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Editor's Choice — Trend-break in Abdominal Aortic Aneurysm Repair With Decreasing Surgical Workload

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WHAT THIS PAPER ADDS

The present study adds knowledge about recent trends in abdominal aortic aneurysm (AAA) epidemiology in the light of the introduction of endovascular management, screening, and decreasing AAA prevalence. It describes a marked decrease in ruptured AAA repair rate, a stabilization of intact AAA repair rate and ever improving survival rates.

Background: The epidemiology and management of abdominal aortic aneurysms (AAAs) has changed drastically in the past decades, with implementation of nationwide screening programs, introduction of endovascular repair (EVAR), and reduced prevalence of the disease. This report aims to assess recent trends in AAA repair epidemiology in Sweden in this context.

Methods: Primary AAA repairs registered in the nationwide Swedish Vascular Registry (Swedvasc) 1994—2014 were analyzed regarding patient characteristics, repair incidence, technique, and outcome. Four time periods were compared: 1994—1999, 2000—2004, 2005—2009, and 2010—2014.

Result: The incidence of intact AAA repair increased (18.4/100,000 1994—1999, 27.3/100,000 2010—2014, $p < .001$) predominantly among octogenarians (12.7/100,000 1994—1999, 36.0/100,000 2010—2014, $p < .001$). The utilization of EVAR increased (58% of all intact AAA repairs 2010—2014), especially among octogenarians (80% 2010—2014). During the last time period, however, the incidence of intact AAA repair stabilized, despite an increasing number of screening-detected AAAs operated on (19% in 2010—2014). Short- and long-term outcome after intact AAA repair continued to improve, most pronounced among octogenarians (30-day mortality 9% 1994—1999, 2% 2010—2014, $p < .001$). The incidence of ruptured AAA repair steadily decreased (9.2/100,000 1994—1999, 6.9/100,000 2010—2014, $p < .001$) and the use of EVAR for ruptures increased (30% in 2010—2014). The previously observed improvement of short- and long-term outcome after ruptured AAA repair (30-day mortality 38% 1994—1999, 28% 2010—2014, $p < .001$) stalled during the last time period. The overall 30-day mortality after ruptured AAA repair was 22% after EVAR versus 31% after open repair in 2010—2014. The corresponding mortality for octogenarians was 28% versus 42%.

Conclusions: For the first time, a halt in intact AAA repair workload could be identified. This trend-break occurred despite continued increase in treatment of octogenarians and screening-detected aneurysms. Additionally, the ruptured AAA repair incidence continued to decrease. These findings, together with the sustained improvement in survival after AAA repair, may have important impact on planning of vascular surgical services.

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INTRODUCTION

In the past two decades important changes in the epidemiology and treatment of abdominal aortic aneurysms (AAAs) have occurred. The introduction of endovascular aortic repair (EVAR)[1,2] has made it possible to offer surgical treatment to patients who are not optimal candidates for open aortic repair (OR).[3,4] With improved perioperative care[5] and centralization of AAA interventions,[6] outcome has steadily improved.[7,8] Screening for AAA has been proven effective from a clinical and health economic perspective,[9,10] and a screening program targeting 65-year-old men was introduced in Sweden in 2006,[11] reaching nationwide coverage in 2015.[12] Similar programs were launched in the UK and United States.[13] Furthermore, the prevalence of the disease has fallen, partly because of changing smoking habits.[14]

These changes affect the epidemiology of AAA repair, which have implications on patient care and the optimal

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provision of vascular surgical services. The Swedish vascular registry (Swedvasc), with its high validity,[15,16] in combination with the Swedish Population Registry, which provides 100% accurate mortality data, offers a great opportunity to monitor AAA repair epidemiology on a national level.

The aim of this paper was to study the AAA repair epidemiology in Sweden 1994–2014, with focus on recent trends.

MATERIALS AND METHODS

All primary AAA interventions performed during the period 1994–2014 were identified in the Swedvasc registry. Re-do procedures, duplicate entries, patients without a Swedish personal identification number (PIN), and patients $<$50 years of age were excluded. Data were cross-checked for mortality against the Swedish Population Registry in August 2015.

Preoperative comorbidities registered in Swedvasc were diabetes (treated by diet, per oral medication, or insulin), pulmonary disease (any diagnosed pulmonary disease), cerebrovascular disease (stroke or transient ischemic attack), renal impairment (serum creatinine $\geq$ 150 mmol/L or renal replacement therapy), and heart disease (history of myocardial infarction, angina pectoris, heart failure, coronary bypass surgery, heart valve surgery, or atrial fibrillation). After May 2008, atrial fibrillation was not considered a cardiac comorbidity in Swedvasc. A nationwide AAA screening program targeting 65-year-old men was gradually introduced in Sweden 2006–2015. From 2010 it is recorded in Swedvasc if an AAA undergoing repair is detected by screening. Data were extrapolated and assumed a linear increase in screening-detected AAAs operated on from 2006 to 2010.

Intact AAA repair was defined as any AAA operated on without any signs of rupture regardless of elective or urgent repair. Data for intact AAA and ruptured AAA were analyzed separately. Based on a predefined protocol for data analysis, data were calculated overall and for three age subgroups (50–64 years, 65–79 years, and $\geq$ 80 years), and for four time periods (1994–1999, 2000–2004, 2005–2009, and 2010–2014). Age- and sex-specific population data for each subgroup and overall (Swedish population $\geq$ 50 years) were obtained from Statistics Sweden.[17]

Statistical analysis

Proportions were compared using the chi-square test. Changes in proportions over time were assessed using the chi square test for trend. Normally distributed data were compared using one-way ANOVA. Histograms were used to assess normality. Long-term survival was calculated using Kaplan–Meier analysis and the log rank test was used to compare groups. To compensate for multiple testing $p < .010$ was considered significant. Ninety-nine percent confidence intervals (CI) for proportions were calculated with the Wald approximation. Calculations were made using SPSS version 22.0 (IBM, Armonk, NY, USA) and GraphPad Prism 6 (Graphpad software, La Jolla, CA, USA).

Ethics approval

The study was approved by the Regional Ethics Board of Uppsala (2014/078) and by the Swedvasc review board. According to the rules of the Swedvasc registry, informed consent is required from each patient or relative prior to registration, except for fatal cases that are exempted from informed consent according to Swedish law.

