	Open Repair (N=22,830)	P Value	Relative Risk Associated with Open Repair (95% CI)
<b>Death (% of patients)</b>				
All ages	1.2	4.8	<0.001	4.00 (3.51–4.56)
67–69 yr	0.4	2.5	<0.001	6.21 (4.98–7.73)
70–74 yr	0.8	3.3	<0.001	4.12 (3.51–4.84)
75–79 yr	1.3	4.8	<0.001	3.69 (3.25–4.19)
80–84 yr	1.6	7.2	<0.001	4.49 (4.02–5.02)
≥85 yr	2.7	11.2	<0.001	4.14 (3.80–4.52)
<b>Medical complications (% of patients)</b>				
Myocardial infarction	7.0	9.4	<0.001	1.34 (1.26–1.42)
Pneumonia	9.3	17.4	<0.001	1.89 (1.79–1.98)
Acute renal failure	5.5	10.9	<0.001	2.00 (1.87–2.14)
Renal failure requiring dialysis	0.4	0.5	0.047	1.33 (1.00–1.75)
Deep-vein thrombosis or pulmonary embolism	1.1	1.7	<0.001	1.51 (1.29–1.76)
<b>Surgical complications (% of patients)</b>				
Conversion to open repair	1.6			
Acute mesenteric ischemia	1.0	2.1	<0.001	2.19 (1.87–2.56)
Reintervention for bleeding	0.8	1.2	<0.001	1.50 (1.24–1.80)
Tracheostomy	0.2	1.5	<0.001	7.46 (5.48–10.14)
Thrombectomy	0.4	0.2	<0.001	0.50 (0.35–0.71)
Embolectomy	1.3	1.7	<0.001	1.29 (1.11–1.50)
Repair of infected graft or graft–enteric fistula	0.01	0.09	<0.001	7.00 (2.09–23.46)
Major amputation	0.04	0.13	0.002	3.00 (1.47–6.14)
<b>Complications related to laparotomy</b>				
Lysis of adhesions without resection	0.1	1.2	<0.001	13.05 (8.37–20.33)
Bowel resection	0.6	1.3	<0.001	2.17 (1.77–2.65)
Ileus or bowel obstruction without resection or lysis of adhesions	5.1	16.7	<0.001	3.25 (3.05–3.46)
Mean length of hospital stay (no. of days)	3.4±4.7	9.3±8.1	<0.001	
<b>Discharged home (% of survivors)</b>				
All ages	94.5	81.6	<0.001	0.87 (0.87–0.88)
67–69 yr	97.8	92.6	<0.001	0.95 (0.95–0.95)
70–74 yr	96.8	88.7	<0.001	0.92 (0.91–0.92)
75–79 yr	94.4	80.4	<0.001	0.85 (0.84–0.86)
80–84 yr	90.6	67.7	<0.001	0.75 (0.74–0.75)
≥85 yr	84.6	57.1	<0.001	0.67 (0.66–0.68)

\* Plus–minus values are means ±SD.

survived the operation, those who underwent open repair were three times as likely as those who underwent endovascular repair to be discharged to another facility (e.g., rehabilitation center or nursing home, or other) rather than home (18.4% vs. 5.6%,  $P<0.001$ ).

