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ORIGINAL ARTICLE: OBSERVATIONAL STUDY

Aneurysm Sac Dynamics and its Prognostic Significance Following Fenestrated/Branched Endovascular Aortic Aneurysm Repair ⋆

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Aneurysm Sac Dynamics Following Fenestrated/Branched Endovascular Aneurysm Repair

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WHAT THIS PAPER ADDS

Just as following infrarenal endovascular aneurysm repair (EVAR), non-regression at 1 year imaging is associated with a higher risk of 5 year all cause mortality and graft related events after fenestrated and branched EVAR (F/BEVAR). Following FEVAR for juxtarenal aortic aneurysm, aneurysm sacs generally displayed regression (66% at 1 year), whereas after BEVAR for thoraco-abdominal aortic aneurysm, aneurysm sacs displayed a concerning proportion of growth at 1 year (28%), potentially suggesting a persistent risk of rupture, and consequently requiring intensified surveillance following BEVAR. Future studies will have to elucidate how to improve sac regression following complex EVAR, and whether the high expansion risk after BEVAR is due to advanced disease extent.

Objective: This study aimed to assess aneurysm sac dynamics and its prognostic significance following fenestrated and branched endovascular aneurysm repair (F/BEVAR).

Methods: Patients undergoing F/BEVAR for degenerative complex aortic aneurysm from 2008 to 2020 at two large vascular centres with two imaging examinations (30 day and 1 year) were included. Patients were categorised as regression and non-regression, determined by the proportional volume change (> 5%) at 1 year compared with 30 days. All cause mortality and freedom from graft related events were assessed using Kaplan–Meier methods. Factors associated with non-regression at 1 year and aneurysm sac volume over time were examined for FEVAR and BEVAR independently utilising multivariable logistic regression and linear mixed effects modelling.

Results: A total of 165 patients were included: 122 FEVAR, of whom 34% did not regress at 1 year imaging (20% stable, 14% expansion); and 43 BEVAR, of whom 53% failed to regress (26% stable, 28% expansion). Following F/BEVAR, after risk adjusted analysis, non-regression was associated with higher risk of all cause mortality within 5 years (hazard ratio [HR] 2.56, 95% confidence interval [CI] 1.09 – 5.37; p = .032) and higher risk of graft related events within 5 years (HR 2.44, 95% CI 1.10 – 5.26; p = .029). Following multivariable logistic regression, previous aortic repair (odds ratio [OR] 2.56, 95% CI 1.11 – 5.96; p = .029) and larger baseline aneurysm diameter (OR/mm 1.04, 95% CI 1.00 – 1.09; p = .037) were associated with non-regression at 1 year, whereas smoking history was inversely associated with non-regression (OR 0.21, 95% CI 0.04 – 0.96; p = .045). Overall following FEVAR, aneurysm sac volume decreased significantly up to 2 years (baseline *vs.* 2 year, 267 [95% CI 250 – 285] cm^3 *vs.* 223

[95% CI 197 – 248] cm^3), remaining unchanged thereafter. Overall following BEVAR, aneurysm sac volume remained stable over time.

Conclusion: Similar to infrarenal EVAR, non-regression at 1 year imaging is associated with higher risk of 5 year all cause mortality and graft related events after F/BEVAR. Following FEVAR for juxtarenal aortic aneurysm, aneurysm sacs generally displayed regression (66% at 1 year), whereas after BEVAR for thoraco-abdominal aortic aneurysm, aneurysm sacs displayed a concerning proportion of growth at 1 year (28%), potentially suggesting a persistent risk of rupture and consequently requiring intensified surveillance following BEVAR. Future studies will have to elucidate how to improve sac regression following complex EVAR, and whether the high expansion risk after BEVAR is due to advanced disease extent.

Keywords: Abdominal aortic aneurysm, Complex, Endovascular procedure, Mid term, Sac dynamics, Survival rate

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INTRODUCTION

Numerous publications have reported the technical feasibility and short term benefits of fenestrated and branched endovascular aneurysm repair (F/BEVAR) compared with complex open repair.[1,2] However, several studies report that these short term benefits regarding mortality diminish in the mid term,[2–6] followed by higher re-intervention rates.[7,8]

Similar to infrarenal endovascular aneurysm repair (EVAR), successful treatment with F/BEVAR is achieved by full exclusion of the aneurysm sac, leading to regression or stability of the aneurysm sac.[9] Stable aneurysm sac size, and particularly sac regression, are important prognostic markers for improved mid to long term outcomes, including reduced re-intervention rates, after infrarenal EVAR.[10,11] Moreover, a previous study by O'Donnell *et al.* also demonstrated that sac regression is associated with greater long term survival compared with a stable sac.[10] However, the literature regarding early sac changes and its prognostic effect in the context of F/BEVAR is scarce.[12] At present, there is little evidence regarding the optimal surveillance strategy after successfully excluding the aneurysm sac following F/BEVAR.[13] Gaining insights into sac dynamics following F/BEVAR may provide a better understanding of success following F/BEVAR and aid in optimising a personalised imaging follow up scheme for these patients.

The aim of this study was (1) to evaluate 1 year sac dynamics following F/BEVAR in order to determine its prognostic significance and (2) to identify factors associated with

non-regression. Finally, aneurysm sac dynamics was assessed over the first 5 post-operative years by measuring aneurysm sac volumes for FEVAR and BEVAR independently.