RESULTS

A total of 15,268 intact AAA repairs and 5,907 ruptured AAA were identified. The repair incidence was 21.9 per 100,000 $\geq$ 50 years for intact AAA, and 8.5 per 100,000 for ruptured AAA. Baseline characteristic are shown in Table 1 and 30-day mortality in Table 2.

Intact AAA repair

The incidence of intact AAA repair increased by 48.5% (99% CI 41.1–55.8) from the first to the last study period. The increase in intact AAA repair incidence was significant in all age groups ($p < .001$; see Fig. 2 and Table 1). The increase was most prominent among octogenarians where repair incidence inclined 184% (99% CI 144.8–223.5) from 12.7 out of 100,000 $\geq$ 80 years in 1994–1999 to 36.0 out of 100,000 $\geq$ 80 years in 2010–2014. However, during the last time period the repair incidence stabilized (incidence 2010–2014 chi square for trend $p = .062$). During the same period, an increasing number of screening-detected AAAs were operated on, constituting 18.6% (99% CI 17.2–20.1) of all intact AAA repairs during the last period (Fig. 1). The proportion of repairs performed with EVAR increased continuously (Fig. 2, Appendix I) from 3.4% (99% CI 2.6–4.2) 1994–1999 to 57.5% (99% CI 55.7–59.3) in 2010–2014. For patients $\geq$ 80 years EVAR was used in 79,7% (99% CI 76.3–83.2) of intact AAA repair in 2010–2014.

Despite progressively older patients, short- and long-term outcome improved over time, most prominent among octogenarians (Tables 1–3). Although 30-day mortality in octogenarians was two to three times higher than in younger patients during the first three time periods, there was no remaining difference between age groups in the last time period (Table 2) ($p = .246$). The prevalence of current smokers decreased and the comorbidity spectrum changed significantly; with fewer patients having a history of heart disease, and more patients were being treated for hypertension and having a history of diabetes, and pulmonary disease (Tables 1 and 2).

Ruptured AAA repair

During the second half of the study period the ruptured AAA repair incidence decreased significantly overall, among men and among patients $<$ 80 years ($p < .001$), but was stable among women. For octogenarians there was a significant increase in repair incidence ($p = 0.007$). The utilization of EVAR slowly increased over time, most prominent in the $\geq$ 80 years group ($p < .001$) (Figs 1 and 2, Table 1, and Appendix I).

Table 1. Patient characteristics and incidence rate for intact AAA repair (iAAA) and ruptured AAA repair (rAAA).

iAAA	1994–1999	2000–2004	2005–2009	2010–2014	Trend	p [c]
Age [a] (years)	71.2 (70.9–71.5)	71.9 (71.5–72.2)	72.2 (71.9–72.5)	72.5 (72.2–72.7)	↗	< .001 [d]
Male (%)	83.3 (81.7–85)	82.4 (80.6–84.1)	81.5 (79.9–83.1)	84.6 (83.2–85.9)	→	.153
Diabetes (%)	6.6 (5.4–7.7)	8.8 (7.4–10.1)	11.1 (9.8–12.5)	13.0 (11.7–14.2)	↗	< .001
Current smoker (%)	52.7 (50.3–55.1)	46.1 (43.6–48.6)	46.6 (44.4–48.8)	30.0 (28.1–31.8)	↘	< .001
Cerebrovascular disease (%)	13.5 (11.9–15.1)	14.9 (13.2–16.6)	15.0 (13.5–16.6)	12.8 (11.5–14.1)	→	.257
Heart disease [b] (%)	54.6 (52.4–56.9)	54.3 (51.9–56.6)	49.3 (47.2–51.5)	39.4 (37.5–41.2)	↘	< .001
Hypertension (%)	50.9 (48.6–53.2)	59.4 (57.0–61.7)	72.0 (70.1–73.9)	78.6 (77.0–80.1)	↗	< .001
Pulmonary disease (%)	17.3 (15.6–19.1)	18.5 (16.7–20.4)	22.4 (20.6–24.2)	22.9 (21.3–24.5)	↗	< .001
Renal disease (%)	10.0 (8.6–11.4)	10.1 (8.7–11.6)	10.8 (9.5–12.1)	5.3 (4.4–6.1)	↘	< .001
≥ 80 years (%)	9.5 (8.2–10.8)	14.4 (12.8–16.0)	17.3 (15.7–18.9)	18.3 (16.9–19.7)	↗	< .001
EVAR (%)	3.4 (2.6–4.2)	20.1 (18.3–22.0)	44.5 (42.4–46.5)	57.5 (55.7–59.3)	↗	< .001
Rate per 100.000 ≥ 50 years	18.4 (17.6–19.2)	19.1 (18.3–20)	22.6 (21.7–23.5)	27.3 (26.3–28.3)	↗	< .001
Rate per 100.000 men ≥ 50 years	33.2 (31.6–34.8)	33.7 (32.0–35,4)	39.0 (37.2–40.7)	48.4 (46.4–50.3)	↗	< .001
Rate per 100.000 women ≥ 50 years	5.7 (5.1–6.3)	6.3 (5.6–7.0)	7.9 (7.2–8.7)	8.1 (7.3–8.8)	↗	< .001
rAAA						
Age [a] (years)	72.8 (72.3–73.3)	73.8 (73.3–74.3)	73.8 (73.3–74.4)	75.3 (74.7–75.9)	↗	.002 [d]
Male (%)	86.3 (84.1–88.4)	85.4 (83.1–87.7)	80.3 (77.6–83.0)	79.6 (76.6–82.5)	↘	< .001
Diabetes (%)	6.8 (5.1–8.5)	7.9 (6.0–9.8)	9.9 (7.8–12.0)	13.4 (10.8–16.0)	↗	< .001
Current smoker (%)	51.9 (47.8–56.1)	44.2 (40.1–48.2)	51.3 (46.8–55.9)	45.1 (39.9–50.3)	→	.105
Cerebrovascular disease (%)	14.8 (12.4–17.3)	15.8 (13.2–18.4)	15.3 (12.7–17.9)	14.8 (12.0–17.6)	→	.948
Heart disease [b] (%)	50.4 (47.1–53.8)	54.1 (50.7–57.6)	47.3 (43.8–50.9)	38.9 (35.0–42.7)	↘	< .001
Hypertension (%)	48.2 (44.8–51.7)	53.1 (49.5–56.6)	65.6 (62.1–69.0)	72.0 (68.4–75.6)	↗	< .001
Pulmonary disease (%)	17.4 (14.8–20.0)	18.4 (15.7–21.2)	22.6 (19.6–25.7)	23.1 (19.7–26.4)	↗	< .001
Renal disease (%)	11.8 (9.5–14.0)	12.2 (9.8–14.5)	15.6 (13.0–18.3)	18.0 (15.0–21.1)	↗	< .001
≥ 80 years (%)	19.1 (16.7–21.6)	26.8 (23.9–29.7)	26.6 (23.6–29.6)	33.3 (29.8–36.7)	↗	< .001
EVAR (%)	0.1 (0.0–0.2)	4.1 (2.8–5.4)	15.4 (12.9–17.8)	29.8 (26.5–33.2)	↗	< .001
Rate per 100.000 ≥ 50 years	9.2 (8.7–9.8)	9.4 (8.7–10.0)	8.4 (7.9–9.0)	6.9 (6.4–7.4)	↘	< .001
Rate per 100.000 men ≥ 50 years	17.3 (16.1–18.4)	17.1 (15.9–18.3)	14.3 (13.2–15.4)	11.5 (10.6–12.4)	↘	< .001
Rate per 100.000 women ≥ 50 years	2.4 (2.0–2.8)	2.6 (2.1–3.0)	3.2 (2.7–3.6)	2.7 (2.3–3.1)	→	.031