**LATE OUTCOMES**

*Survival*

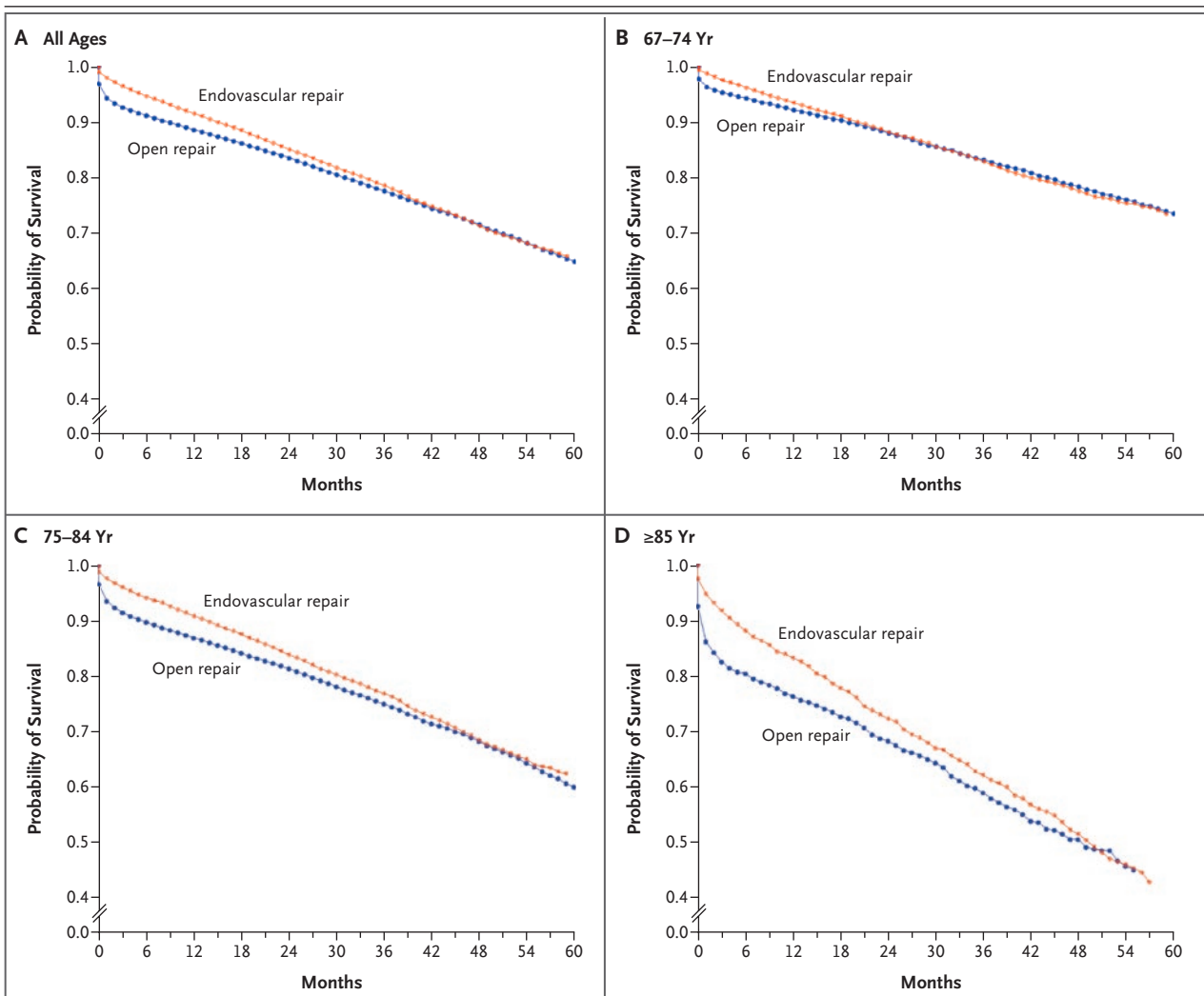
Long-term survival rates, both overall and stratified according to age, are shown in Figure 2. The early benefit from endovascular repair persisted for more than 3 years, after which the survival

rates associated with the two procedures were similar. The durability of the survival benefit from endovascular repair was age-dependent and appeared to be due primarily to differences in perioperative mortality. The difference in survival rates between the two procedural groups among patients 67 to 74 years of age dissipated after approximately 1 year but persisted for more than 4 years among those 85 years or older.