METHODS

Study design and patient population

All consecutive patients undergoing F/BEVAR for degenerative aortic aneurysm in two large teaching hospitals in the Netherlands (Erasmus University Medical Center and Maasstad Hospital, Rotterdam) from 2008 to 2020 were included and studied retrospectively (*n* = 229). The study protocol was approved by the institutional and ethical review board of both hospitals, which waived the need for informed consent due to its retrospective design (MEC-2017-243 and L2018103). Follow up ended in December 2022.

Sizing of stent grafts was performed by an experienced vascular surgeon in collaboration with the manufacturers (Cook's European planning centre, London, UK, or Vascutek Ltd.) with final approval by the surgeon.

Data collection and image measurements

Baseline patient demographics, anatomical characteristics of the aneurysm, and clinical success including all individual components were collected for each patient from the

hospital's electronic patient database (HiX; ChipSoft, Amsterdam, the Netherlands) following the recommendations of the Society for Vascular Surgery (SVS).[14]

All measurements were obtained by computed tomography (CT) imaging using semi-automatically generated centre lumen line reconstructions performed on dedicated reconstruction software (3mensio Vascular 4.2; Pie Medical, Bilthoven, the Netherlands). A previous study of aneurysm volumes has previously been validated for intra-observer and inter-observer variability by our group in infrarenal abdominal aortic aneurysm (AAA).[15,16] Three measurement protocols were performed depending on the anatomical variants of complex aneurysmal aortic disease in order to maximise detection of proportional aneurysm sac volume change over time. In the first group, which included juxtarenal AAA, suprarenal AAA, and thoracic AAA (TAAA) type IV (Crawford classification), the volume was measured between 10 mm proximal to the upper renal artery to 10 mm proximal to the aortic bifurcation. In the second group, which consisted of TAAA types I and V, the volume was measured from 10 mm distal to the left subclavian artery to 10 mm proximal above the upper renal artery. Finally, the third group included TAAAs types II and III, which were measured from 10 mm distal to the left subclavian artery to 10 mm above the iliac bifurcation.

Definitions and outcomes

Sac changes were determined at 1 year (to allow a grace period, the CT image between 6 – 24 months was used) and at last imaging follow up. Sac regression and sac growth were considered to have occurred when the volume decreased or increased,

respectively, by > 5% from baseline value (first post-operative CT angiography [CTA] as per SVS reporting guidelines[17]). In the case of staged repair, baseline imaging was defined as the first CTA after full exclusion of the aorta was achieved, or after verification of an occlusion of the remaining open branch on CTA or angiography. Chronic kidney disease was defined as an estimated glomerular filtration rate < 60 mL/kg/m^2. Patients treated with an endograft that included both fenestrations and branches were included in the BEVAR group. Scallops were not included as fenestrations. Patients were categorised depending on the occurrence of sac regression at 1 year imaging as regression or non-regression. Performance of a graft related re-intervention before 1 year imaging was defined as early re-intervention.

The primary outcome was 5 year all cause mortality. Secondary outcomes included occurrence of a graft related event following 1 year imaging, which was a composite outcome of a graft related complication (type I/III endoleak, migration, graft infection, secondary rupture, visceral patency loss) or procedure (proximal cuff, distal extension, visceral percutaneous transluminal angioplasty, visceral stent).[12,13] Furthermore, factors associated with non-regression at 1 year imaging were assessed. Finally, aneurysm sac dynamics over time was examined for FEVAR and BEVAR independently.

Statistical analysis

Categorical variables were presented as counts and percentages. Continuous variables were presented either as mean ± standard deviation or median and interquartile range (IQR) depending on whether the results were normally distributed. Normal distribution

was tested with visual aid and the Shapiro–Wilk test. When comparing categorical variables between two groups, Pearson's χ^2 test or Fisher's exact test (in case of counts < 8) was used. For comparison of continuous variables, independent Student's *t* test or Mann–Whitney *U* test were used, depending on the parametric or non-parametric nature, respectively. Statistical significance was defined as a *p* value of < .050.

To examine the prognostic effect of regression and non-regression at 1 year imaging, Kaplan–Meier methods were utilised to estimate the risk of 5 year mortality and graft related events following F/BEVAR. Multivariable Cox regression analysis was performed to adjust for confounding. Covariates that were included in the multivariable Cox regression model were age, sex, smoking history, previous aortic repair, aneurysm diameter at baseline, endograft configuration (F/BEVAR), and early re-intervention.

Multivariable logistic regression was performed to determine factors associated with non-regression at 1 year imaging among the F/BEVAR cohort. Factors in the model were predefined and were the same as those entered in the Cox regression model.

To investigate the aneurysm sac volume over time, two longitudinal mixed effects model were made for FEVAR and BEVAR independently owing to heterogeneity in disease extent between the respective treatment modalities. In these models, time was entered as the independent variable and aneurysm volume as the dependent variable, assuming random intercepts and slopes to allow individual variation per patient (fixed: time + time^2 [+ time^3]; random: ~time) (Supplementary Table S1). To compare the time

sensitivity of the models, the models were run with and without different polynomial terms for time, and the difference in likelihood ratios was calculated.[18]

All statistical analyses were performed using IBM SPSS Statistics version 25.0.0.1 (IBM Corp., Armonk, NY, USA) and R version 4.0.3 (http://www.r-project.org).