Note. Values in parenthesis are 99% confidence intervals. EVAR = endovascular aortic repair.
[a] Age is reported with mean value.
[b] The definition of cardiac disease was changed in the Swedvasc registry in 2008. See Methods.
[c] Chi-square test for trend.
[d] ANOVA.

Table 2. Thirty day mortality (%) for intact and ruptured abdominal aortic aneurysm (AAA) repair by surgical techniques, age and gender.

iAAA	1994–1999	2000–2004	2005–2009	2010–2014	Trend	p [a]
All	4.7 (3.7–5.6)	3.1 (2.3–3.9)	2.5 (1.9–3.2)	1.7 (1.2–2.1)	↘	< .001
EVAR	2.6 (0.0–6.5)	2.2 (0.7–3.7)	1.9 (1.1–2.8)	0.9 (0.4–1.3)	↘	.001
Open repair	4.7 (3.8–5.7)	3.3 (2.4–4.3)	3.0 (2.0–3.9)	2.7 (1.8–3.7)	↘	< .001
50–64 years	2.5 (0.8–4.2)	1.6 (0.2–3.1)	0.6 (0.0–1.4)	1.2 (0.0–2.4)	→	.028
65–79 years	4.6 (3.5–5.7)	3.2 (2.2–4.2)	2.5 (1.7–3.3)	1.7 (1.1–2.2)	↘	< .001
≥ 80 years	9.0 (4.9–13.1)	4.5 (1.9–7.0)	4.5 (2.4–6.6)	2.0 (0.8–3.2)	↘	< .001
Female	6.7 (4.0–9.4)	4.0 (1.8–6.2)	3.8 (1.9–5.6)	2.5 (1.0–4.0)	↘	< < .001
Male	4.2 (3.3–5.2)	2.9 (2.1–3.8)	2.2 (1.6–2.9)	1.5 (1.0–2.0)	↘	< .001
rAAA						
All	38.3 (35.2–41.3)	32.9 (29.8–36)	27.9 (24.9–31.0)	28.2 (24.9–31.5)	↘	< .001
EVAR	– [b]	15.9 (4.0–27.7)	18.1 (11.4–24.8)	22.2 (16.6–27.8)	→	.137
Open repair	38.2 (35.2–41.3)	33.6 (30.4–36.8)	29.7 (26.3–33.1)	30.7 (26.7–34.8)	↘	< .001
50–64 years	21.2 (14.4–27.9)	16.3 (9.7–22.8)	12.7 (7.0–18.4)	20.8 (11.6–29.9)	→	.333
65–79 years	38.3 (34.5–42.0)	29.2 (25.3–33.1)	25.4 (21.5–29.3)	24.6 (20.4–28.8)	↘	< .001
≥ 80 years	50.9 (43.8–58.1)	49.6 (43.3–56.0)	42.6 (36.1–49.1)	36.7 (30.5–42.8)	↘	< .001
Female	43.6 (35.2–51.9)	43.0 (34.5–51.6)	35.2 (27.9–42.5)	34.4 (26.7–42.1)	→	.011
Male	37.4 (34.2–40.7)	31.2 (27.9–34.5)	26.1 (22.8–29.5)	26.6 (23.0–30.2)	↘	< .001

Note. Values in parentheses are 99% confidence intervals. iAAA = intact abdominal aortic aneurysm; rAAA = ruptured abdominal aortic aneurysm.
[a] Chi-square test for trend.
[b] Only one endovascular repair occurred in the first cohort. This was excluded from the trend analysis.