#### RUPTURE OF ABDOMINAL AORTIC ANEURYSM AND RELATED REINTERVENTIONS

Rupture was uncommon in both groups, but by

the fourth year, the rate of rupture was three times higher in the endovascular-repair group (1.8%, vs. 0.5% in the open-repair group;  $P<0.001$ ) (Table 3). At 4 years, reinterventions related to abdominal aortic aneurysm were more common after endovascular repair (rate, 9.0% vs. 1.7%;  $P<0.001$ ), including both major reinterventions (e.g., open repair with in-line or extra-anatomical bypass, conversion to open repair, or repair of an infected graft) (1.6% vs. 0.6%,  $P<0.001$ ) and minor reinterventions (7.8% vs. 1.3%,  $P<0.001$ ). The majority of reinterventions related to abdominal aortic aneurysm were minor.



**Figure 2.** Survival of Patients Undergoing Endovascular Repair or Open Repair of Abdominal Aortic Aneurysms, Overall and According to Age.

Data are shown for all patients (Panel A), for those 67 to 74 years of age (Panel B), those 75 to 84 years of age (Panel C), and those 85 years of age or older (Panel D).

**Table 3. Postoperative Outcomes after Endovascular Repair or Open Repair.\***

Outcome	Year 1		Year 2		Year 3		Year 4		P Value
	Endovascular Repair	Open Repair	Endovascular Repair	Open Repair	Endovascular Repair	Open Repair	Endovascular Repair	Open Repair	
	<i>percent of patients</i>								
Rupture	0.3	0.2	0.7	0.3	1.3	0.4	1.8	0.5	<0.001
Any aneurysm-related reintervention	2.7	0.5	4.8	0.8	7.0	1.2	9.0	1.7	<0.001
Major reintervention	0.4	0.2	0.7	0.3	1.2	0.3	1.6	0.6	<0.001
Conversion to open repair	0.1		0.2		0.3		0.4		
Open aneurysm repair	0.3	0.1	0.5	0.1	0.9	0.2	1.1	0.4	<0.001
Repeat aneurysm repair or aortobifemoral bypass	0.1	0.1	0.4	0.1	0.7	0.1	0.9	0.2	<0.001
Axillofemoral or axillobifemoral bypass	0.1	0.1	0.2	0.1	0.2	0.1	0.2	0.3	0.40
Repair of infected graft or graft-enteric fistula	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.3	0.13
Minor reintervention	2.4	0.4	4.2	0.6	6.1	0.9	7.8	1.3	<0.001
Endovascular	1.9	0.2	3.5	0.3	5.2	0.5	6.7	0.6	<0.001
Repeat endovascular aneurysm repair	0.2	0.04	0.4	0.1	0.8	0.1	1.2	0.1	<0.001
Embolization	0.7	0.04	1.3	0.1	2.0	0.2	2.3	0.2	<0.001
Angioplasty (aortic or iliac)	0.6	0.1	0.8	0.2	1.0	0.3	1.1	0.3	<0.001
Extension cuff	0.8	0.03	1.6	0.04	2.7	0.04	3.8	0.1	<0.001
Open	0.6	0.2	0.9	0.3	1.1	0.5	1.2	0.7	<0.001
Thrombectomy	0.1	0.1	0.2	0.2	0.2	0.3	0.3	0.4	0.61
Femoral-femoral bypass	0.5	0.1	0.7	0.2	0.9	0.2	0.9	0.3	<0.001

\* Data are hierarchical within indented subheadings (e.g., a given patient may have undergone and been counted for both embolization and extension cuff but would have been counted only once for endovascular reintervention; similarly, a patient may have been counted for both minor and major reinterventions but would have been counted only once for the overall category of aneurysm-related reintervention). P values were obtained with the use of log-rank analysis of Kaplan-Meier curves.

**LAPAROTOMY-RELATED REINTERVENTION AND HOSPITALIZATION**

Laparotomy-related complications were more common after open repair than after endovascular repair (Table 4). Overall, at 4 years, interventions occurred in 4.1% of patients in the endovascular-repair group, as compared with 9.7% of those in the open-repair group (P<0.001). These included repair of an abdominal-wall hernia (1.1% vs. 5.8%, P<0.001) and bowel resection (3.0% vs. 3.4%, P=0.02). Lysis of adhesions without bowel resection was also more common after open repair. Similarly, at 4 years, the rate of hospitaliza-

tion without surgery for a diagnosis of either bowel obstruction or abdominal-wall hernia was higher after open repair than after endovascular repair (8.1% vs. 14.2%, P<0.001).

