Outcomes in octogenarians and the effect of comorbidities after intact abdominal aortic aneurysm repair in the Netherlands: a nationwide cohort study

Alberga, A.J.; Karthaus, E.G.; Zwet, E.W. van; Bruin, J.L. de; Herwaarden, J.A. van; Wever, J.J.; ... ; Dutch Inst Clin Auditing

Eur J Vasc Endovasc Surg (2021) 61, 920—928

EJVES Open Access

NATIONAL REGISTRY

Outcomes in Octogenarians and the Effect of Comorbidities After Intact Abdominal Aortic Aneurysm Repair in the Netherlands: A Nationwide Cohort Study

Anna J. Alberga [a,b,*], Eleonora G. Karthaus [c], Erik W. van Zwet [d], Jorg L. de Bruin [a], Joost A. van Herwaarden [e], Jan J. Wever [f], Hence J.M. Verhagen [a], in collaboration with the Dutch Society of Vascular Surgery [†], the Steering Committee of the Dutch Surgical Aneurysm Audit [†], the Dutch Institute for Clinical Auditing

[a] Department of Vascular Surgery, Erasmus University Medical Centre, Rotterdam, the Netherlands
[b] Scientific Bureau, Dutch Institute for Clinical Auditing, Leiden, the Netherlands
[c] Department of Surgery, Amsterdam UMC, Amsterdam, the Netherlands
[d] Department of Biomedical Data Sciences, Leiden University Medical Centre, Leiden, the Netherlands
[e] Department of Vascular Surgery, University Medical Centre Utrecht, Utrecht, the Netherlands
[f] Department of Vascular Surgery, Haga Teaching Hospital, The Hague, the Netherlands

WHAT THIS PAPER ADDS

This paper examined retrospectively the outcomes of octogenarians that underwent either open surgical repair or endovascular repair for an intact abdominal aortic aneurysm in an obligatory nationwide registry, reflecting daily clinical practice in the Netherlands. The study showed that besides an increased age, comorbidities were clearly associated with impaired peri-operative survival after both open surgical and endovascular repair.

Objective: Age is an independent risk factor for mortality after both elective open surgical repair (OSR) and endovascular aneurysm repair (EVAR). As a result of an ageing population, and the less invasive nature of EVAR, the number of patients over 80 years (octogenarians) being treated is increasing. The mortality and morbidity following aneurysm surgery are increased for octogenarians. However, the mortality for octogenarians who have either low or high peri-operative risks remains unclear. The aim of this study was to provide peri-operative outcomes of octogenarians *vs.* non-octogenarians after OSR and EVAR for intact aneurysms, including separate subanalyses for elective and urgent intact repair, based on a nationwide cohort. Furthermore, the influence of comorbidities on peri-operative mortality was examined.

Methods: All patients registered in the Dutch Surgical Aneurysm Audit (DSAA) undergoing intact AAA repair between 2013 and 2018, were included. Patient characteristics and peri-operative outcomes (peri-operative mortality, and major complications) of octogenarians *vs.* non-octogenarians for both OSR and EVAR were compared using descriptive statistics. Multivariable logistic regression analyses were used to examine whether age and the presence of cardiac, pulmonary, or renal comorbidities were associated with mortality.

Results: This study included 12 054 EVAR patients (3 015 octogenarians), and 3 815 OSR patients (425 octogenarians). Octogenarians in both the EVAR and OSR treatment groups were more often female and had more comorbidities. In both treatment groups, octogenarians had significantly higher mortality rates following intact repair as well as higher major complication rates. Mortality rates of octogenarians were 1.9% after EVAR and 11.8% after OSR. Age $\geq$ 80 and presence of cardiac, pulmonary, and renal comorbidities were associated with mortality after EVAR and OSR.

Conclusion: Because of the high peri-operative mortality rates of octogenarians, awareness of the presence of comorbidities is essential in the decision making process before offering aneurysm repair to this cohort, especially when OSR is considered.

Keywords: Abdominal aortic aneurysm, Elderly, Endovascular procedure, Octogenarians, Operative surgical procedure
Article history: Received 29 May 2020, Accepted 23 February 2021, Available online 16 April 2021

† For collaborators, please see Appendix A.

* Corresponding author. Scientific Bureau, Dutch Institute for Clinical Auditing, Rijnsburgerweg 10, 2333 AA, Leiden, the Netherlands.
E-mail address: a.alberga@dica.nl (Anna J. Alberga).

https://doi.org/10.1016/j.ejvs.2021.02.047

INTRODUCTION

In the last decade, endovascular aneurysm repair (EVAR) has become the preferred treatment for many patients with an intact abdominal aortic aneurysm (AAA),[1] because of its lower peri-operative risks. Age is a known independent risk factor for post-operative mortality after both elective open surgical repair (OSR) and EVAR.[2] As a result of an ageing population,[3] the number of patients over 80 years (octogenarians) who qualify for elective AAA repair is increasing.[4,5] However, the mortality and morbidity after AAA surgery for octogenarians is increased,[6–9] which is important in the decision making process of when and how to intervene in this usually frailer population.

In current literature that reports on octogenarians, meta-analyses that include mainly observational studies have not described outcomes with details for octogenarians,[7–9] while RCTs barely enrolled patients over 80 years.[6] Peri-operative mortality of octogenarians after primary AAA repair in 11 countries was assessed by the Vascunet collaboration. However, the morbidity of these patients was not described.[4] Therefore, there is a paucity of real life clinical data concerning mortality and morbidity after AAA surgery for octogenarians. Moreover, published studies scarcely report on the peri-operative mortality of subgroups of octogenarians with either low or high peri-operative risks. The recent ESVS guideline state that it is reasonable to consider elective AAA repair of octogenarians with reasonable life expectancy and quality of life after informing them of the pros and cons of different treatment strategies including conservative treatment.[10] However, no statements were made on which octogenarians have high peri-operative risks. The aim of this study was to provide peri-operative mortality and major complication rates of octogenarians *vs.* non-octogenarians following intact AAA repair. This was assessed following both open surgical and endovascular aneurysm repair including separate subanalyses for elective and urgent intact repair using a nationwide prospective registry. Furthermore, which octogenarians have low and high peri-operative risks was identified, examining the influence of age and the presence of comorbidities on peri-operative mortality.