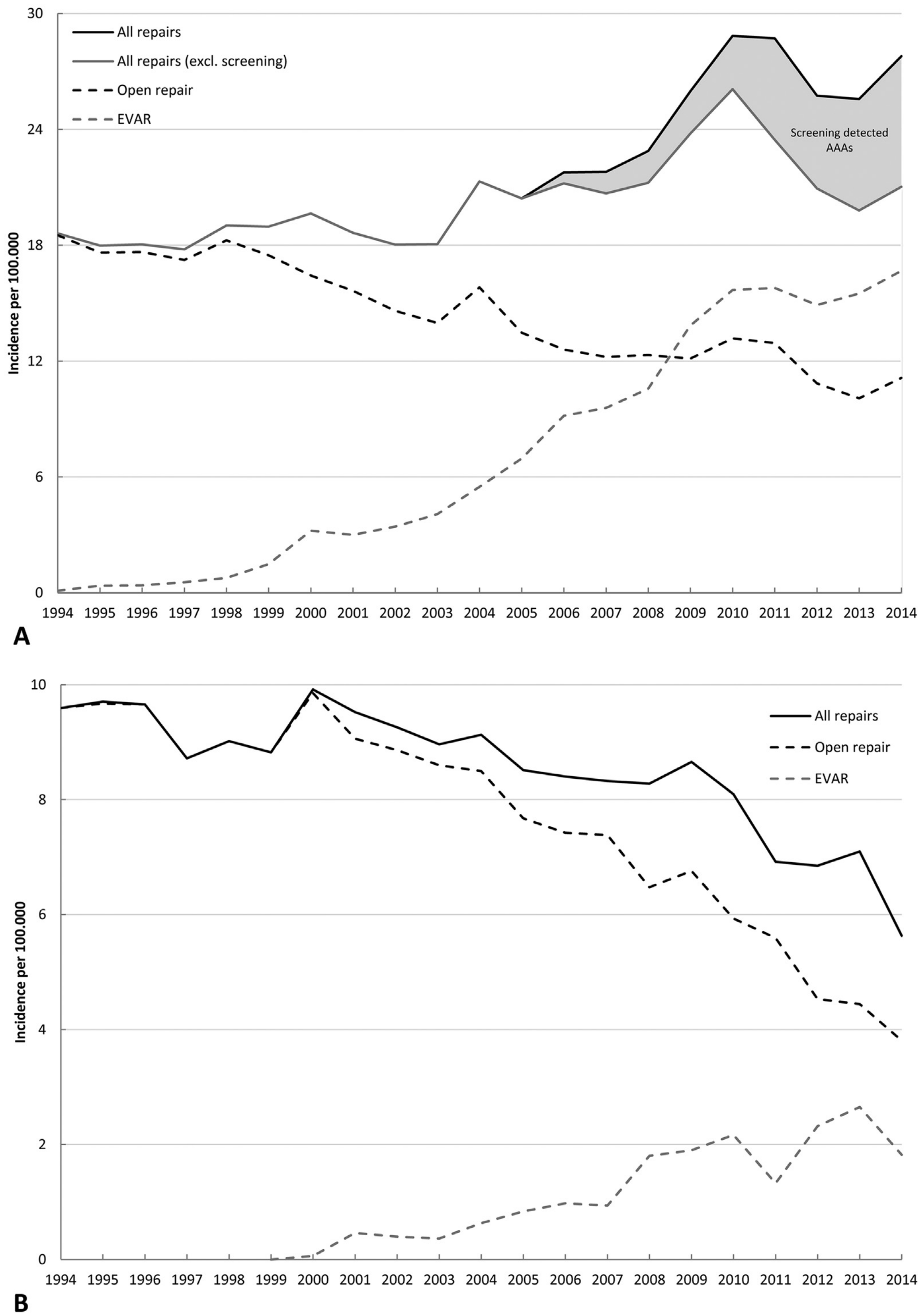
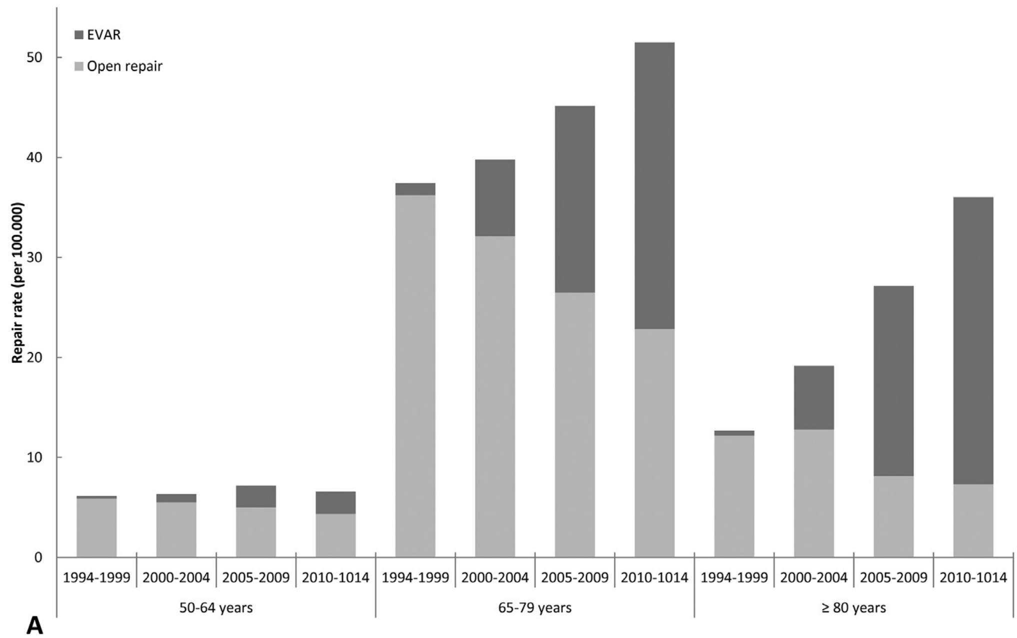


Figure 1. Incidence of repair of (A) intact and (B) ruptured abdominal aortic aneurysms (AAA) over time per 100,000 Swedish residents $\geq$ 50 years of age. EVAR, endovascular repair.

Despite higher age (Table 1), short- and long-term outcome improved during the three first time periods and stabilized during the last time period (Table 3); however, the proportion of octogenarians undergoing ruptured AAA repair increased from 26.6% to 33.3% between the two last periods (Tables 1—3 and Fig. 3). The prevalence of current smokers and the comorbidity spectrum changed in a similar way as for intact AAA repair (Table 1).

DISCUSSION

The benefit of the highly validated Swedish Vascular Registry is that it gives the possibility to study AAA repair epidemiology in a nationwide real-world situation where patient selection, operation method, and outcome are the result of everyday clinical decisions based on the available resources, surgeons' experience, and judgment and