**DISCUSSION**

In this large national study of 45,660 patients who underwent either open or endovascular repair of an abdominal aortic aneurysm in a U.S. hospital, we found that endovascular repair was associated with lower perioperative mortality, fewer major complications, a shorter length of stay,

**Table 4. Laparotomy-Related Outcomes after Endovascular Repair or Open Repair.\***

Outcome	Year 1		Year 2		Year 3		Year 4		P Value
	Endovascular Repair	Open Repair	Endovascular Repair	Open Repair	Endovascular Repair	Open Repair	Endovascular Repair	Open Repair	
	<i>percent of patients</i>								
Laparotomy-related reintervention	1.4	3.4	2.4	6.3	3.5	8.1	4.1	9.7	<0.001
Repair of an abdominal-wall hernia	0.3	1.9	0.6	4.0	0.9	5.1	1.1	5.8	<0.001
Lysis of adhesions without bowel resection	0.2	0.6	0.3	0.9	0.4	1.1	0.5	1.5	<0.001
Bowel resection	1.0	1.1	1.7	1.9	2.5	2.7	3.0	3.4	0.02
Large bowel	0.8	0.9	1.4	1.4	2.1	2.0	2.5	2.6	0.57
Small bowel	0.2	0.3	0.3	0.6	0.5	0.9	0.7	1.1	<0.001
Laparotomy-related hospitalization without bowel resection or lysis of adhesions	2.2	4.9	4.4	8.8	6.4	11.7	8.1	14.2	<0.001

\* Data are hierarchical within indented subheadings (e.g., a given patient may have had both repair of an abdominal-wall hernia and lysis of adhesions but would have been counted only once for laparotomy-related reintervention). P values were obtained with the use of log-rank analysis of Kaplan–Meier curves.

and a greater likelihood of being discharged to home. The perioperative survival benefit was strongly related to age, with the oldest patients (85 years or older) in the endovascular-repair group having an absolute reduction in mortality of 8.5%. The initial survival benefit was maintained for at least 3 years, after which the survival curves came together, suggesting a prolonged benefit of endovascular repair. The survival benefit was related to age and was primarily driven by the observed differences in perioperative mortality. Although patients who underwent endovascular repair were more likely to undergo interventions related to abdominal aortic aneurysm during the 4-year follow-up period, patients who underwent open repair were equally more likely to undergo laparotomy-related interventions.

Our data on perioperative mortality replicate data from previous randomized trials and several large observational studies.<sup>2-5,18</sup> However, previous information on long-term mortality rates for open repair and endovascular repair of abdominal aortic aneurysm has been limited to two randomized, controlled trials with relatively small numbers of patients from selected high-volume institutions.<sup>7,8</sup> Both of those trials showed that the benefits of endovascular repair diminished with time and had disappeared by 1 to 2 years after the procedure.<sup>7,8</sup> Several other randomized

trials are ongoing, including one in the United States, and the data have not yet been reported. Our data extend the reported findings to the full Medicare population and also suggest that the survival benefit of endovascular repair might be longer lasting than previously thought, because of the greater benefits for older patients, who were not included in large numbers in the initial clinical trials.

In addition to the more prolonged survival benefit, our findings suggest that the increased risk of interventions not related to abdominal aortic aneurysm in the open-repair group might offset the increased risk of aneurysm-related reinterventions in the endovascular-repair group. Given the similar late survival rates associated with open repair and endovascular repair in previous studies and the higher rate of reintervention after endovascular repair, many had suggested that open surgery was preferable. However, all previous analyses failed to account for the complications associated with laparotomy, such as abdominal-wall hernia and bowel obstruction. Our analysis shows that hospital admission and operative interventions are frequently required and include repair of an abdominal-wall hernia, lysis of adhesions, and even bowel resection.