MATERIALS AND METHODS

Data sources and study design

The dataset was retrieved from the Dutch Surgical Aneurysm Audit (DSAA), a nationwide prospective and compulsory quality registry that registers all patients undergoing aortic aneurysm surgery in the Netherlands. The DSAA was initiated in 2013, and includes all patients who underwent surgical repair of an infrarenal or juxtarenal AAA without previous aortic surgery. Since 2016, patients undergoing revisional aneurysm surgery and/or patients undergoing thoracic or thoraco-abdominal aortic aneurysm repair have been registered as well. Data verification took place through a random sample of hospitals.[11] The data were analysed retrospectively and reported following the STROBE guidelines.[12]

Participants

For this study, all patients who were registered in the DSAA undergoing primary repair (EVAR or OSR) for an intact AAA between January 2013 and December 2018 were included for analysis, provided that sex, date of birth, date of surgery, survival status at the time of discharge or 30 days post-operatively were registered. Data analyses were performed on an anonymised dataset. Ethical approval was not needed according to Dutch law.

Definitions

Patients were considered octogenarians when turning 80 years old or older in the year of surgery. EVAR procedures followed by immediate conversion were categorised by intention to treat. Intact aneurysm repairs included pooled data of both elective repair and urgent intact AAA repair. "Cardiac comorbidity" was defined as the use of diuretic or digoxin, antianginal or antihypertensive therapy, peripheral oedema, warfarin therapy, raised jugular venous pressure, or cardiomegaly.[13] "Abnormality on ECG" was defined as atrial fibrillation, ischaemia or any other ECG abnormalities.[13] Because of possible confounding caused by the variables "Cardiac comorbidity" and "Abnormality on ECG", it was decided to combine these variables into the variable "Cardiac comorbidity including abnormality on ECG" in the analyses. "Pulmonary comorbidity" was defined as dyspnoea on exertion, limiting dyspnoea, dyspnoea at rest, or visible consolidations or fibrosis on chest imaging.[13] "Renal comorbidity" was defined as an eGFR < 60 mL/min/1.73m^2, which is categorised as "chronic kidney disease" by the International Society of Nephrology.[14] The eGFR was estimated using the CKD-EPI equation[15] and the variables "creatinine", "sex", and "age".

Outcomes

All outcomes of octogenarians were compared with the results of non-octogenarians. The primary outcome was peri-operative mortality, which was defined as intra-operative mortality, mortality $\leq$ 30 days after surgery, or during admission (in hospital mortality). The secondary outcomes were peri-operative major complications ($\leq$ 30 days), defined as either an intra-operative or post-operative complications that needed a re-intervention, induced prolonged stay, or caused death[16] and the peri-operative mortality in patients with and without comorbidities. Furthermore, subgroup analyses were performed to compare outcomes of octogenarians and non-octogenarians treated in elective and urgent intact settings.

Statistical methods

Descriptive analysis was performed using *t* tests for parametrically distributed data, chi square tests and Fisher exact tests. Baseline characteristics, as well as peri-operative outcomes, were compared between octogenarians and non-octogenarians undergoing either EVAR or OSR. Missing values were shown as separate categories. A p value of $<.05$ was considered statistically significant.

To investigate whether age $\geq$ 80 was associated with peri-operative mortality, multivariable logistic regression analyses were performed for both EVAR and OSR. Patient and aneurysm related variables, based on the V(p)-POSSUM predictive score,[13,17] that were potential confounders and available in the DSAA were included as covariates: age $\geq$80, sex, pulmonary comorbidity, cardiac comorbidity including results of last pre-operative electrocardiogram, renal comorbidity, pre-operative haemoglobin, urgency, location, and diameter of the aneurysm. Factors with a p value of $<.10$ in univariable analysis were selected for multivariable analysis. Finally, the peri-operative mortality rates of octogenarians and non-octogenarians with no comorbidities, cardiac comorbidity (including abnormality on the ECG), pulmonary comorbidity, and renal comorbidity were shown.

Missing data

The data for this study contained some variables with missing values. If patients with any missing data had been excluded from the analyses, information on 2 477 (19.1%) patients including 538 octogenarians who underwent EVAR and 685 (18.0%) patients including 74 octogenarians who underwent OSR would have been lost. To prevent such loss of information, a state of the art method of multiple imputation using chained equations (MICE) was used.[18]

Missing data were imputed separately for EVAR and OSR patients. The outcome peri-operative mortality was not imputed, and the following variables were used in the imputation process: age, sex, cardiac and pulmonary comorbidity, results of the last electrocardiogram, haemoglobin, creatinine, diameter, location, urgency, peri-operative mortality, pre- and post-operative complications, length of ICU stay, length of hospital stay, re-intervention, and re-admission. Twenty-five completed datasets were generated (each with 10 iterations) for both EVAR and OSR patients.[18] Values that were imputed were compared with values that were observed using scatter and density plots. For the multivariable regression models, the results of the imputed datasets were combined to produce a final result using Rubin's rules.[18] For comparison, multivariable regression analyses using the subsets of complete cases were performed.

All analyses were performed using R version 3.6.1.

RESULTS

Between January 2013 and December 2018, 21 950 consecutive patients were registered in the DSAA. Of these patients, 15 906 underwent primary AAA repair for an intact aneurysm, of whom 15 869 (99.8%) were eligible for analysis (Figure 1). In total, 12 054 EVAR patients including 3 015 (25%) octogenarians, and 3 815 OSR patients including 425 (11%) octogenarians, were included.

Patient characteristics, aneurysm morphology, and operative data

Patient characteristics, aneurysm morphology, and operative data comparing octogenarians and non-octogenarians who received either EVAR or OSR are shown in Table 1. In both groups, octogenarians were more often female, had larger aneurysm diameters, and more often had pulmonary and renal comorbidity compared with younger patients. In the EVAR group and after multiple imputation in the OSR group, octogenarians suffered more often from cardiac comorbidity. In both the EVAR and OSR groups, octogenarians were more often treated for urgent intact aneurysms compared with non-octogenarians.

Peri-operative outcomes

Mortality. As shown in Table 2, octogenarians had statistically significantly higher peri-operative mortality rates than non-octogenarians after surgery for all intact AAA. The odds ratio for peri-operative mortality in octogenarians compared with non-octogenarians was 2.5 for EVAR (1.9% *vs.* 0.8%, $p < .001$, OR 2.51) and 2.7 for OSR respectively (11.8% *vs.* 4.7%, $p < .001$, OR 2.73). In the Supplementary material, Appendix B shows the distribution of 30 day mortality and in hospital mortality in the composite outcome peri-operative mortality. In subgroup analyses of electively treated AAA patients (both EVAR and OSR), mortality rates were higher for octogenarians compared with non-octogenarians as well (EVAR: 1.4% *vs.* 0.6%, $p <$ .001, OR 2.28; OSR: 9.3% *vs.* 4.4%, $p < .001$, OR 2.24). In patients treated for urgent intact AAAs, octogenarians had higher mortality rates compared with non-octogenarians (EVAR: 6.6% *vs.* 2.6%, $p = .007$, OR 2.59; OSR: 20.7% *vs.* 6.6%, $p < .001$, OR 3.69).