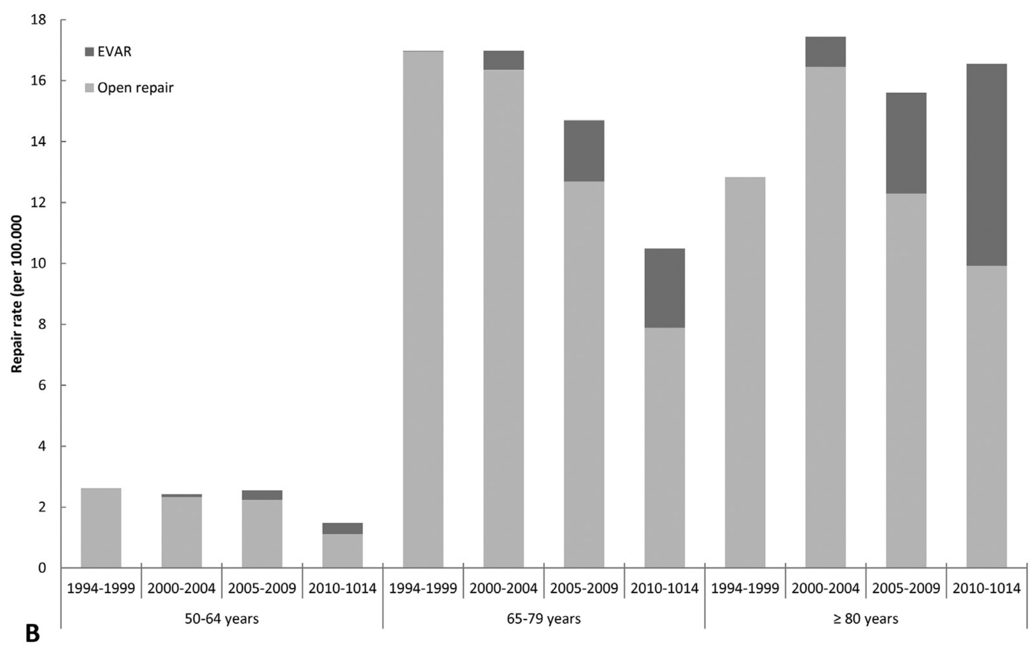


Figure 2. (A) Incidence of open and endovascular repair (EVAR) of intact abdominal aortic aneurysms (AAA) in different age groups over time, per 100,000 Swedish residents $\geq$ 50 years of age. (B) Incidence of open repair and EVAR in ruptured AAAs in different age groups over time.

geographical factors. In this study of AAA repair epidemiology over a 20-year period some important new trends were found: (1) the longstanding increase in incidence of intact AAA repair has now come to an end, although the incidence of ruptured AAA repair continues to decrease, and (2) short- and long-term outcome continued to improve after intact AAA repair, but it has stabilized after ruptured AAA repair. In summary, the total AAA surgical workload has begun to decrease, and it is the decline in resource-intensive ruptured AAA repair that is the main factor in this process. This marked shift in the epidemiology of AAA repair is important for healthcare planning and allocation of resources.

The marked increase in intact AAA repair incidence up till 2010 followed by stabilization, or even a decrease in incidence (if AAAs detected by screening are excluded), is likely explained by a combination of factors. The effect of the increased use of EVAR and treatment of increasing number of octogenarians, and more recently the introduction of screening, is counterbalanced by the effect of a reduced prevalence of the disease. A point has now been reached where the reduced prevalence of the disease evens out the other factors for the first time.

Similarly, the reduced prevalence of the disease combined with the longstanding increase in prophylactic AAA repair likely explains the marked reduction in ruptured AAA

Table 3. Mid- and long-term survival after repair of intact abdominal aortic aneurysm and ruptured abdominal aortic aneurysm.

iAAA	1994—1999	2000—2004	2005—2009	2010—2014	Trend
90 day survival	94.0 (93.0—95.0)	95.5 (94.5—96.5)	96.0 (95.2—96.8)	97.1 (96.6—97.6)	↗
1 year survival	90.2 (88.9—91.5)	92.2 (90.9—93.5)	92.2 (91.2—93.2)	94.1 (93.3—94.9)	↗
5 year survival	67.3 (65.2—69.4)	72.4 (70.3—74.5)	73.2 (71.4—75.0)	75.3 (72.7—77.9)	↗
rAAA					
90 day survival	57.4 (54.3—60.5)	63.6 (60.5—66.7)	67.8 (64.7—70.9)	67.2 (63.9—70.5)	↗
1 year survival	54.0 (50.9—57.1)	60.0 (56.7—63.3)	64.0 (60.7—67.3)	62.4 (58.8—66.0)	↗
5 year survival	39.3 (36.2—42.4)	44.1 (40.8—47.4)	50.0 (46.7—53.3)	47.0 (42.1—51.9)	↗

Note. $p < 0.001$ for both iAAA and rAAA, log rank test. iAAA = intact abdominal aortic aneurysm; rAAA = ruptured abdominal aortic aneurysm.

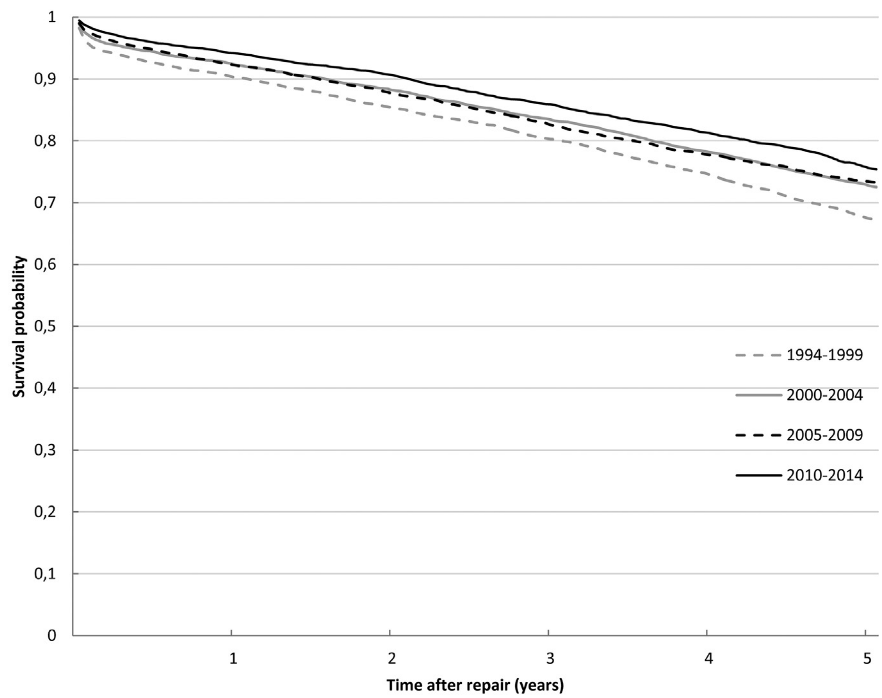
repair incidence.[14,18] This trend has previously been observed both in Sweden and in other countries.[7,8,19—21] The lack of reduction of ruptured AAA repair in the octogenarian population could be related to a continuously increasing use of EVAR in ruptures, which allows repair in patients previously deemed unfit for open ruptured AAA repair. Interestingly, no reduction in ruptured AAA repair rate was seen in women, a population not included in the Swedish screening program. Owing to a low prevalence, population screening of women is currently not recommended,[22] although a more selective high-risk screening strategy, targeting for example smoking women, is an ongoing discussion.[12]