An important caveat is that our study was observational; it was not a randomized, controlled

trial. Thus, the choice of treatment was left to the physician. In some cases, because of anatomical issues or patients' preferences, one or the other of the procedures might have been contraindicated. However, the extent to which some of these contraindications would have affected short-term and long-term survival is not clear. For instance, a particular anatomical feature that might preclude endovascular repair might not be predictive of death during open surgery.

We attempted to minimize selection bias by using propensity-score methods to create matched cohorts of patients. The propensity-score models we used were adjusted for differences among patients in demographic characteristics and coexisting conditions, with the use of claims data, from both inpatient and outpatient settings, accumulated over the previous 2 years. After propensity-score matching, there were no clinically or statistically significant differences between the two cohorts. Although this method accounts only for known confounders, our list of confounders was extensive, and it is unlikely that an unmeasured confounder could have substantially affected our results. Furthermore, by using these methods, we were able to extend our findings to the entire Medicare population. Nevertheless, propensity analyses cannot account for selection bias related to unmeasured characteristics.

Endovascular repair requires certain anatomical characteristics, including an adequate length of normal aorta below the renal arteries for attachment of the device. Another limitation of our study was that we could not determine a patient's anatomical suitability from the administrative data. We did, however, eliminate all patients in the open-repair group who underwent renal or visceral bypass, since these patients were more likely than those who did not undergo bypass surgery to have extensive abdominal aortic aneurysms that would not have been suitable for endovascular repair. In addition, we have no data regarding the diameters of the abdominal aortic aneurysms. Although there have been reports of improved outcomes associated with endovascular treatment of smaller abdominal aortic aneurysms, as compared with larger aneurysms, this probably represents the natural history of the abdominal aortic aneurysm (with smaller aneurysms less prone to rupture) and appropriate selection of patients (with a slightly higher risk of endo-

vascular failure tolerated for an older, more frail patient and the most anatomically suitable abdominal aortic aneurysm chosen for treatment if the aneurysm and the attendant risk of rupture were small). Although we could not stratify our patients on the basis of aneurysm diameter, differences among them should have been minimized by our propensity matching according to age and preexisting conditions.

There are several additional limitations to our study. The administrative data we used are subject to coding errors and the difficulty of differentiating complications from preexisting conditions. We limited the effect of these problems by using files for Medicare Parts A and B rather than Part A files alone. This allowed for more accurate determination of the initial operation, as well as any reinterventions during the follow-up period. Several of the codes we used to determine reinterventions are not specific to treatment related to abdominal aortic aneurysm. For instance, we assumed that embolizations after endovascular repair were related to the initial repair, even though they might have been unrelated. This assumption, however, should not bias our findings, since it was applied to both procedural groups. The absolute rates of reinterventions are therefore probably overestimated in both groups. However, the relative difference in the rates of reinterventions should be accurate. Given that the ICD-9-CM codes for endovascular procedures are more generalized than those for open procedures, our results were more likely to be biased against endovascular repair than for it. In addition, we did not attempt to control for previous laparotomy. It is likely that a previous laparotomy would prompt a physician to choose endovascular repair if the patient were anatomically suitable. This would also lead to bias against endovascular repair, in terms of late laparotomy-related complications.

Our analysis confirms the perioperative benefits of endovascular repair over open repair of abdominal aortic aneurysm. There was a perioperative survival benefit for all age groups, but it increased with increasing age. The survival rate eventually became similar in the two groups, but the benefit was more durable in the older age groups. Reinterventions related to abdominal aortic aneurysm were more common after endovascular repair, but laparotomy-related reinterven-

tions occurred more commonly after open repair, which must be considered in comparing the two therapies at the population level or recommending one of them for the care of an individual patient with an abdominal aortic aneurysm.

The opinions expressed are those of the authors and do not necessarily represent the views or policy positions of the Centers for Medicare and Medicaid Services.