Major complications. Table 2 shows that octogenarians more often developed major complications compared with non-octogenarians following both intact EVAR and OSR, as well as following elective and urgent intact repair. Major octogenarian complication rates in the intact setting were 12.4% after EVAR and 28.0% after OSR.

Associations with mortality

After univariable analyses, the factor "location" (EVAR) was not selected for multivariable analysis because of a p value $>$ .10 (Table 3). The factor "age $\geq$ 80" was statistically significantly associated with higher mortality rates after adjusting for confounding factors after both EVAR and OSR (Tables 3 and 4). Sensitivity analysis involving multivariable analysis using complete cases showed a similar association of "age $\geq$ 80", with mortality after EVAR (OR 1.67, 95% CI 1.09 − 2.56) and OSR (OR 1.99, 95% CI 1.34 − 2.92) (Supplementary material, Appendix B).

Observed comorbidities and corresponding peri-operative mortality

Only 317 (10.5% in original data; 12.0% in imputed data) and 42 (9.9% in original data; 12.8% in imputed data)

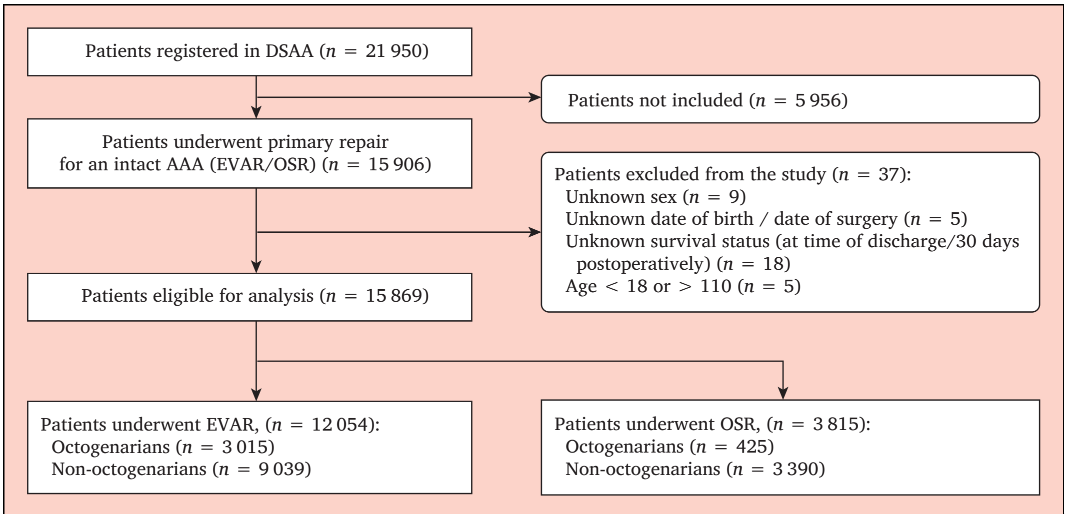

Figure 1. Study flow chart of included octogenarians and non-octogenarians who were registered in the Dutch Surgical Aneurysm Audit (DSAA) and who underwent primary repair of an intact abdominal aortic aneurysm (AAA) by endovascular aneurysm repair (EVAR) or open surgical repair (OSR).

octogenarians undergoing EVAR and OSR had no comorbidities, respectively (Table 5). Observed peri-operative mortality rates following intact AAA repair in patients with no comorbidity, cardiac, pulmonary, or renal comorbidity are shown in Table 5. After EVAR, the mortality rates of octogenarians with a cardiac, pulmonary, or renal comorbidity reached 2.4%, 4.2%, or 2.5%, respectively, while octogenarians with no comorbidities had a rate of 0.4% (all percentages are based on imputed data). After OSR, the mortality rates of octogenarians with cardiac, pulmonary, or renal comorbidity reached 13.4%, 13.6%, and 14.8%, while octogenarians with no comorbidities had a mortality rate of 3.8% (based on imputed data).

DISCUSSION

The octogenarians in this study were at risk of significantly higher peri-operative mortality and major complication rates after both EVAR and OSR for intact AAA compared with younger patients. Furthermore, the effect of comorbidities in this age group was more pronounced and was clearly associated with impaired survival. In octogenarians, mortality after OSR exceeded 10%, especially when comorbidities were present. After EVAR, octogenarians with pulmonary comorbidities had a mortality rate of approximately 4%. In contrast, mortality was 1.9% for all octogenarians in the EVAR group.

Surgical risk is at the heart of clinical (shared) decision making, especially when prophylactic surgery is performed on asymptomatic patients such as in elective AAA care.[19] To inform patients appropriately before undergoing high risk surgery, robust data are needed concerning morbidity and mortality. The DSAA is a mandatory national verified quality registry, set up to monitor and improve the quality of AAA care by providing benchmarked information to vascular surgeons. Since 2013, all patients undergoing primary abdominal aortic aneurysm surgery in the Netherlands have been registered, providing objective, real world data. Because of its scale and in contrast to other published studies, it enables relevant subanalyses such as the analysis described in this paper.[8,9] Additionally, local data on outcomes of octogenarians could be valuable to inform patients and family accurately, for example because of a potential hospital related volume outcome relationship for OSR.[20] Since 2019, a specific dashboard called the Codman Dashboard has enabled all Dutch vascular surgeons to analyse their registered outcomes of particular subgroups.[21]

This study describes a mortality rate of 11.8% for all octogenarians after OSR, and this seems to exceed the yearly rupture risks of smaller aneurysms. Moreover, octogenarians with comorbidities have mortality rates > 10% after OSR, in contrast to the mortality rate of 3.6% in the (small) group of octogenarians without comorbidities (12.8% of all octogenarians in this cohort, based on imputed data). In the literature, a mortality rate of 7.5% for octogenarians who were treated electively by OSR was described in a meta-analysis.[7] For intact aneurysm repair, a mortality rate of 9.5% for octogenarians was described in an international study by Budtz-Lilly *et al.*, which combined the results of 11 vascular registries,[4] similar to the results from the present study. However, mortality rates in these studies were rarely specified for either high or low risk octogenarians.[22] In previous studies that examined the safety of surveillance for small aneurysms up to 5.5 cm, 30 day operative mortality rates of only 5.5%[23] and 2.1%[24] were described. This poses the question of whether operative mortality rates exceeding these numbers are acceptable, in particular in elderly patients undergoing preventive aneurysm repair at relatively small diameters that are at low risk of rupture.