Associated with the rapid increase in the use of EVAR two other observations can be made. Firstly, the 30-day mortality has decreased by 64%, from 4.7% in 1994—1999 to 1.7% in 2010—2014. This compares favorably in an international perspective, where intact AAA repair mortality was reported at 2.0—5.0% in an international registry-based analysis.[23] The improved short-term outcome is sustained for at least 5 years as indicated by the improving long-term survival. Secondly, there is no longer a significantly higher 30-day mortality after intact AAA repair among octogenarians than in younger patients. Although good results of open repair in octogenarians have been reported,[24] this is likely related to the preferential use of EVAR for treatment of octogenarians. These findings contrast to the EVAR 2 trial[25] that randomized patients considered unfit for open repair to either EVAR or conservative treatment and failed to show any survival benefit in the EVAR group, possibly because of the unexpectedly high 30-day mortality rate (7.3%) after EVAR. In the present study the 30-day mortality rate was only 2.0% for octogenarians (of which 79.7% treated with EVAR). On the other hand, a meta-analysis of six observational studies showed significant survival benefits in octogenarians treated with EVAR compared with open repair.[4] Against this background one can make the case that the clinical decisions to use EVAR to treat older and sicker patients have been sound.

For ruptured AAA repair perioperative mortality improved up to the 2005—2009 cohort (a 28% reduction in 30-day mortality from 1994—1999 to 2005—2009) and then stabilized. This result is similar to other international reports.[26] Also long-term survival improved in the first three periods and stabilized thereafter, indicating that the change in short-term survival is sustained over time. These improvements were seen in parallel with an ever-increasing proportion of repairs being performed in octogenarians and a much-increased uptake of EVAR. This is of particular interest as four randomized controlled trials (RCTs)[27—30] and one individual-patient meta-analysis[31] failed to show any benefit of EVAR in patients suffering from ruptured AAA. However, the data suggests that in an unselected patient population the approach to preferentially perform EVAR in the elderly has been successful also for ruptured AAA. On the other hand, the stabilization of outcome suggests that with the treatment options at hand today it is no longer possible to operate on increasingly older patients suffering from ruptured AAA and continue to improve survival rate. But considering the bleak prognosis of an untreated ruptured AAA, and a 63% chance of perioperative survival in an elderly patient, an active treatment approach seems fair in patients who agree to surgical attempt. This approach is supported by a study from Switzerland, where it was concluded elderly patients who survived surgery for a ruptured AAA had a near normal long-term prognosis.[32]

The improving survival rates after intact AAA repair has led to a discussion on lowering the threshold diameter for AAA repair. In a recent publication, Karthikesalingam et al.[33] observed a significantly lower AAA-related mortality in the United States compared with the UK, which was linked to a lower size threshold for AAA repair, and higher rate of EVAR, in the United States. No benefit of a threshold for repair < 5.5 cm (mean 4.6 cm) was, however, found in two recent RCTs investigating early EVAR versus surveillance, despite an operative mortality rate of only 0.6% observed. This was due to a very low rupture rate in the surveillance group.[34,35] In the present report the observed 30-day mortality after intact AAA repair was overall 1.7% and 0.9% after EVAR, suggesting that the benefit of repair of small aneurysms at low risk of rupture is likely to be outweighed by the risk of repair. In an international comparison, the rate of intact small AAA repair in Sweden was on the same level as other countries with population-based reimbursement system (e.g., other Scandinavian countries), and lower than in countries with a fee-for-service healthcare system (e.g., Australia and United States).[36]

During the study period there has been a centralization of AAA surgery in Sweden,[6] where a few very small centers have stopped performing AAA repair. At the same time the number of centers able to preform EVAR has increased. These two trends are likely to contribute to the lower



No. at risk						
1994-1999	3392	3061	2892	2719	2510	2282
2000-2004	3121	2880	2748	2598	2433	2259
2005-2009	3854	3555	3373	3174	2990	2822
2010-2014	4897	4209	3152	2190	1321	416

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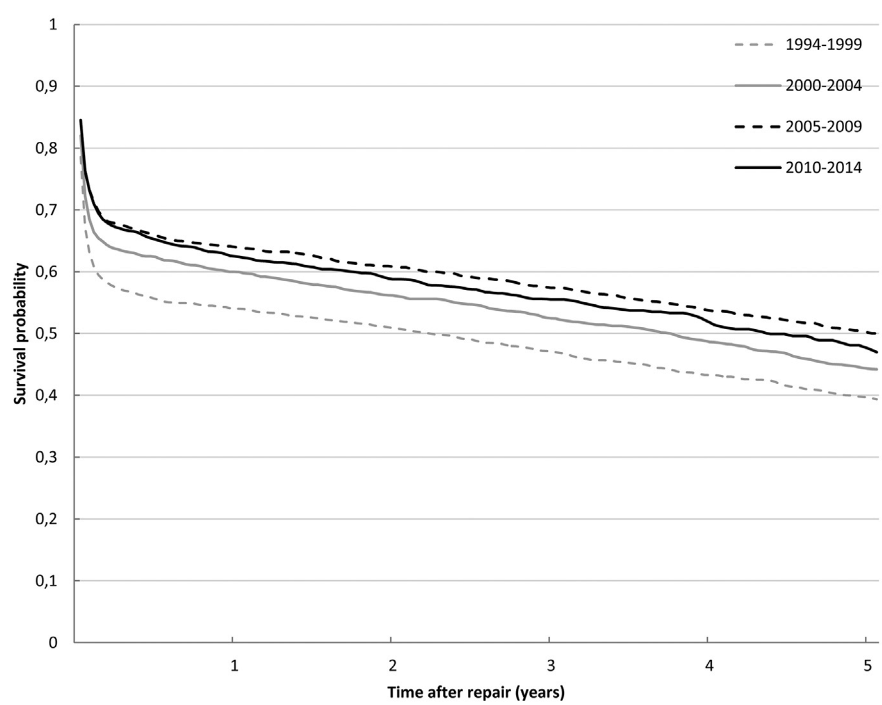

