Abdominal aortic aneurysm neck remodeling after open aneurysm repair

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Purpose: **Proximal endovascular aortic graft fixation and maintenance of hemostatic seal depends on the long-term stability of the aortic neck. Previous investigations of aortic neck dilation mostly focused on the infrarenal aortic diameter. Fenestrated and branched stent grafts facilitate suprarenal graft fixation and may thereby improve the long-term integrity of the aortic attachment site. For these devices, the natural history of the suprarenal aortic segment is also of interest. We investigated the natural history of the supra- and infrarenal aortic segment after open abdominal aortic aneurysm (AAA) repair.**

Methods: **For this retrospective analysis, we reviewed the preoperative and the initial postoperative as well as the most recent CT series that were obtained from 52 patients undergoing conventional repair of an infrarenal abdominal aortic aneurysm between January 1998 and December 2002. Measurements were performed using electronic calipers on a "split screen", allowing direct comparison of subsequent CT series at corresponding levels along the vessel. Main outcome measures were changes in postoperative measures of the supra- and infrarenal aortic diameters.**

Results: **The first postoperative exam was at a mean (±SD) of 7.0 ± 3.5 months, and the final exams were at 44.4 ± 21 months. Over this time period, the estimated rate of change in suprarenal diameter was 0.18 mm/ y with 95% confidence interval (CI) from 0.08 to 0.27. The estimated rate of change for the infrarenal diameter was 0.16 (95% CI: 0.05 to 0.27). A clinically relevant diameter increase of ≥3 mm was observed in seven patients (13%). There was evidence of larger diameter increases associated with larger AAA diameters (*P* = .003 and <.001 for suprarenal and infrarenal diameters), an inverted funnel shape (*P* = .002 and <.001), and marginal evidence of association with a history of inguinal hernia (*P* = .043 and .066).**

Conclusions: **Although there is statistically significant evidence of increases in the supra- and infrarenal aortic diameters after conventional AAA repair, mean annual increases tended to be small and clinically relevant increases of 3 mm or more were observed in only a small proportion of cases. (J Vasc Surg 2007;45:900-5.)**

Endovascular aneurysm repair (EVAR) has been established as an efficient and safe alternative to open repair of abdominal aortic aneurysms.[1,2] Endovascular graft fixation and maintenance of hemostatic seal depends on the long-term stability of the aorta at the proximal and distal attachment sites. The recent addition of fenestrated and branched stent grafts as an armament in the treatment of aortoiliac aneurysms may improve the long-term integrity of the aortic attachment site.[3] Previous investigations of aortic neck dilation (AND) mostly focused on the infrarenal aortic diameter. Proximal AND is a phenomenon observed after endovascular[4-13] as well as after open aortic aneurysm repair.[14-17] However, for fenestrated and branched devices that attach proximal to the renal arteries, the natural history of the suprarenal aortic segment is also of interest.

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The aim of the present study was to retrospectively analyze the fate of the supra-and infrarenal aortic neck after open aneurysm repair and to identify clinical risk factors and anatomical properties of the aorta that may be associated with relevant aortic neck dilation.

METHODS

The records of all patients who underwent abdominal aortic aneurysm repair between January 1, 1998 and December 31, 2002 were obtained. Patients were eligible if one preoperative as well as two postoperative computed tomographies (CTs) were available as electronic files. Patients were excluded if the proximal aortic anastomosis was above the lower renal artery origin or if the postoperative follow-up period was less than 1 year.

Clinical data including cardiovascular risk factors (hypertension, hyperlipidemia, diabetes mellitus, smoking habits), history of coronary artery disease, history of inguinal hernia, and treatment indication (acute or elective) were obtained from patients' records. The surgical reports were reviewed for procedural details including the localization of the aortic clamp.

The last preoperative, the first postoperative as well as the most recent CT scans were reviewed. All measurements were performed using electronic calipers on a "split screen", allowing direct comparison of subsequent CT series at corresponding levels along the vessel. Measurements were performed outer wall to outer wall across the shorter axis. The aortic diameter was measured to the nearest mm at the first image distal to the superior mesenteric artery (SMA) origin (D1) and at the first image distal to the lower renal artery origin (D2). The aortic neck length was estimated by counting the number of images between the lower renal artery origin and the beginning of the aneurysm and multiplying the number by the width of the CT image intervals (ie, 2.5 or 5 millimeters). Anatomic features of the abdominal aorta were defined according to findings from the preoperative CTs. The aortic neck was classified as "funnel-shaped" when the preoperative suprarenal diameter was at least 2 mm larger than the infrarenal diameter. An infrarenal diameter at least 2 mm larger than D1 defined the "inverted-funnel" configuration. We also assessed the maximum preoperative aortic diameter (D3) and common iliac artery (CIA) diameters. CIA diameters ≥25 mm were considered aneurysmal. For the preoperative CTs, significant calcifications (defined as a continuous calcified plaque covering 75% or more of the circumference of the aorta at the D1 and/or D2 level, respectively) as well as significant wall thrombi (defined as noncalcified material covering 75% or more of the circumference of the inner wall of the aorta at the D1 and/or D2 level, respectively) were recorded.