After EVAR, this study reports a mortality rate of 1.9% for octogenarians. This is in line with the previously mentioned international study by Budtz-Lilly *et al.*, which reported a mortality rate of 1.8% of octogenarians after EVAR. Meta-analyses that included older studies have described

Table 1. Patient characteristics, aneurysm morphology, and operative data for octogenarians *vs.* non-octogenarians who underwent either endovascular aneurysm repair (EVAR) or open surgical repair (OSR) of an intact abdominal aortic aneurysm

	EVAR			OSR		
	<80 y (n = 9 039)	≥80 y (n = 3 015)	p value	<80 y (n = 3 390)	≥80 y (n = 425)	p value
Female sex	1095 (12.1) [12.1]	495 (16.4) [16.4]	<.001 [<.001]	624 (18.4) [18.4]	108 (25.4) [25.4]	.001 [<.001]
Age − y	70.76 ± 5.95	83.30 ± 2.91	N.A.	69.27 ± 6.85	82.18 ± 2.21	N.A.
Cardiac comorbidity including abnormalities on ECG			<.001 [<.001]			<.001 [.11]
No	2556 (33.2) [28.3]	678 (25.2) [22.5]		981 (32.1) [28.9]	104 (27.9) [24.5]	
Yes	5810 (66.8) [64.3]	2190 (74.8) [72.6]		2244 (67.9) [66.2]	295 (72.1) [69.4]	
Unknown/missing	673 (−) [7.4]	147 (−) [4.9]		165 (−) [4.9]	26 (−) [6.1]	
Pulmonary comorbidity			<.001 [.014]			<.001 [.028]
No	6623 (74.5) [73.3]	2143 (72.7) [71.1]		2521 (76.3) [74.4]	296 (72.9) [69.6]	
Yes	2263 (25.5) [25.0]	802 (27.3) [26.6]		781 (23.7) [23.0]	110 (27.1) [25.9]	
Unknown/missing	153 (−) [1.7]	70 (−) [2.3]		88 (−) [2.6]	19 (−) [4.5]	
Renal comorbidity			<.001 [<.001]			<.001 [<.001]
No, eGFR ≥ 60 mL/min/1.73m^2	6603 (74.8) [73.1]	1477 (50.2) [49.0]		2371 (72.6) [69.9]	209 (50.6) [49.2]	
Yes, eGFR <60 mL/min/1.73m^2	2224 (25.2) [24.6]	1471 (49.8) [48.8]		893 (27.4) [26.3]	206 (49.4) [48.5]	
Unknown/missing	212 (−) [2.3]	67 (−) [2.2]		126 (−) [3.7]	10 (−) [2.4]	
Haemoglobin − mmol/L	8.75 ± 1.00	8.36 ± 1.02	<.001 [<.001]	8.65 ± 1.01	8.25 ± 0.99	<.001 [<.001]
Missing	228 (−) [2.5]	74 (−) [2.5]		87 (−) [2.6]	8 (−) [1.9]	
Urgency: urgent intact	606 (6.7) [6.7]	274 (9.1) [9.1]	<.001 [<.001]	425 (12.5) [12.5]	92 (21.6) [21.6]	<.001 [<.001]
Location: aortoiliac aneurysm	600 (6.6) [6.6]	160 (5.3) [9.1]	.010 [<.001]	208 (6.1) [6.1]	16 (3.8) [3.8]	<.001 [.064]
Aneurysm diameter − mm	58.97 ± 10.73	61.41 ± 11.51	<.001 [<.001]	62.68 ± 13.99	67.31 ± 15.48	<.001 [<.001]
Missing	109 (−) [1.2]	33 (−) [1.1]		72 (−) [2.1]	10 (−) [2.4]	
Procedure			<.001 [.003]			
EVAR	8484 (93.9) [93.9]	2878 (95.5) [95.5]				
Conversion	26 (0.3) [0.3]	10 (0.3) [0.3]				
Complex endovascular	529 (5.8) [5.8]	127 (4.2) [4.2]				

Data are presented as n (%) [%] and for continuous variables as mean ± standard deviation. Values in parentheses "(%)" are percentages after multiple imputation (25 datasets for EVAR patients, 25 datasets for OSR patients). Values in square brackets "[%]" are percentages including missing data with p values presented in square brackets as well.

mortality rates for octogenarians of 3.7%[9] and 4.6%[7] after EVAR. The impact of improved device technology (lower profile devices), peri-operative management including better anaesthetic techniques,[25] and cardioprotective medication[26] might play a role in improved survival of octogenarians in this study compared with the meta-analyses with older data.[4] In the present study, a peri-operative mortality rate of 4.2% was observed for octogenarians with a pulmonary comorbidity. This mortality rate was low compared with the mortality rate of 7.3% reported in the EVAR-2 study in patients who were considered not physically fit enough to undergo OSR.[27]

Apart from the mortality rates following intact AAA repair, other outcomes for octogenarians are important as well and could assist in the clinical decision making process. First, to deal with the heterogeneity in the group of intact AAA repairs, subanalyses were performed for elective and urgent intact repair including adjustment for urgent intact repair in the multivariable analyses. Furthermore, in the present study, major complication rates were examined. As expected, octogenarians had higher major complication rates compared with non-octogenarians. Obviously, other outcome parameters, such as quality of life,[28] re-intervention rate,[6] long term outcomes,[29] and costs,[30] are also important to consider in the clinical decision making process for octogenarians, but these are not captured in the DSAA registry.