RESULTS

Patient population

Initially, 229 patients were included. Patients with less than two post-operative CTAs (*n* = 64; 27.9%) were excluded. Of these, 21 patients (9.2%) did not have adequate (at least two post-operative CTAs) imaging follow up due to death before 1 year, and 19 patients (8.3%) were excluded as they received their CTA imaging outside of the imaging grace period. Five patients (2.2%) received follow up with duplex ultrasound, thus no aneurysm volume could be measured. Finally, 19 patients (8.3%) were excluded as they did not have complete CTAs, thus aneurysm volumes could not be measured, or because they were lost in follow up.

Baseline characteristics

A total of 165 patients were included for analysis, of whom 64 patients (38.8%) displayed non-regression at 1 year imaging (fenestrated EVAR, 34%; branched EVAR, 53%). Of these, 35 patients (21.2%) had a stable sac (fenestrated EVAR, 20%;

branched EVAR, 26%) and 29 patients (17.6%) had sac expansion (fenestrated EVAR, 14%; branched EVAR, 28%).

The non-regression cohort was significantly older (76 [IQR 71, 81] years *vs.* 72 [IQR 69, 77] years; $p = .006$), was less likely to have a history smoking (80% *vs.* 93%; $p = .034$), but was more likely to have undergone previous aortic repair (58% *vs.* 23%; $p < .001$). (Table 1) Specifically, the non-regression cohort was more likely to have undergone previous endovascular AAA repair (41% *vs.* 7.9%; $p < .001$). Furthermore, patients in the non-regression cohort had a larger aortic diameter at baseline (63.8 [IQR 58.7, 73.0] mm *vs.* 59.5 [IQR 56.8, 63.7] mm; $p < .001$) as well as a larger aneurysm volume at baseline (264 [IQR 191, 337] cm^3 vs. 233 [IQR 193, 281] cm^3; $p = .001$). Patients who displayed non-regression were significantly more likely to have undergone branched EVAR (36% *vs.* 20%; $p = .034$) but did not have a significantly higher rate of more proximal disease (suprarenal/TAAA, 41% *vs.* 26%; $p = .11$) or a higher number of target vessels (≥ four-vessel device, 56% *vs.* 42%; $p = .23$). Between groups, no differences were found in endoleaks on 30 day imaging. Finally, there was no difference in early re-intervention rate between groups (23% *vs.* 12%; $p = .082$).

Five year all cause mortality

Of all 165 patients, 33 patients (20.0%) had ≥ 5 years of follow up.

After risk adjustment, non-regression was associated with a significantly higher risk of 5 year all cause mortality (34% *vs.* 26%; hazard ratio [HR] 2.56, 95% confidence interval [CI] 1.09 – 5.37; *p* = .032) (Fig. 1).

Following multivariable Cox regression analysis, no other factors were found to be associated with 5 year mortality, including branched device (HR 0.93, 95% CI 0.35 – 2.25; *p* = .88) and early re-intervention (HR 0.46, 95% CI 0.11 – 1.89; *p* = .28).

Five year graft related events

Non-regression was associated with a significantly higher risk of 5 year graft related events (50% *vs.* 25%; HR 2.44, 95% CI 1.10 – 5.26; *p* = .029) (Fig. 2). The details of the graft related events are shown in Table 2. Furthermore, female sex was found to be associated with a higher risk of graft related events (HR 2.53, 95% CI 1.11 – 5.78; *p* = .027). Other factors, including branched device (HR 0.83, 95% CI 0.37 – 1.90; *p* = .67) and early re-intervention (HR 0.57, 95% CI 0.17 – 2.00; *p* = .38). were not associated with a higher risk of graft related events.

Factors associated with non-regression at 1 year imaging

Factors that were associated with non-regression at 1 year imaging included previous aortic repair (odds ratio [OR] 2.56, 95% CI 1.11 – 5.96; *p* = .029) and larger aneurysm diameter at baseline (OR/mm 1.04, 95% CI 1.00 – 1.09; *p* = .037). Smoking history was inversely associated with non-regression (OR 0.21, 95% CI 0.04 – 0.96; *p* = .045)

(Table 3). In contrast, procedural characteristics, such as endograft configuration, were not associated with non-regression at 1 year imaging (branched versus fenestrated EVAR, OR 1.52, 95% CI 0.57 – 4.12; *p* = .41). Furthermore, early re-intervention following F/BEVAR was also not significantly associated with non-regression (OR 1.76, 95% CI 0.62 – 5.00; *p* = .28).

Aneurysm sac dynamics over time

Overall following FEVAR, aneurysm sac volume decreased significantly up to 2 years: 2 years versus baseline, 223 (95% CI 197 – 248) cm^3 *vs.* 267 (95% CI 250 – 285) cm^3, remaining unchanged thereafter (Fig. 3).

Overall following BEVAR, in the full population, aneurysm sac volume remained stable over the 5 year time period (Fig. 3). It must be noted that this is an average and that independent volume trajectories may be variable.

DISCUSSION

The present study shows that, similar to infrarenal EVAR, absence of aneurysm sac regression at 1 year was associated with a higher risk of 5 year all cause mortality and a higher risk 5 year graft related events following F/BEVAR. Disease specific factors such as previous aortic repair and aneurysm diameter at baseline were associated with non-regression, while early re-intervention (before 1 year imaging) was not associated with a higher likelihood of non-regression or a higher risk of 5 year mortality or graft related

events. Finally, it was found that patients who underwent FEVAR generally regress up to the 2 year time point, remaining unchanged thereafter up to 5 years. Following BEVAR, aneurysm sac volume on average remained unchanged over the course of 5 years post-operatively, although a significant portion displayed sac expansion at the 1 year time point (28%).