No potential conflict of interest relevant to this article was reported.

#### REFERENCES

1. Parodi JC, Palmaz JC, Barone HD. Transfemoral intraluminal graft implantation for abdominal aortic aneurysms. *Ann Vasc Surg* 1991;5:491-9.
2. Nowygrod R, Egorova N, Greco G, et al. Trends, complications, and mortality in peripheral vascular surgery. *J Vasc Surg* 2006;43:205-16.
3. Dillavou ED, Muluk SC, Makaroun MS. Improving aneurysm-related outcomes: nationwide benefits of endovascular repair. *J Vasc Surg* 2006;43:446-51.
4. Greenhalgh RM, Brown LC, Kwong GP, Powell JT, Thompson SG. Comparison of endovascular aneurysm repair with open repair in patients with abdominal aortic aneurysm (EVAR trial 1), 30-day operative mortality results: randomised controlled trial. *Lancet* 2004;364:843-8.
5. Prinssen M, Verhoeven EL, Buth J, et al. A randomized trial comparing conventional and endovascular repair of abdominal aortic aneurysms. *N Engl J Med* 2004;351:1607-18.
6. Harris PL, Vallabhaneni SR, Desgranges P, Becquemin JP, van Marrewijk C, Laheij RJ. Incidence and risk factors of late rupture, conversion, and death after endovascular repair of infrarenal aortic aneurysms: the EUROSTAR experience. *J Vasc Surg* 2000;32:739-49.
7. Endovascular aneurysm repair versus open repair in patients with abdominal aortic aneurysm (EVAR trial 1): randomised controlled trial. *Lancet* 2005;365:2179-86.
8. Blankensteijn JD, de Jong SE, Prinssen M, et al. Two-year outcomes after conventional or endovascular repair of abdominal aortic aneurysms. *N Engl J Med* 2005;352:2398-405.
9. Schermerhorn ML, Finlayson SR, Fillinger MF, Buth J, van Marrewijk C, Cronenwett JL. Life expectancy after endovascular versus open abdominal aortic aneurysm repair: results of a decision analysis model on the basis of data from EUROSTAR. *J Vasc Surg* 2002;36:1112-20.
10. Hallett JW Jr, Marshall DM, Petterson TM, et al. Graft-related complications after abdominal aortic aneurysm repair: reassurance from a 36-year population-based experience. *J Vasc Surg* 1997;25:277-84.
11. Biancari F, Ylönen K, Anttila V, et al. Durability of open repair of infrarenal abdominal aortic aneurysm: a 15-year follow-up study. *J Vasc Surg* 2002;35:87-93.
12. Laheij RJ, Buth J, Harris PL, Moll FL, Stelter WJ, Verhoeven EL. Need for secondary interventions after endovascular repair of abdominal aortic aneurysms: intermediate-term follow-up results of a European collaborative registry (EUROSTAR). *Br J Surg* 2000;87:1666-73.
13. Lifeline Registry of Endovascular Aneurysm Repair: long-term primary outcome measures. *J Vasc Surg* 2005;42:1-10.
14. Elixhauser A, Steiner C, Harris DR, Coffey RM. Comorbidity measures for use with administrative data. *Med Care* 1998;36:8-27.
15. Baldwin LM, Klabunde CN, Green P, Barlow W, Wright G. In search of the perfect comorbidity measure for use with administrative claims data: does it exist? *Med Care* 2006;44:745-53.
16. Gu XS, Rosenbaum PR. Comparison of multivariate matching methods: structure, distances, and algorithms. *J Comput Graph Stat* 1993;2:405-20.
17. Cochran WG, Rubin DB. Controlling bias in observational studies: a review. *Sankhya-A* 1973;35:417-46.
18. Lee WA, Carter JW, Upchurch G, Seeger JM, Huber TS. Perioperative outcomes after open and endovascular repair of intact abdominal aortic aneurysms in the United States during 2001. *J Vasc Surg* 2004;39:491-6.

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