In this study, no association between aneurysm size and mortality was found in OSR patients, which might suggest that postponing OSR does not result in higher mortality rates. Remarkably, in EVAR patients, aneurysm size was associated with mortality. The diameter threshold for elective abdominal aneurysm repair is based on both peri-operative risk and the risk of rupture. However, the risk of rupture according to aneurysm diameter was not investigated. In the literature, little is known about the diameters of ruptured aneurysms between octogenarians and non-octogenarians.[31] In studies up to 2010, the mean annual risk of rupture of a 5 cm aneurysm was 0.6% in men and 2.9% in women. It is stated that the mean diameter of ruptured aneurysms in all patients has increased during the last decade, possibly because of increased statin therapy.[26] A previous study demonstrated that some patients with severe comorbidities and large aneurysms could be managed conservatively with acceptable results for long periods (7 − 76 months).[32] Therefore, the question remains

Table 2. Peri-operative mortality rates and major complications rates for octogenarians *vs.* non-octogenarians who underwent either endovascular aneurysm repair (EVAR) or open surgical repair (OSR) of abdominal aortic aneurysm in intact, elective, and intact urgent setting

	Patients		Peri-operative mortality*				Major complications†			
	<80 y	≥80 y	<80 y (ref.)	≥80 y	*p*	OR (95% CI)	<80 y (ref.)	≥80 y	*p*	OR (95% CI)
EVAR										
Intact	9039 (75.0)	3015 (25.0)	69 (0.8)	57 (1.9)	<.001	2.51 (1.75–3.56)	700 (7.7)	375 (12.4)	<.001	1.69 (1.47–1.92)
Elective	8433	2741	53 (0.6)	39 (1.4)	<.001	2.28 (1.50–3.45)	600 (7.1)	298 (10.9)	<.001	1.59 (1.37–1.83)
Urgent intact	606	274	16 (2.6)	18 (6.6)	.009	2.59 (1.30–5.22)	100 (16.5)	77 (28.1)	<.001	1.98 (1.41–2.79)
OSR										
Intact	3390 (88.9)	425 (11.1)	158 (4.7)	50 (11.8)	<.001	2.73 (1.93–3.79)	672 (19.8)	119 (28.0)	<.001	1.58 (1.25–1.98)
Elective	2965	333	130 (4.4)	31 (9.3)	<.001	2.24 (1.46–3.33)	580 (19.6)	86 (25.8)	.012	1.44 (1.10–1.86)
Urgent intact	425	92	28 (6.6)	19 (20.7)	<.001	3.69 (1.94–6.92)	92 (21.6)	33 (35.9)	.006	2.02 (1.24–3.27)

Data are presented as *n* (%) unless stated otherwise.
* Peri-operative mortality including intra-operative, 30 day, and in hospital mortality.
† Major complication: post-operative death or a peri- or post-operative complication leading to a re-intervention or prolonged hospital stay.

Table 3. Multivariable logistic regression analysis to examine the association between age ≥ 80 and peri-operative mortality in patients with endovascular repair of abdominal aortic aneurysm. Missing data were completed by multiple imputation

Factor	Univariable analysis		Multivariable analysis	
	OR (95% CI)	*p* value	aOR (95% CI)	*p* value
Age ≥ 80	2.51 (2.33–2.69)	<.001	1.66 (1.54–1.79)	<.001
Female sex	1.48 (1.35–1.62)	<.001	1.16 (1.06–1.28)	.002
Cardiac comorbidity including abnormalities on ECG	2.43 (2.21–2.67)	<.001	1.69 (1.53–1.86)	<.001
Pulmonary comorbidity	3.98 (3.46–3.98)	<.001	3.18 (2.96–3.42)	<.001
Renal comorbidity, eGFR <60 mL/min/1.73m^2	2.66 (2.48–2.86)	<.001	1.84 (1.70–1.98)	<.001
Haemoglobin	0.62 (0.60–0.64)	<.001	0.75 (0.73–0.78)	<.001
Urgent intact	4.84 (4.47–5.24)	<.001	3.89 (3.57–4.24)	<.001
Aortoiliac location of aneurysm	1.01 (0.90–1.16)	.92	–	–
Aneurysm diameter per 10 mm	1.28 (1.25–1.32)	<.001	1.10 (1.07–1.13)	<.001

OR = odds ratio; aOR = adjusted odds ratio; CI = confidence interval.

Table 4. Multivariable logistic regression analyses to examine the association between age ≥ 80 and peri-operative mortality in patients with open surgical repair of abdominal aortic aneurysm. Missing data were completed by multiple imputation

Factor	Univariable analysis		Multivariable analysis	
	OR (95% CI)	*p* value	aOR (95% CI)	*p* value
Age ≥80	2.73 (2.55–2.92)	<.001	2.02 (1.88–2.17)	<.001
Female sex	1.73 (1.62–1.84)	<.001	1.42 (1.33–1.52)	<.001
Cardiac comorbidity including abnormalities on ECG	1.99 (1.86–2.13)	<.001	1.76 (1.64–1.89)	<.001
Pulmonary comorbidity	1.98 (1.87–2.10)	<.001	1.78 (1.67–1.89)	<.001
Renal comorbidity, eGFR <60 mL/min/1.73m^2	2.30 (2.18–2.44)	<.001	1.85 (1.75–1.96)	<.001
Haemoglobin	0.74 (0.72–0.76)	<.001	0.85 (0.83–0.88)	<.001
Urgent intact	1.95 (1.82–2.08)	<.001	1.81 (1.68–1.95)	<.001
Aortoiliac location of aneurysm	0.38 (0.32–0.45)	<.001	0.48 (0.40–0.58)	<.001
Aneurysm diameter per 10 mm	1.07 (1.05–1.09)	<.001	0.99 (0.97–1.01)	.25

OR = odds ratio; aOR = adjusted odds ratio; CI = confidence interval.

of whether the diameter threshold at which to intervene should be increased for octogenarians because of a much higher peri-operative risk, in particular when octogenarians experience comorbidities and OSR is considered to be the treatment modality.