The finding of an association between 1 year aneurysm sac dynamics after F/BEVAR and all cause mortality corroborates previous findings in the context of infrarenal EVAR.[10,19] Initially, Deery *et al.* demonstrated the association between expansion and mortality utilising data from a regional registry (*n* = 2 437).[19] Thereafter, using a large national database (*n* = 14 817), O'Donnell *et al.* demonstrated that sac regression is associated with higher survival, even when compared with a stable sac.[10] Interestingly, we were able to find a similar association between 1 year aneurysm sac dynamics and mortality following F/BEVAR in a much smaller sample size. Given our finding in this smaller sample size, it may be hypothesised that the association between 1 year aneurysm sac dynamics and mortality is stronger in the context of F/BEVAR, although future studies will need to confirm these findings. There are various theories explaining the reason for the association between 1 year aneurysm sac dynamics and mortality, as a potential increase in rupture in patients with non-regression, though attributable, does not fully capture the mortality difference that is found between the regression and non-regression groups. Non-regression has previously shown to be associated with an inflammatory cascade.[20–22] Based on these findings, it has been suggested that this association between non-regression and systemic inflammation may secondarily lead to

higher atherothrombosis and cardiovascular mortality. However, recently Boer *et al.* published a single centre series in which they compared causes of death between patients with a stable sac and sac regression at 1 year, but found no statistically significant difference between groups.[23]

The current results also demonstrate that, just as following infrarenal EVAR,[24] sac regression at 1 year imaging is also prognostically favourable after F/BEVAR, given its association with the occurrence of graft related events. Antoniou *et al.* performed a meta-analysis regarding the prognostic significance of early sac regression following infrarenal EVAR, suggesting that patients with different sac dynamics may require different surveillance strategies.[11] Again, due to the lack of any customised F/BEVAR surveillance strategy, most F/BEVAR patients may follow a similar regimen to their infrarenal counterparts. Although we found an association between 1 year aneurysm sac dynamics and graft related events, this study population was limited to assess individual outcomes adequately. Furthermore, it will be utmost importance to gain insights in long term sac dynamics in those patients who regress effectively in order to eliminate any concerns of potential late sac expansion. On these grounds, this study alone does not provide enough evidence to suggest any lenience in surveillance in patients who demonstrate regression, but this remains an interesting topic for future research.

We also found that disease specific variables, such as previous aortic repair and baseline aneurysm diameter, were associated with non-regression. Previous studies

have elucidated the increased technical challenges that are associated with salvage of previous endovascular repair.[25,26] It could be hypothesised that this is due to an aggressive continuous disease process in these patients. Similarly, it could be suggested that aneurysm diameter may also be a proxy for disease severity, potentially explaining the reduced likelihood of regression in larger aneurysms. Due to a lack of factors that could be included in the model, we did not account for proximal disease extent, although we do believe that the previously mentioned disease specific factors are also a proxy for this variable, and future studies with larger numbers shall have to investigate this further. Another variable that could not be studied independently due to the limited number of variables that could be added to the model was the type of previous aortic repair. However, the data suggest that patients who underwent previous endovascular AAA repair might be driving this difference. Future studies will have to identify whether this is due to, e.g., a high proportion of persistent endoleaks, biological factors of these aneurysms, or another cause. Moreover, we found that smoking history was inversely associated with non-regression, and these findings are in line with findings from previous studies in context of infrarenal EVAR.[11] For infrarenal AAA, other factors that have been theoretically linked to sac regression are use of a statin, diabetic status, and use of calcium channel blockers.[27,28] Determining other factors associated with non-regression remains an interesting point for future research, as we were limited in adding a large number of factors to our models due to limited sample size.

Interestingly, we found that early re-intervention (before 1 year imaging) was not significantly associated with non-regression, which is in contrast to previous findings in

infrarenal EVAR.[10] Previous studies have reported that early re-intervention after infrarenal EVAR is associated with higher mortality,[29] although this is not the case after FEVAR.[30,31] The current findings also confirm the lack of an association between early re-intervention following F/BEVAR and mortality. It may be suggested that early re-interventions following F/BEVAR are inherently different than those performed following infrarenal EVAR, as large parts of the re-interventions following F/BEVAR are likely related to technical failure of the fenestrations and branches. Future studies will have to confirm these findings in larger sample sizes, and independently assess which specific re-interventions or types of endoleaks may be associated with non-regression of the aneurysm sac.

The observations regarding post-operative aneurysm sac behaviour may support adequate mid term effectivity of FEVAR, as the majority of FEVAR patients displayed aneurysm sac regression (66%) at 1 year imaging. This is higher than that previously found in infrarenal EVAR (40 – 52%).[10,24] There is a paucity of data regarding aneurysm sac dynamics after F/BEVAR, highlighting the importance of our findings. Furthermore, we determined aneurysm sac dynamics with aneurysm volume, and this metric has previously been shown to be more sensitive in detection of subtle sac changes in follow up compared with aneurysm diameter.[32] Hypothetically, the importance of measuring aneurysm sac volume for post-operative sac change detection may be of increased importance in the F/BEVAR population because, due to the increased disease extent, the aneurysm sac could regress or expand above or below the diameter measurement plane. Despite the satisfactory sac dynamics following FEVAR, patients undergoing