No. At risk						
1994-1999	1703	920	866	800	735	669
2000-2004	1525	915	855	796	740	673
2005-2009	1438	921	874	826	772	719
2010-2014	1237	718	508	372	225	82

B

Figure 3. Kaplan−Meier analysis of crude survival after repair of (A) intact abdominal aortic aneurysm (AAA) and (B) ruptured AAA.

mortality rates after both intact and ruptured AAA repair in Sweden. Interestingly, a recent study testing the hypothesis that centers with a primary EVAR strategy for ruptured AAA would have better results failed to show any such differences.[37]

From a health policy perspective, the findings of the current report indicate that the introduction of a national AAA screening program among men is not likely to result in a significant increase in AAA repair workload over time. It is important, however, to acknowledge that this report only included primary AAA repairs, while re-intervention and secondary interventions were excluded. The increasing uses of EVAR results in a significant need for resources for postoperative surveillance and re-intervention,[38] which will have an impact on the overall AAA-related operative workload. Additionally, the increasingly important role of EVAR in treatment of intact- and ruptured AAA patients with excellent results suggest a need for harmonization of vascular services, where vascular centers preferably should have 24/7 coverage for both open and endovascular repair of AAA. Currently, significant variations are present in EVAR availability and usage both between centers within one country, and between nations.[37,39]

LIMITATIONS

Patients who are declined surgical repair are not registered in Swedvasc registry and this study is unable to report the rate of AAAs treated conservatively. The registry contains no information regarding why EVAR was chosen over open repair or vice versa. It is likely that the basis for the choice of operation method (i.e., the aneurysm anatomy, severe comorbidity) affects outcome, which is why this analysis was not aimed at assessing differences in outcome based on surgical technique. The change of definition of heart disease (see methods) in Swedvasc and the inability to register if an AAA was discovered in screening until 2010, even though the screening program started in 2006, constitutes other potential sources of error.

CONCLUSIONS

In this nationwide analysis of AAA repair epidemiology in Sweden, a halt in the increase in incidence of intact AAA repair could be identified for the first time. This trend-break occurred despite increasing rate of EVAR, a continued increase in the surgical treatment of octogenarians, and an increasing number of screening-detected aneurysms being operated. The incidence of ruptured AAA repair has steadily declined since 2000, likely because of a combination of increased prophylactic intact AAA repair activity and decreased AAA prevalence. The perioperative and long-term survival after intact AAA repair continued to improve, especially in the elderly population. Thanks to the increasing use of EVAR in octogenarians, the perioperative survival after intact AAA repair was equally good in elderly patients when compared with younger patients. These findings have implications in the planning of provision of vascular surgical services in the future, where further centralization may be required due to reduction in AAA repair activity, specially considering open surgery.

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CONFLICT OF INTEREST

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APPENDIX A. SUPPLEMENTARY DATA

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.ejvs.2017.02.031.

REFERENCES

1 Volodos NL, Karpovich IP, Troyan VI, Kalashnikova Yu V, Shekhanin VE, Ternyuk NE, et al. Clinical experience of the use of self-fixing synthetic prostheses for remote endoprosthetics of the thoracic and the abdominal aorta and iliac arteries through the femoral artery and as intraoperative endoprosthesis for aorta reconstruction. *Vasa Suppl* 1991;**33**:93—5.

2 Parodi JC, Palmaz JC, Barone HD. Transfemoral intraluminal graft implantation for abdominal aortic aneurysms. *Ann Vasc Surg* 1991;**5**(6):491—9.

3 Moll FL, Powell JT, Fraedrich G, Verzini F, Haulon S, Waltham M, et al. Management of abdominal aortic aneurysms clinical practice guidelines of the European society for vascular surgery. *Eur J Vasc Endovasc Surg* 2011;**41**(Suppl 1):S1—58.

4 Biancari F, Catania A, D'Andrea V. Elective endovascular vs. open repair for abdominal aortic aneurysm in patients aged 80 years and older: Systematic review and meta-analysis. *Eur J Vasc Endovasc Surg* 2011;**42**(5):571—6.

5 Papia G, Klein D, Lindsay TF. Intensive care of the patient following open abdominal aortic surgery. *Curr Opin Crit Care* 2006;**12**(4):340—5.

6 Swedvasc. *Annual reports from the Swedish vascular register 2015*. 2015-12-21. Retrieved March 14, 2017, from http://www.ucr.uu.se/swedvasc/.

7 Wanhainen A, Bylund N, Bjorck M. Outcome after abdominal aortic aneurysm repair in Sweden 1994—2005. *Br J Surg* 2008;**95**(5):564—70.

8 Mani K, Bjorck M, Wanhainen A. Changes in the management of infrarenal abdominal aortic aneurysm disease in Sweden. *Br J Surg* 2013;**100**(5):638—44.

9 Lindholt JS, Juul S, Fasting H, Henneberg EW. Cost-effectiveness analysis of screening for abdominal aortic aneurysms based on five year results from a randomised hospital based mass screening trial. *Eur J Vasc Endovasc Surg* 2006;**32**(1):9—15.