Despite the relatively large number of octogenarians in this cohort, this study has some limitations. First, the DSAA includes only patients who were considered fit enough to undergo surgery, which was a clinical decision by the surgeon. Because of this selection bias, predictions of mortality

Table 5. Peri-operative mortality rates for octogenarians and non-octogenarians who underwent either endovascular aneurysm repair (EVAR) or open surgical repair (OSR) of abdominal aortic aneurysm in intact setting, stratified by the presence of comorbidities

	EVAR		OSR	
	<80 y (n = 9 039)	≥80 y (n = 3 015)	<80 y (n = 3 390)	≥80 y (n = 425)
Comorbidities				
No comorbidities*	1654 (22.2) [18.3]	317 (12.0) [10.5]	612 (21.0) [18.1]	42 (12.8) [9.9]
Cardiac comorbidity including abnormalities on ECG	5810 (66.8) [64.3]	2190 (74.8) [72.6]	2244 (67.9) [66.2]	295 (72.1) [69.4]
Pulmonary comorbidity	2263 (25.5) [25.0]	802 (27.3) [26.6]	781 (23.7) [23.0]	110 (27.1) [25.9]
Renal comorbidity	2224 (25.2) [24.6]	1471 (49.8) [48.8]	893 (27.4) [26.3]	206 (49.4) [48.5]
Peri-operative mortality				
All patients	69 (0.8) [0.8]	57 (1.9) [1.9]	158 (4.7) [4.7]	50 (11.8) [11.8]
No comorbidities*	4 (0.3) [0.2]	1 (0.4) [0.3]	11 (1.9) [1.8]	2 (3.8) [4.8]
Cardiac comorbidity including abnormalities on ECG	51 (0.9) [0.9]	51 (2.4) [2.3]	234 (5.5) [5.5]	38 (13.4) [12.9]
Pulmonary comorbidity	35 (1.6) [1.5]	32 (4.2) [4.0]	60 (7.8) [7.7]	14 (13.6) [12.7]
Renal comorbidity	31 (1.4) [1.4]	36 (2.5) [2.4]	67 (7.5) [7.5]	30 (14.8) [14.6]

Data are presented as n (%) [%]. Values in parentheses "(%)" are percentages after multiple imputation (25 datasets for EVAR patients, 25 datasets for OSR patients). Values in square brackets "[%]" are percentages including missing data.
* No comorbidities: based on no pulmonary comorbidity, no cardiac comorbidity including no abnormalities on ECG, and no renal dysfunction (eGFR <60 mL/min/1.73m^2).

rates based on the number of comorbidities of octogenarians who could be incorporated in the decision making process could not be made, as the decision to perform surgery had already been made. Therefore, the reported peri-operative outcomes of octogenarians in this study will probably be better than peri-operative outcomes of all octogenarians with an intact AAA. Second, information bias might have taken place, as age was calculated as the year of surgery minus the year of birth. This calculation included some patients of age 79 in the group "octogenarians", which might have led to an underestimation of the outcomes of octogenarians. Furthermore, this was a retrospective study of a retrieved dataset from the DSAA, a prospectively maintained national quality registry. As this audit is not designed purely for scientific research, information on some potential confounders such as peripheral artery obstructive disease,[33] type of anaesthetic, anatomical details, surgeon experience, or frailty were not available. It would be interesting to examine the influence of frailty, as it has been reported that frailty is associated with age as well as with peri-operative mortality.[34] Furthermore, Joseph *et al.* stated that a frailty index was better for predicting mortality compared with age in emergency general surgery in the elderly,[35] while age was a predictor of mortality in vascular studies that did not report on frailty.[36,37] Another limitation of this study is that the specific categories in the groups cardiac and pulmonary comorbidity were potentially not equally weighted between octogenarians and non-octogenarians, which might have caused heterogeneity in the groups of octogenarians *vs.* non-octogenarians and thus, these groups were not compared. Finally, the dataset had some missing data and thus, for multivariable logistic regression analyses and analyses stratified for the presence of comorbidities, missing data were imputed using multiple imputation. Sensitivity analyses using complete cases were performed for the multivariable analyses that examined the association of age $\geq$ 80 with mortality, with similar results.

In conclusion, age $\geq$ 80 and comorbidities are significantly associated with mortality after endovascular and open repair for abdominal aortic aneurysms. Mortality after OSR in octogenarians is exceedingly high, especially in the presence of comorbidities. Reported observed rates in this study can be used by everyone involved in the decision making process considering optimal care for aneurysm patients. More research focused on optimal treatment thresholds for elective AAA repair in both low and high risk subgroups of octogenarians is needed. For now, awareness of the presence of comorbidities is key in the decision making process.

CONFLICTS OF INTEREST

HV: consultant for Medtronic, WL Gore, Terumo, Endologix, and Arsenal AAA.

FUNDING

None.

ACKNOWLEDGEMENTS

The authors would like to thank the members of the Dutch Society for Vascular Surgery who registered their patients in the DSAA, the Dutch Institute for Clinical Auditing that facilitated the registry, and the Steering Committee of the Dutch Surgical Aneurysm Audit.