BEVAR displayed more concerning sac dynamics, with a significant proportion of 28% displaying sac expansion at 1 year. To our knowledge, this study is the first to report 1 year aneurysm sac dynamics following BEVAR, and future studies shall have to confirm these findings. We hypothesise that the high risk of expansion at 1 year following BEVAR is due to the increased disease extent rather than due to treatment effectivity, as BEVAR generally has longer sealing zones compared with FEVAR. Moreover, the prior argument is supported by our data regarding the associations between disease specific variables (previous aortic repair and baseline diameter) and non-regression, thus these data do not directly suggest that BEVAR is an ineffective therapy. Otherwise, this difference could be secondary to a difference in type II endoleaks in BEVAR patients owing to the increased aortic coverage in BEVAR versus FEVAR. Although we did not find a higher rate of type II endoleaks on the baseline CTA scan in the non-regression group, this may be secondary to the smaller population. Nevertheless, due to the current lack of a customised F/BEVAR surveillance strategy, F/BEVAR patients frequently undergo a similar surveillance to infrarenal EVAR patients. The current results may potentially suggest intensified monitoring of BEVAR patients, but this shall have to be elucidated in future larger studies.

This study needs to be interpreted within the context of its retrospective study design. Only patients with adequate imaging follow up were included as no imaging analyses could have been performed otherwise. Furthermore, this study was prohibited in assessing aneurysm related mortality as autopsies are not routinely done in the Netherlands, limiting diagnostic accuracy in cause of death. Although aneurysm sac

volume methodologies are more accurate and sensitive, these usually remain time consuming and laborious. Furthermore, as volumes were measured based upon the extent of the specific pathology, this might have led to slight variability within the cohorts, although these mostly remained uniform within the respective endograft configurations. Thus, pre-operative aneurysm volume could not be factored in multivariable adjustment, but pre-operative aneurysm diameter was used instead. As we utilised aneurysm sac volumes for our analyses, we were unable to utilise measurements from duplex ultrasound, which was one reason to extend the grace period of the 1 year imaging scan to 6 – 24 months (compared with 6 – 18 months as previously used in the context of infrarenal EVAR). Furthermore, we utilised an extended grace period as the first post-operative scan after F/BEVAR with an early re-intervention frequently did not fall within the grace period of 6 – 18 months. However, sensitivity analyses were performed with the 6 – 18 month grace period, displaying similar trends in outcomes. Another limitation was the population size, especially within the BEVAR group with relatively low numbers. Subsequently, low event rates could have led to the presence of type II errors in this study. Furthermore, as the inclusion was done over a 12 year period, this could have led to heterogeneity of treatment, and thus future studies will be required to validate the findings. Moreover, due to a limited sample size, we could not account for variables such as endograft type (Zenith COOK Fenestrated AAA Graft versus Vascutek Fenestrated Anaconda Custom AAA Stent Graft System) and pre-operative statin use, although this remains an important subject for future research. Furthermore, we did not include granularity such as family history or timing of smoking, although these may also be important factors for future research. We

also did not include any granularity regarding pre-operative antithrombotic therapy (i.e., antiplatelet or anticoagulation), but this remains an important factor for future studies, as a recent study by Stern and Lee reported an association between anticoagulation use and persistent type II endoleak.[33] Finally, registration of complications was mainly dependent on the number and timing of post-operative CTAs. We tried to correct for this by using a composite outcome, but this limitation remains a lead for information bias.

Conclusion

Just as following infrarenal EVAR, non-regression at 1 year imaging is associated with higher risk of 5 year all cause mortality and graft related events after F/BEVAR. Furthermore, disease specific variables such as previous aortic repair and baseline aneurysm diameter were associated with non-regression at 1 year imaging, whereas early re-intervention before 1 year imaging was not. Following FEVAR for juxtarenal aortic aneurysm, aneurysm sacs generally displayed regression (1 year, 66%), whereas after BEVAR for thoraco-abdominal aortic aneurysm, a concerning proportion displayed growth at 1 year (28%), potentially suggesting an increased or persistent risk of rupture and requiring an intensified surveillance following BEVAR. Future studies will have to elucidate how to improve sac regression following complex EVAR, and whether the high expansion risk after BEVAR is due to advanced disease extent.

CONFLICTS OF INTEREST

H.J.M.V. is a consultant of Medtronic, WL Gore, Terumo, Endologix, Artivion, and Philips. F.B.G. has received speaker and proctoring fees from Medtronic, WL Gore, and Cook Medical.

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Figure 1. Cumulative Kaplan–Meier estimate of freedom from all cause mortality stratified by occurrence of aneurysm volume regression (> 5%) within the first year following fenestrated/branched endovascular aneurysm repair (F/BEVAR). * Adjusted for age, sex, endograft configuration (F/BEVAR), baseline aneurysm diameter, previous aortic repair, smoking history, and early re-intervention. The unadjusted hazard ratio is given in Supplementary Table S2.

Figure 2. Cumulative Kaplan–Meier estimate of freedom from graft related events stratified by occurrence of aneurysm volume regression (> 5%) within the first year following fenestrated/branched endovascular aneurysm repair (F/BEVAR). * Adjusted for age, sex, endograft configuration (F/BEVAR), baseline aneurysm diameter, previous aortic repair, smoking history, and early re-intervention. The unadjusted hazard ratio is given in Supplementary Table S2.

Figure 3. Linear mixed effects model displaying aneurysm sac volume (cm^3) over time for patients undergoing (A) fenestrated endovascular aneurysm repair (FEVAR) patients and (B) branched endovascular aneurysm repair (BEVAR). CI = confidence interval.