10 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**(9345):1531—9.
11 Wanhainen A, Bjorck M. The Swedish experience of screening for abdominal aortic aneurysm. *J Vasc Surg* 2011;**53**(4):1164—5.
12 Svensjo S, Bjorck M, Wanhainen A. Update on screening for abdominal aortic aneurysm: a topical review. *Eur J Vasc Endovasc Surg* 2014;**48**(6):659—67.
13 Stather PW, Dattani N, Bown MJ, Earnshaw JJ, Lees TA. International variations in AAA screening. *Eur J Vasc Endovasc Surg* 2013;**45**(3):231—4.
14 Svensjo S, Bjorck M, Gurtelschmid M, Djavani Gidlund K, Hellberg A, Wanhainen A. Low prevalence of abdominal aortic aneurysm among 65-year-old Swedish men indicates a change in the epidemiology of the disease. *Circulation* 2011;**124**(10):1118—23.
15 Venermo M, Lees T. International vascunet validation of the Swedvasc registry. *Eur J Vasc Endovasc Surg* 2015;**50**(6):802—8.
16 Troeng T, Malmstedt J, Bjorck M. External validation of the Swedvasc registry: a first-time individual cross-matching with the unique personal identity number. *Eur J Vasc Endovasc Surg* 2008;**36**(6):705—12.
17 Statistics Sweden. *Population by age and gender 1860—2014 [Befolkning efter ålder och kön år 1860—2014]*. Stockholm: Statistics Sweden; 2015.
18 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**(2):161—6.
19 Wendt K, Kristiansen R, Krohg-Sorensen K, Gregersen FA, Fosse E. Trends in abdominal aortic and iliac aneurysm repairs in Norway from 2001 to 2013. *Eur J Vasc Endovasc Surg* 2015.
20 Mohan PP, Rozenfeld M, Kane RA, Calandra JD, Hamblin MH. Nationwide trends in abdominal aortic aneurysm repair and use of endovascular repair in the emergency setting. *J Vasc Interv Radiol* 2012;**23**(3):338—44.
21 Mureebe L, Egorova N, Giacovelli JK, Gelijns A, Kent KC, McKinsey JF. National trends in the repair of ruptured abdominal aortic aneurysms. *J Vasc Surg* 2008;**48**(5):1101—7.
22 Svensjo S, Bjorck M, Wanhainen A. Current prevalence of abdominal aortic aneurysm in 70-year-old women. *Br J Surg* 2013;**100**(3):367—72.
23 Mani K, Venermo M, Beiles B, Menyhei G, Altreuther M, Loftus I, et al. Regional differences in case mix and perioperative outcome after elective abdominal aortic aneurysm repair in the Vascunet database. *Eur J Vasc Endovasc Surg* 2015;**49**(6):646—52.
24 Dainese L, Barili F, Spirito R, Topkara VK, Pompilio G, Trezzi M, et al. Abdominal aortic aneurysm repair in octogenarians: Outcomes and predictors. *Eur J Vasc Endovasc Surg* 2006;**31**(5):464—9.
25 United Kingdom EVAR Trial Investigators, Greenhalgh RM, Brown LC, Powell JT, Thompson SG, Epstein D. Endovascular repair of aortic aneurysm in patients physically ineligible for open repair. *N Engl J Med* 2010;**362**(20):1872—80.
26 Bastos Goncalves F, Ultee KH, Hoeks SE, Stolker RJ, Verhagen HJ. Life expectancy and causes of death after repair of intact and ruptured abdominal aortic aneurysms. *J Vasc Surg* 2016;**63**(3):610—6.
27 Desgranges P, Kobeiter H, Katsahian S, Bouffi M, Gouny P, Favre JP, et al. Editor's Choice - ECAR (Endovasculaire ou Chirurgie dans les Anevrysmes aorto-iliaques Rompus): A French randomized controlled trial of endovascular versus open surgical repair of ruptured aorto-iliac aneurysms. *Eur J Vasc Endovasc Surg* 2015;**50**(3):303—10.
28 Hinchliffe RJ, Bruijstens L, MacSweeney ST, Braithwaite BD. A randomised trial of endovascular and open surgery for ruptured abdominal aortic aneurysm - results of a pilot study and lessons learned for future studies. *Eur J Vasc Endovasc Surg* 2006;**32**(5):506—13. discussion 14—5.
29 IMPROVE Trial Investigators. Endovascular strategy or open repair for ruptured abdominal aortic aneurysm: one-year outcomes from the IMPROVE randomized trial. *Eur Heart J* 2015;**36**(31):2061—9.
30 Reimerink JJ, Hoornweg LL, Vahl AC, Wisselink W, van den Broek TA, Legemate DA, et al. Endovascular repair versus open repair of ruptured abdominal aortic aneurysms: A multicenter randomized controlled trial. *Ann Surg* 2013;**258**(2):248—56.
31 Sweeting MJ, Balm R, Desgranges P, Ulug P, Powell JT, Ruptured Aneurysm T. Individual-patient meta-analysis of three randomized trials comparing endovascular versus open repair for ruptured abdominal aortic aneurysm. *Br J Surg* 2015;**102**(10):1229—39.
32 Opfermann P, von Allmen R, Diehm N, Widmer MK, Schmidli J, Dick F. Repair of ruptured abdominal aortic aneurysm in octogenarians. *Eur J Vasc Endovasc Surg* 2011;**42**(4):475—83.
33 Karthikesalingam A, Vidal-Diez A, Holt PJ, Loftus IM, Schermerhorn ML, Soden PA, et al. Thresholds for abdominal aortic aneurysm repair in England and the United States. *N Engl J Med* 2016;**375**(21):2051—9.
34 Cao P, De Rango P, Verzini F, Parlani G, Romano L, Cieri E, et al. Comparison of surveillance versus aortic endografting for small aneurysm repair (CAESAR): results from a randomised trial. *Eur J Vasc Endovasc Surg* 2011;**41**(1):13—25.
35 Ouriel K, Clair DG, Kent KC, Zarins CK. Positive impact of endovascular options for treating aneurysms early I. Endovascular repair compared with surveillance for patients with small abdominal aortic aneurysms. *J Vasc Surg* 2010;**51**(5):1081—7.
36 Beck AW, Sedrakyan A, Mao J, Venermo M, Faizer R, Debus S, et al. Variations in abdominal aortic aneurysm care: A report from the International consortium of vascular registries. *Circulation* 2016;**134**(24):1948—58.
37 Gunnarsson K, Wanhainen A, Djavani Gidlund K, Bjorck M, Mani K. Endovascular versus open repair as primary strategy for ruptured abdominal aortic aneurysm: A national population-based study. *Eur J Vasc Endovasc Surg* 2016;**51**(1):22—8.
38 Giles KA, Landon BE, Cotterill P, O'Malley AJ, Pomposelli FB, Schermerhorn ML. Thirty-day mortality and late survival with reinterventions and readmissions after open and endovascular aortic aneurysm repair in Medicare beneficiaries. *J Vasc Surg* 2011;**53**(1). 6—12.3.e1.
39 Mani K, Lees T, Beiles B, Jensen LP, Venermo M, Simo G, et al. Treatment of abdominal aortic aneurysm in nine countries 2005—2009: A vascunet report. *Eur J Vasc Endovasc Surg* 2011;**42**(5):598—607.