APPENDIX A. COLLABORATORS

Van den Akker PJ, Akkersdijk GJ, Akkersdijk GP, Akkersdijk WL, van Andringa de Kempenaer MG, Arts CH, Avontuur JA, Bakker OJ, Balm R, Barendregt WB, Bekken JA, Bender MH, Bendermacher BL, van den Berg M, Berger P, Beuk RJ, Blankensteijn JD, Bleker RJ, Blok JJ, Bode AS, Bodegom ME, van der Bogt KE, Boll AP, Booster MH, Borger van der Burg BL, de Borst GJ, Bos- van Rossum WT, Bosma J, Botman JM, Bouwman LH, Brehm V, de Bruijn MT, de Bruin JL, Brummel P, van Brussel JP, Buijk SE, Buijs MA, Buimer MG, Burger DH, Buscher HC, Cancrinus E, Castenmiller PH, Cazander G, Coester AM, Cuypers PH, Daemen JH, Dawson I, Dierikx JE, Dijkstra ML, Diks J, Dinkelman MK, Dirven M, Dolmans DE, van Doorn RC, van Dortmont LM, Drouven JW, van der Eb MM, Eefting D, van Eijck GJ, Elshof JW, Elsman BH, van der Elst A, van Engeland MI, van Eps RG, Faber MJ, de Fijter WM, Fioole B, Fokkema TM, Frans FA, Fritschy WM, Fung Kon Jin PH, Geelkerken RH, van Gent WB, Glade GJ, Govaert B, Groenendijk RP, de Groot HG, van den Haak RF, de Haan EF, Hajer GF, Hamming JF, van Hattum ES, Hazenberg CE, Hedeman Joosten PP, Helleman JN, van der Hem LG, Hendriks JM, van Herwaarden JA, Heyligers JM, Hinnen JW, Hissink RJ, Ho GH, den Hoed PT, Hoedt MT, van Hoek F, Hoencamp R, Hoffmann WH, Hogendoorn W, Hoksbergen AW, Hollander EJ, Hommes M, Hopmans CJ, Huisman LC, Hulsebos RG, Huntjens KM, Idu MM, Jacobs MJ, van der Jagt MF, Jansbeken JR, Janssen RJ, Jiang HH, de Jong SC, Jongbloed-Winkel TA, Jongkind V, Kapma MR, Keller BP, Khodadade Jahrome A, Kievit JK, Klemm PL, Klinkert P, Koedam NA, Koelemaij MJ, Kolkert JL, Koning GG, Koning OH, Konings R, Krasznai AG, Krol RM, Kropman RH, Kruse RR, van der Laan L, van der Laan MJ, van Laanen JH, van Lammeren GW, Lamprou DA, Lardenoye JH, Lauret GJ, Leenders BJ, Legemate DA, Leijdekkers VJ, Lemson MS, Lensvelt MM, Lijkwan MA, Lind RC, van der Linden FT, Liqui Lung PF, Loos MJ, Loubert MC, van de Luijtgaarden KM, Mahmoud DE, Manshanden CG, Mattens EC, Meerwaldt R, Mees BM, von Meijenfeldt GC, Menting TP, Metz R, Minnee RC, de Mol van Otterloo JC, Molegraaf MJ, Montauban van Swijndregt YC, Morak MJ, van de Mortel RH, Mulder W, Nagesser SK, Naves CC, Nederhoed JH, Nevenzel-Putters AM, de Nie AJ, Nieuwenhuis DH, Nieuwenhuizen J, van Nieuwenhuizen RC, Nio D, Noyez VJ, Oomen AP, Oranen BI, Oskam J, Palamba HW, Peppelenbosch AG, van Petersen AS, Petri BJ, Pierie ME, Ploeg AJ, Pol RA, Ponfoort ED, Post IC, Poyck PP, Prent A, ten Raa S, Raymakers JT, Reichart M, Reichmann BL, Reijnen MM, de Ridder JA, Rijbroek A, van Rijn MJ, de Roo RA, Rouwet EV, Saleem BR, Salemans PB, van Sambeek MR, Samyn MG, van ’t Sant HP, van Schaik J, van Schaik PM, Scharn DM, Scheltinga MR, Schepers A, Schlejen PM, Schlosser FJ, Schol FP, Scholtes VP, Schouten O, Schreve MA, Schurink GW, Sikkink CJ, te Slaa A, Smeets HJ, Smeets L, Smeets RR, de Smet AA, Smit PC, Smits TM, Snoeijs MG, Sondakh AO, Speijers MJ, van der Steenhoven TJ, van Sterkenburg SM, Stigter DA, Stokmans RA, Strating RP, Stultiëns GN, Sybrandy JE, Teijink JA, Telgenkamp BJ, Teraa M, Testroote MJ, Tha-In T, The RM, Thijsse WJ, Thomassen I, Tielliu IF, van Tongeren RB, Toorop RJ, Tournoij E, Truijers M, Türkcan K, Tutein Nolthenius RP, Ünlü Ç, Vaes RH, Vafi AA, Vahl AC, Veen EJ, Veger HT, Veldman MG, Velthuis S, Verhagen HJ, Verhoeven BA, Vermeulen CF, Vermeulen EG, Vierhout BP, van der Vijver-Coppen RJ, Visser MJ, van der Vliet JA, Vlijmen - van Keulen CJ, Voorhoeve R, van der Vorst JR, Vos AW, de Vos B, Vos CG, Vos GA, Voute MT, Vriens BH, Vriens PW, de Vries AC, de Vries DK, de Vries JP, de Vries M, van der Waal C, Waasdorp EJ, Wallis de Vries BM, van Walraven LA, van Wanroij JL, Warlé MC, van de Water W, van Weel V, van Well AM, Welten GM, Welten RJ, Wever JJ, Wiersema AM, Wikkeling OR, Willaert WI, Wille J, Willems MC, Willigendael EM, Wilschut ED, Wisselink W, Witte ME, Wittens CH, Wong CY, Wouda R, Yazar O, Yeung KK, Zeebregts CJ, van Zeeland ML.

APPENDIX B. SUPPLEMENTARY DATA

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ejvs.2021.02.047.

REFERENCES

1 Lilja F, Mani K, Wanhainen A. Editor’s Choice – Trend-break in abdominal aortic aneurysm repair with decreasing surgical workload. *Eur J Vasc Endovasc Surg* 2017;**53**:811–9.
2 Arhuidese IJ, Salami A, Obeid T, Qazi U, Abularrage CJ, Black JH, et al. The age effect in increasing operative mortality following delay in elective abdominal aortic aneurysm repair presented at the society for clinical vascular surgery 42nd Annual Symposium, Carlsbad, CA, March 18-22, 2014. *Ann Vasc Surg* 2015;**29**:1181–7.
3 Centraal Bureau voor de Statistiek. Bevolkingspiramide. Available at: https://www.cbs.nl/nl-nl/visualisaties/bevolkingspiramide [Accessed 5 November 2020].
4 Budtz-Lilly J, Venermo M, Debus S, Behrendt CA, Altreuther M, Beiles B, et al. Editor’s Choice – Assessment of international outcomes of intact abdominal aortic aneurysm repair over 9 years. *Eur J Vasc Endovasc Surg* 2017;**54**:13–20.
5 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**:598–607.
6 Powell JT, Sweeting MJ, Ulug P, Blankensteijn JD, Lederle FA, Becquemin JP, et al. Meta-analysis of individual-patient data from EVAR-1, DREAM, OVER and ACE trials comparing outcomes of endovascular or open repair for abdominal aortic aneurysm over 5 years. *Br J Surg* 2017;**104**:166–78.
7 Henebiens M, Vahl A, Koelemay MJW. Elective surgery of abdominal aortic aneurysms in octogenarians: A systematic review. *J Vasc Surg* 2008;**47**:676–81.
8 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**:571–6.
9 Han Y, Zhang S, Zhang J, Ji C, Eckstein HH. Outcomes of endovascular abdominal aortic aneurysm repair in octogenarians: meta-analysis and systematic review. *Eur J Vasc Endovasc Surg* 2017;**54**:454–63.
10 Wanhainen A, Verzini F, Van Herzeele I, Allaire E, Bown M, Cohnert T, et al. Editor’s Choice – European Society for Vascular Surgery (ESVS) 2019 Clinical Practice Guidelines on the Management of Abdominal Aorto-iliac Artery Aneurysms. *Eur J Vasc Endovasc Surg* 2019;**57**:8–93.
11 Dutch Institute for Clinical Auditing. Eindrapport dataverificatie DSAA. Available at: https://dica.nl/media/660/Eindrapport_dataverificatie_DSAA_2016.pdf [Accessed 5 November 2020].
12 STROBE Statement—checklist of items that should be included in reports of observational studies. Available at: https://www.strobe-statement.org/fileadmin/Strobe/uploads/checklists/STROBE_checklist_v4_combined.pdf [Accessed 8 November 2020].