Table 1. Baseline characteristics of imaging cohort undergoing fenestrated/branched endovascular aneurysm repair (F/BEVAR) (*n* = 165) stratified by occurrence of sac regression (> 5%) within 1 year.

Characteristic	Non-regression (*n* = 64, 38.8%)	Regression (*n* = 101, 61.2%)	*p* value
Stable sac	35/165 (21.2)	NA	
Sax expansion	29/165 (17.6)	NA	
Age – y	76 (71, 81)	72 (69, 77)	.006
Female sex	13 (20)	25 (24.8)	.64
Smoking history	52 (81)	94 (93.1)	.034
Hypertension	56 (88)	84 (83.2)	.54
PAOD	25 (39)	42 (41.6)	.94
Myocardial infarction	17 (27)	26 (25.7)	>.99
COPD	24 (38)	35 (34.7)	.94
Prior CKD (eGFR <60 mL/kg/m^2)	24 (38)	36 (35.6)	.80
Previous aortic repair	37 (58)	23 (22.8)	<.001
Open AAA repair	3 (5)	7 (6.9)	
Endovascular AAA repair	26 (41)	8 (7.9)	
Thoracic endovascular aortic repair	2 (3)	8 (7.9)	
Multiple procedures	3 (5)	0 (0.0)	
Proximal aneurysm extent			.11
Juxtarenal	38 (59)	75 (74.3)	
Suprarenal/TAAA type IV	8 (13)	10 (9.9)	
TAAA type II/III	11 (17)	13 (12.9)	
TAAA type I/V	7 (11)	3 (3.0)	
Baseline aneurysm diameter – mm	63.8 (58.7, 73.0)	59.5 (56.8, 63.7)	<.001
Baseline aneurysm volume – cm^3	264 (191, 337)	233 (193, 281)	.001
BEVAR	24 (38)	20 (19.8)	.034
Target vessels (fenestration/branch)			.23
1 vessel	1 (2)	1 (1.0)	
2 vessels	4 (6)	17 (16.8)	

3 vessels	23 (36)	41 (40.6)	
≥4 vessels	36 (56)	42 (41.6)	
30 day endoleak	9 (14)	12 (11.9)	.87
Type IA	1 (2)	2 (2.0)	.69
Type IB	0 (0)	0 (0.0)	NA
Type IC	3 (5)	7 (6.9)	.87
Type II	8 (13)	6 (5.9)	.24
Type IIIA	0 (0)	1 (1.0)	1.0
Early re-intervention *	15 (23)	12 (11.9)	.082

Data are presented as *n* (%) or median (interquartile range).

F/BEVAR = fenestrated/branched endovascular aneurysm repair; NA = not applicable; PAOD = peripheral arterial occlusive disease; COPD = chronic obstructive pulmonary disease; CKD = chronic kidney disease; eGFR = estimated glomerular filtration rate ; AAA = abdominal aortic aneurysm; TAAA = thoracic abdominal aortic aneurysm.

* Before 1 year imaging

Due to rounding, numbers may not add up.

Table 2. Details of graft related events following fenestrated and branched endovascular aneurysm repair (F/BEVAR) (*n* = 165) stratified by occurrence of sac regression (> 5%) within 1 year.

Event	Non-regression (*n* = 64, 38.8%)	Regression (*n* = 101, 61.2%)	*p* value
Follow up – mo	35 (20, 67)	41 (25, 66)	<.001
Graft related event – no. of patients	19	18	.029 *
Graft related complication – no. of patients	13	14	.23 *
Post-implant rupture	1	2	
Secondary endoleak			
Type IA	1	2	
Type IB	2	1	
Type IC	0	2	
Type II	6	3	
Type IIIa	1	0	
Migration	0	0	
Graft thrombosis	0	0	
Endograft infection	0	1	
Visceral occlusion	1	3	
Permanent paraplegia	1	0	
Secondary intervention – no. of patients	11	10	.098 *
Secondary intervention			
Proximal cuff	2	3	
Distal extension	3	2	
Visceral PTA	1	2	
Visceral restenting	1	1	
Coiling/gluing/embolisation	2	1	
Open/laparoscopic ligation of collaterals	1	0	
Surgical intervention †	1	1	

Data are presented as *n* or median (interquartile range).

F/BEVAR = fenestrated/branched endovascular aneurysm repair; PTA = percutaneous transluminal angioplasty.

* Calculated using log rank analysis.