Because of a possible immediate, not necessarily predictable, influence of surgery on the aortic diameters, as well as to avoid "contamination" of estimates of postoperative rates of change by possibly different rates before surgery, the first postoperative measurements of D1 and D2 were used as baseline for investigations of aortic neck diameter changes. Based on a suggestion by Cao et al[4] clinically relevant aortic neck dilation was defined as a diameter increase of ≥3 mm of either D1 or D2 or both.

Variables were summarized as mean ± standard deviation (SD). A linear regression model with the change in diameter as response variable and time between measures as the explanatory variable, along with zero intercept, was used to estimate rates of change in aortic diameter (per year). This was done separately for D1 and D2 and takes account of differences in times between measures. To investigate evidence for the association of potential risk factors with rates of change, a similar regression model was used with an interaction between each variable and the time between measures. The relatively small sample size along with the highly discrete changes in diameters precluded multivariable analysis. The significance level was set at $P \leq .05$ and no formal adjustments were made for multiple comparisons in this descriptive study.

RESULTS

One hundred and one patients underwent open abdominal aortic aneurysm repair during the observed time period. Four patients were treated for juxtarenal aneurysm and 45 patients were excluded due to a lack of CT scans. Fifty-two patients met the inclusion criteria as defined above. Demographic data and anatomical characteristics of the aorta are given in Table I. For the included patients, mean age was 73 years (range 63 to 85) and 45 (87%) were male. The mean preoperative AAA diameter was 57.8 ± 10.5 mm (range: 40 to 100 mm), D1 was 25.7 ± 2.7 mm (range: 20 to 33 mm), and D2 was 24.5 ± 2.9 mm (range: 19 to 32 mm). In 18 cases (35%), the aortic neck was defined as funnel-shaped and in six cases (12%) an inverted funnel was detected. Five mm slices were used for the preoperative assessment of 10 patients who underwent open AAA repair in 1998; 2.5 mm slices were acquired for all other measurements. The mean length of the infrarenal aortic neck was 26.8 ± 18.4 mm (range: 5 to 80 mm). A significant wall thrombus was found in nine patients (17%) and extensive calcifications in three cases (6%). The mean maximal aortic diameter was 58±10mm preoperatively, and this decreased to 34 ± 12 mm and 30 ± 7 mm at the first and last postoperative observation times.

Table I. Demographic data and anatomical characteristics of the abdominal aorta

	Number (percent)
Total number	52
Gender (male)	45 (87%)
Age*	73.8 ± 5.8 (63.5–85.4)
Family history	6 (12%)
Cardiovascular risk factors	
Hypertension	42 (81%)
Hyperlipidemia	25 (48%)
Diabetes mellitus	8 (15%)
Smoking	
Current	10 (19%)
Former (>1 year abstinent)	24 (46%)
H/O coronary heart disease	25 (48%)
H/O COPD	15 (29%)
H/O inguinal hernia	9 (17%)
Anatomical specifications	
AAA diameter (mm)*	57.8 ± 10.5 (40.0–100.0)
Neck configuration	
Neck length (mm)*	26.8 ± 18.4 (5.0–80.0)
Suprarenal diameter (mm)*	25.7 ± 2.7 (20–33)
Infrarenal diameter (mm)*	24.5 ± 2.9 (19–32)
Funnel	18 (35%)
Inverted funnel	6 (12%)
Aortic wall thrombus	9 (17%)
Aortic wall calcification	3 (6%)
Iliac artery aneurysm ≥ 25 mm	13 (25%)
Treatment indication	
Asymptomatic	49 (94%)
Symptomatic	2 (4%)
Ruptured	1 (2%)
Clamp position (suprarenal)	10 (19%)

H/O, history of.
*For numerical variables, the mean ± standard deviation (SD) as well as the range is given.