13 Copeland GP, Jones D, Walters M. POSSUM: A scoring system for surgical audit. *Br J Surg* 1991;**78**:355–60.
14 Kidney Disease: Improving Global Outcomes (KDIGO) CKD Work Group. KDIGO 2012 clinical practice guideline for the evaluation and management of chronic kidney disease. *Kidney Int Suppl* 2013;**3**:1–150.
15 Levey AS, Stevens LA, Schmid CH, Zhang YL, Castro 3rd AF, Feldman HI, et al. A new equation to estimate glomerular filtration rate. *Ann Intern Med* 2018;**150**:604–12.
16 Lijftogt N, Karthaus EG, Vahl A, van Zwet EW, van der Willik EM, Tollenaar RAEM, et al. Failure to rescue – a closer look at mortality rates has no added value for hospital comparisons but is useful for team quality assessment in abdominal aortic aneurysm surgery in the Netherlands. *Eur J Vasc Endovasc Surg* 2018;**56**:652–61.
17 Smith J, Tekkis P. Risk prediction in surgery. Available at: http://www.riskprediction.org.uk/vasc-index.php. [Accessed 8 November 2020].
18 White IR, Royston P, Wood AM. Multiple imputation using chained equations: issues and guidance for practice. *Stat Med* 2011;**30**:377–99.
19 de Mik SML, Stubenrouch FE, Balm R, Ubbink DT. Systematic review of shared decision-making in surgery. *Br J Surg* 2018;**105**:1721–30.
20 Gray WK, Day J, Horrocks M. Volume–outcome relationships in elective abdominal aortic aneurysm surgery: analysis of the UK Hospital Episodes Statistics Database for the Getting It Right First Time (GIRFT) Programme. *Eur J Vasc Endovasc Surg* 2020;**60**:509–17.
21 Beck N, van Bommel AC, Eddes EH, van Leersum NJ, Tollenaar RA, Wouters MW. The Dutch Institute for Clinical Auditing: achieving Codman's Dream on a nationwide basis. *Ann Surg* 2020;**271**:627–31.
22 Berry AJ, Smith RB, Weintraub WS, Chaikof EL, Dodson TF, Lumsden AB, et al. Age versus comorbidities as risk factors for complications after elective abdominal aortic reconstructive surgery. *J Vasc Surg* 2001;**33**:345–52.
23 Brady AR, Brown LC, Fowkes FGR, Greenhalgh RM, Powell JT, Ruckley CV, et al. Long-term outcomes of immediate repair compared with surveillance of small abdominal aortic aneurysms. *N Engl J Med* 2002;**346**:1445–52.
24 Lederle FA, Samuel EW, Johnson GR, Reinke DB, Littooy FN, Acher CW, et al. Immediate repair compared with surveillance of small aortic aneurysms. *N Engl J Med* 2002;**346**:1437–44.
25 Armstrong RA, Squire YG, Rogers CA, Hinchliffe RJ, Mouton R. Type of anesthesia for endovascular abdominal aortic aneurysm repair. *J Cardiothorac Vasc Anesth* 2019;**33**:462–71.
26 Salata K, Syed M, Hussain MA, De Mestral C, Greco E, Mamdani M, et al. Statins reduce abdominal aortic aneurysm growth, rupture, and peri-operative mortality: a systematic review and meta-analysis. *J Am Heart Assoc* 2018;**7**:e008657.
27 United Kingdom EVAR Trial Investigators, Greenhalgh RM, Brown LC, Powell JT, Thompson SG, Epstein D. Endovascular repair of abdominal aortic aneurysm in patients physically ineligible for open repair. *N Engl J Med* 2010;**362**:1872–80.
28 Prinssen M, Buskens E, Blankensteijn JD, Buth J, Tielbeek AV, Verhoeven ELG, et al. Quality of life after endovascular and open AAA repair. Results of a randomised trial. *Eur J Vasc Endovasc Surg* 2004;**27**:121–7.
29 Li B, Khan S, Salata K, Hussain MA, de Mestral C, Greco E, et al. A systematic review and meta-analysis of the long-term outcomes of endovascular versus open repair of abdominal aortic aneurysm. *J Vasc Surg* 2019;**70**:954–69.
30 Burgers LT, Vahl AC, Severens JL, Wiersema AM, Cuypers PWM, Verhagen HJM, et al. Cost-effectiveness of elective endovascular aneurysm repair versus open surgical repair of abdominal aortic aneurysms. *Eur J Vasc Endovasc Surg* 2016;**52**:29–40.
31 Sweeting MJ, Thompson SG, Brown LC, Powell JT. Meta-analysis of individual patient data to examine factors affecting growth and rupture of small abdominal aortic aneurysms. *Br J Surg* 2012;**99**:655–65.
32 Tanquilut EM, Veith FJ, Ohki T, Lipsitz EC, Shaw PM, Suggs WD, et al. Nonoperative management with selective delayed surgery for large abdominal aortic aneurysms in patients at high risk. *J Vasc Surg* 2002;**36**:41–6.
33 Pini R, Gallitto E, Faggioli G, Mascoli C, Vacirca A, Fenelli C, et al. Predictors of peri-operative and late survival in octogenarians undergoing elective endovascular abdominal aortic repair. *J Vasc Surg* 2019;**69**:1405–11.
34 Houghton JSM, Nickinson ATO, Morton AJ, Nduwayo S, Pepper CJ, Rayt HS, et al. Frailty factors and outcomes in vascular surgery patients: a systematic review and meta-analysis. *Ann Surg* 2020;**272**:266–76.
35 Joseph B, Zangbar B, Pandit V, Fain M, Mohler MJ, Kulvatunyou N, et al. Emergency general surgery in the elderly: too old or too frail? *J Am Coll Surg* 2016;**222**:805–13.
36 Ambler GK, Gohel MS, Mitchell DC, Loftus IM, Boyle JR. The abdominal aortic aneurysm statistically corrected operative risk evaluation (AAA SCORE) for predicting mortality after open and endovascular interventions. *J Vasc Surg* 2015;**61**:35–43.
37 Grant SW, Hickey GL, Grayson AD, Mitchell DC, McCollum CN. National risk prediction model for elective abdominal aortic aneurysm repair. *Br J Surg* 2013;**100**:645–53.