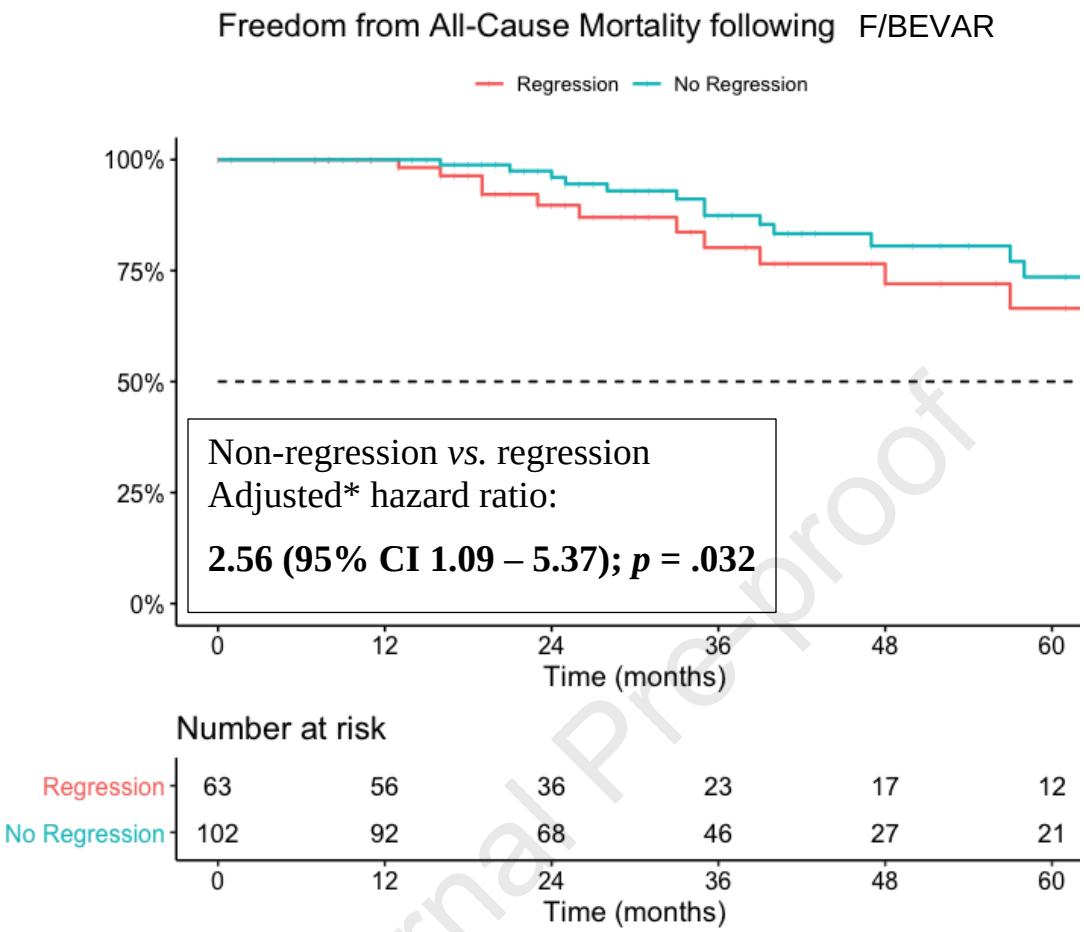
† Surgical interventions included explantation for graft infection and laparoscopic ligation of type II endoleak.

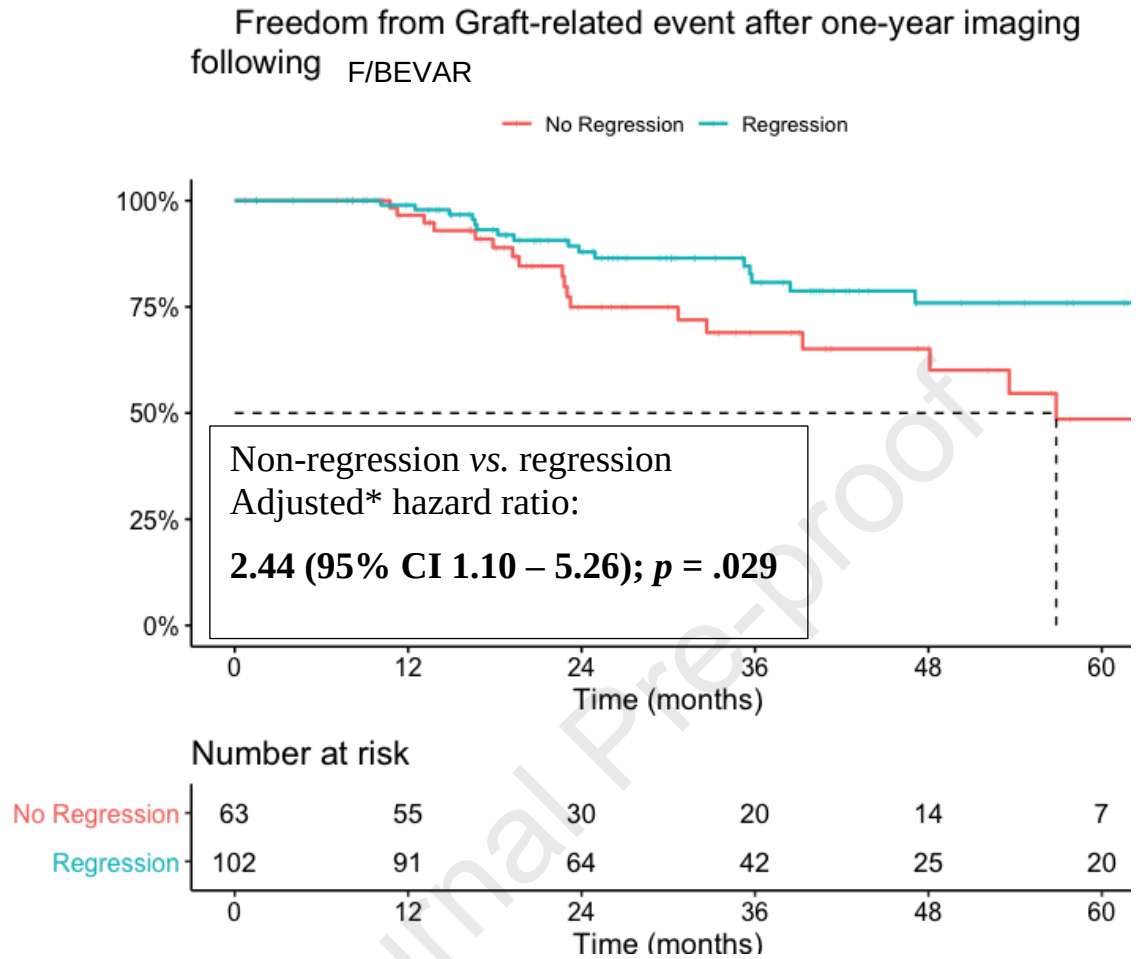
Due to rounding, numbers may not add up.