The initial postoperative CT was performed 5.2 ± 2.7 months after surgery. The mean suprarenal diameter at this time was 25.8 ± 3.0 mm and the infrarenal aortic diameter was 24.9 ± 2.9 mm. The final postoperative CT was performed 44.4 ± 21.0 months after surgery, resulting in an observation period of 39.2 ± 20.9 months (range 6.2 to 84.9 months). Over this time period, the mean rate of change in the suprarenal diameter was estimated as 0.18

Table II. Natural history of the supra- and infrarenal aortic segment after conventional AAA repair

	Suprarenal diameter		*Infrarenal diameter*
Preoperative CT			
Time before surgery (months)		1.7 ± 2.1 (0.0 to 11.1)	
Diameter (mm)	25.7 ± 2.7 (20 to 33)		24.5 ± 2.9 (19 to 32)
Early postoperative CT			
Time after surgery (months)		7.0 ± 3.5 (0.2 to 17.4)	
Diameter (mm)	25.8 ± 3.0 (19 to 33)		24.9 ± 2.9 (18 to 32)
Diameter increase (mm)	0.10 ± 0.66 (−2 to 1)		0.46 ± 1.41 (−2 to 5)
Significance	$P = .30$		$P = .022$
Late postoperative CT			
Time after surgery (months)		44.4 ± 21.0 (11.7 to 91.7)	
Time interval (months)		39.2 ± 20.9 (6.2 to 84.9)	
Diameter (mm)	26.4 ± 2.8 (19 to 34)		25.5 ± 3.4 (18 to 37)
Rate of change (mm/year)*	0.18 ± 0.05 (0.08 to 0.27)		0.16 ± 0.06 (0.05 to 0.27)
Significance	$P = .001$		$P = .007$

*Means ± standard deviation (SD) as well as the range are given, except in the case of the rate of change per year where the estimate ± standard error and a 95% confidence interval are given.

mm per year with a 95% confidence interval (CI) from 0.08 to 0.27mm per year ($P = .001$); the mean rate of change in the infrarenal aortic diameter was 0.16 mm per year with a 95% CI from 0.05 to 0.27 mm per year ($P = .007$). (See Table II and Fig). Although the rate of change was significantly different from zero for both diameter measures, a clinically relevant aortic neck dilation of greater than or equal to 3 mm of either type was found in only seven patients (13%). Aortic neck dilation at one level corresponded with a dilation of at least 2 mm at the second assessed level in all but one of these patients, reflecting the strong interdependency of D1 and D2 changes.

When testing for associations of rates of change with clinical parameters and anatomical properties of the aneurysm, we found strong evidence of association with larger aneurysm diameters and an inverted funnel shape of the aortic neck, and marginal evidence of association with a history of inguinal hernia (Table III).

DISCUSSION

Aortic neck dilation following endovascular aortic aneurysm repair may be detrimental by causing a proximal type I endoleak and/or dislocation of the endograft.[4-6] Endoleaks compromise short and long-term success of EVAR[18,19] and are a major factor limiting long-term durability of this technique.[7,8] The development of fenestrated and branched aortic endografts was in part triggered by the desire to create a longer sealing zone in the presence of short infrarenal aortic necks.[3] However, the long-term reliability of the hemostatic seal will still depend on the degree of aortic neck dilation. Aortic neck dilatation may also be detrimental after conventional open AAA repair, leading to para-anastomotic aneurysm formation, risk of rupture and need for repair in a reoperative field. After open AAA repair, a diameter increase of 0.48 mm to 1.0 mm per year has been reported.[14-17] It should be mentioned that in these studies the preoperative aortic neck diameter was taken as baseline, which may distort the actual degree of AND. The continuous suture of the aorto-prosthetic anas-