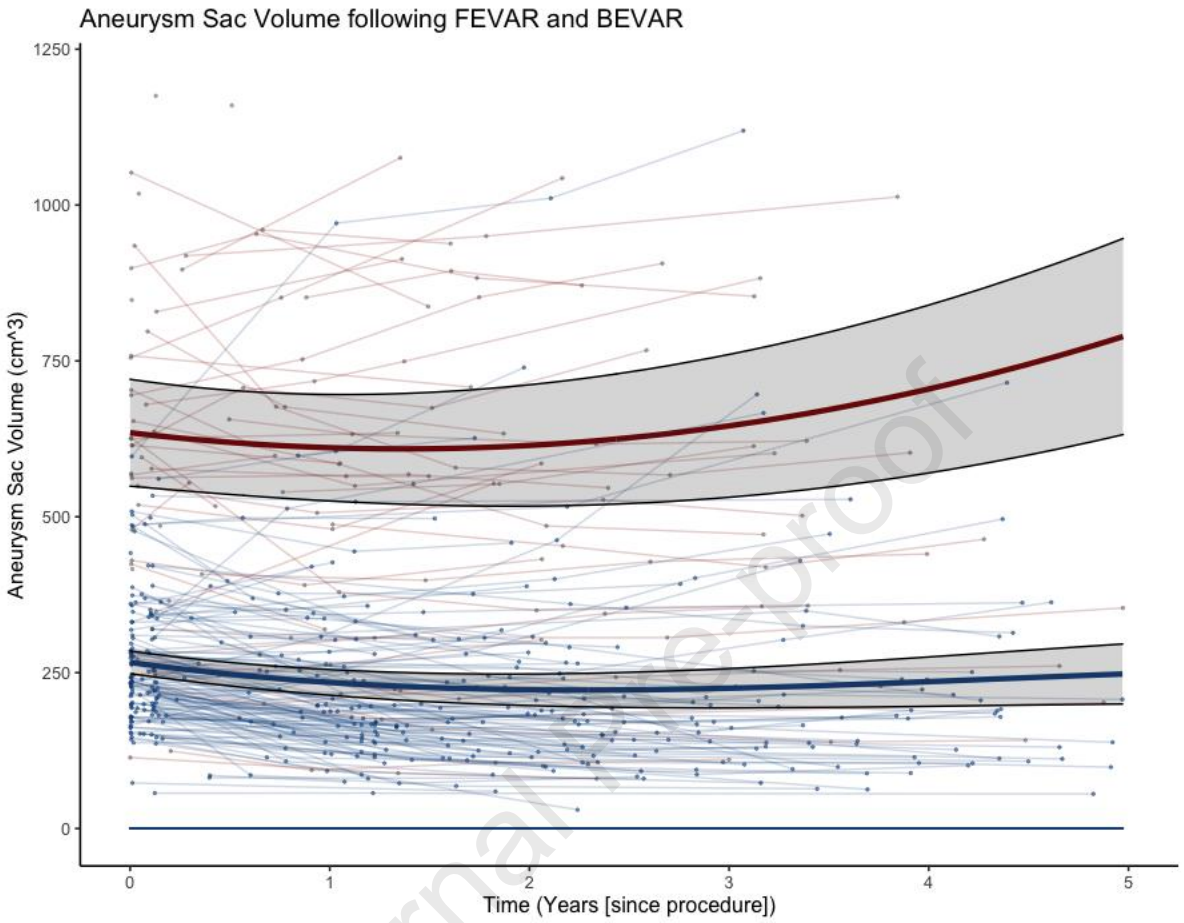
Table 3. Multivariable logistic regression of factors associated with non-regression at 1 year following F/BEVAR and FEVAR.

Factor	OR (95% CI)	*p* value
Age (/year)	1.04 (0.98–1.11)	.17
Female sex	0.62 (0.22–1.61)	.34
Smoking history	0.21 (0.04–0.96)	.045
Previous aortic repair	2.56 (1.11–5.96)	.029
Aneurysm diameter at baseline (/mm)	1.04 (1.00–1.09)	.037
Branched device (ref. fenestrated)	1.52 (0.57–4.12)	.41
Re-intervention before 1 year imaging	1.76 (0.62–5.00)	.28

OR = odds ratio; CI = confidence interval.







	Baseline	1 year	2 years	3 years	4 years	5 years
BEVAR Aneurysm volume – cm^3 (95% CI)	635 (549 – 721)	611 (525 – 696)	614 (517 – 712)	646 (531 – 760)	704 (570 – 839)	794 (635 – 949)
FEVAR Aneurysm volume, cm^3 (95% CI)	267 (250 – 285)	234 (214 – 255)	**223 (197 – 248)**	225 (193 – 257)	236 (196 – 275)	248 (200 – 296)