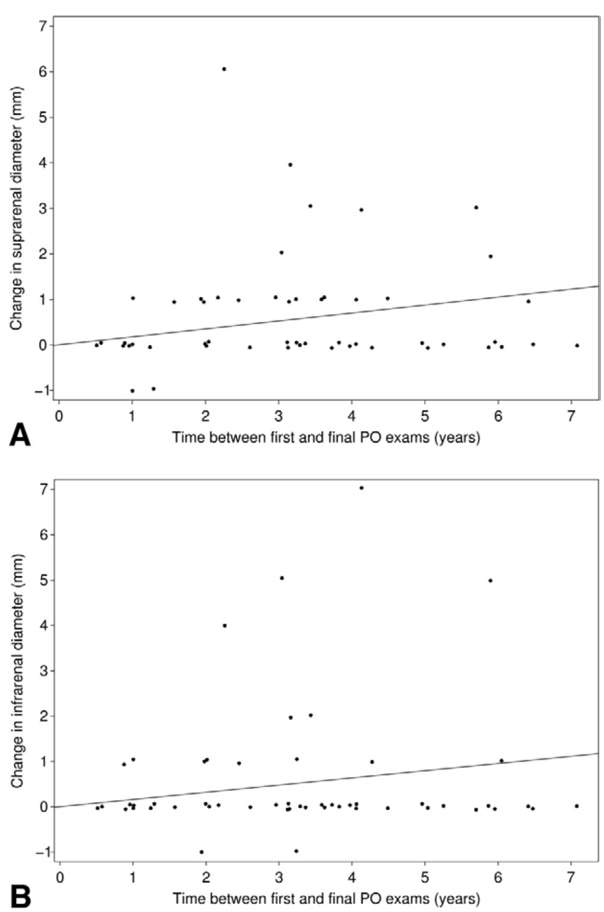

Fig. Changes in suprarenal (**A**) and infrarenal (**B**) diameters plotted against time between measures on first and final postoperative CTs. Actual changes are in whole millimeters; changes are randomly "jittered" on this plot to more clearly separate points. Lines correspond to estimated mean rates of change per year of 0.18 mm (**A**) and 0.16 mm (**B**).

Table III. Associations of potential risk factors with rate of change in suprarenal and infrarenal diameters

	Suprarenal diameter			*Infrarenal diameter*		
Variable	*Estimate*	*SE*	P*-value*	*Estimate*	*SE*	P*-value*
Male	0.010	0.135	.94	−0.147	0.160	.36
Age (10 yrs)	−0.022	0.008	.78	0.004	0.009	.97
Family history	−0.038	0.158	.81	−0.177	0.187	.35
Hypertension	0.015	0.124	.91	−0.132	0.147	.37
Hyperlipidemia	0.080	0.098	.42	0.076	0.117	.52
Diabetes mellitus	−0.081	0.128	.53	−0.114	0.152	.46
Current or former smoker	0.025	0.106	.82	−0.012	0.140	.93
H/O coronary heart disease	−0.022	0.096	.82	−0.070	0.114	.54
H/O COPD	0.124	0.102	.23	0.203	0.119	.10
H/O inguinal hernia	0.242	0.117	.043	0.263	0.140	.066
AAA diameter (10 mm)	0.146	0.005	.003	0.285	0.005	<.001
Neck length (10 mm)	−0.016	0.002	.51	−0.039	0.003	.17
Suprarenal diameter (10 mm)	−0.232	0.016	.16	−0.009	0.020	.96
Intrarenal diameter (10 mm)	−0.003	0.016	.99	0.278	0.018	.13
Funnel	−0.076	0.098	.44	−0.041	0.117	.73
Inverted funnel	0.512	0.154	.002	0.688	0.177	<.001
Aortic wall thrombus	0.090	0.107	.40	0.105	0.128	.41
Aortic wall calcification	0.094	0.176	.60	−0.040	0.210	.85
Iliac artery aneurysm ≥25 mm	0.012	0.112	.92	0.104	0.132	.43
Clamp position (suprarenal)	−0.019	0.121	.88	−0.105	0.143	.47

Estimates correspond to the difference in rates of change according to whether the characteristic is present of absent for binary variables and to an increase of 10 units for continuous variables.

tomosis may have a pursestring effect, causing tapering of the aortic neck in a technically proper anastomosis and also straightening of an angulation of the aortic neck may give the impression of a diameter change. We found evidence that the infrarenal aortic diameter may change between the preoperative and first postoperative observation time points more than expected by the small annual increases expected from the main results of this study, suggesting that preoperative CT images may not be appropriate for evaluation of postoperative aortic neck dilation (Table IV). This could partly be related to the open aneurysm repair itself. Timing of preoperative CTs was variable, with 29% greater than 60 days, and the max 337 days before surgery so that using preoperative CTs as baseline would contribute information about preoperative rates of change, potentially contaminating results intended to investigate postoperative change. To address sensitivity of results to choice of timing of baseline we performed a re-analysis of the data using preoperative measures as baseline. Results were qualitatively similar except that the estimated rate of change of infrarenal diameter was a little higher (0.22 rather than 0.16), most likely reflecting the increases in diameter seen between the pre- and first postoperative measures; also there was no longer any evidence of association with a history of inguinal hernia ($P = .44$ and .18) when the preoperative baseline was used. Following EVAR, initial postoperative imaging studies have typically been used as baseline and the infrarenal aortic neck was found to increase at a mean rate of 1 to 1.5 mm per year.[9-11] Most previous studies focused on the infrarenal aortic diameter only. Those that did consider the suprarenal aortic segment could not verify any significant changes after open or endovascular repair.[10,11,16] Our finding of significant, albeit small, average diameter increases of 0.18 and 0.16 mm per year respectively for the supra- and infrarenal segments clearly differed from previously published data. It has been suggested that clinically relevant AND may only occur in a subgroup of 13% to 28% of patients,[4,20] which is in accordance with the incidence of 13% in our population; although all such estimates should bear in mind the corresponding length of patient follow-up.

The discrimination of a patient population that is at higher risk of aortic neck dilation led to investigations on what clinical risk factors[16] or anatomical properties of the aorta[4,14-16] may promote AND. Female gender, smoking, and higher age have been associated with an increased growth rate of abdominal aortic aneurysms[8,21-25] while reports on the influence of hypertension were inconsistent.[23,26] A certain "protective effect" was found for diabetes mellitus[8,23,26,27] that was ascribed to a downregulation of metalloproteinases in diabetic patients.[27,28] We could not verify that any of these factors had an influence on aortic neck dilation and Liapis et al came to the same conclusion (Table IV).[16] Previous investigations showed a correlation of abdominal aortic aneurysm disease with a history of inguinal hernia.[29,30] Recent research linked the etiologies of both, inguinal hernias and aortic aneurysms with deregulations of metalloproteinases.[31-34] We found marginally significant evidence of an association between a history of inguinal hernia and postoperative rates of change of D1 and D2.

Previous investigations of anatomic properties of the abdominal aorta that may be associated with aortic neck dilation after aneurysm repair have provided inconclusive results. Studies on AND after open aneurysm repair hardly focused on risk factors. Liapis et al[16] and Lipski and Ernst[17] described an association with the initial neck diameter that we could not confirm in our patients (Table IV). Cao et al

Table IV. Characteristics of the seven patients experiencing increases in infrarenal or suprarenal diameter of 3 mm or more between first and last postoperative CT scans

	Patient with clinically significant aortic diameter increase						
Variable	*1*	*2*	*3*	*4*	*5*	*6*	*7*
Time of CT (months)							
Pre-op	−0.9	−0.7	−0.2	−1.0	−0.2	−0.2	−0.8
First pre-op	6.2	1.0	1.2	6.0	6.0	0.0	6.3
Last post-op	76.9	69.4	37.7	33.1	55.6	41.2	44.3
Suprarenal diameter (mm)							
Pre-op	29	23	24	20	26	27	23
First pre-op	30	22	24	20	26	28	22
Last post-op	32	25	26	26	29	31	26
Infrarenal diameter (mm)							
Pre-op	26	20	26	20	30	26	25
First pre-op	26	19	24	20	30	27	26
Last post-op	31	19	29	24	37	29	28
Gender	F	M	M	M	M	M	M
Age	79	65	73	71	67	70	75
Family history							
Hypertension	*	*	*	*		*	*
Hyperlipidemia	*	*			*	*	*
Diabetes mellitus							
Current or former smoker		*	*	*	*	N/A	N/A
H/O coronary heart disease				*		*	*
H/O COPD	*	*			*	*	
H/O inguinal hernia		*	*		*		*
AAA diameter (mm)	65	66	100	50	80	70	59
Neck length (mm)	5	10	20	50	15	15	40
Funnel	*	*					
Inverted funnel			*		*		*
Aortic wall thrombus				*	*	*	
Aortic wall calcification						*	
Iliac artery aneurysm ≥25 mm	*					*	
Clamp position (suprarenal)						*	

N/A indicates data not available.
*Present/Occurred.

identified the presence of a circumferential neck thrombus, the preoperative neck diameter and the AAA diameter as predictors of AND after EVAR.[4] These results were in conflict with the report from Makaroun et al[20] who found AND to be inversely related to the initial neck diameter and independent of the AAA size. However, due to a different pattern of physical interaction of endografts with the aortic wall, direct comparisons with studies on AND after EVAR may not be appropriate.

Limitations of this study include the variability of the observation period and the lower average follow-up times than other reports,[14,15] the relatively small number of patients, the small number of observation time points per patient, the discreteness of diameter measures (to the nearest mm), and the inaccuracy of aortic neck length estimation. All of these characteristics of the study make it difficult to adequately explore the appropriateness of the assumption of linearity of postoperative changes in diameter, as well as limiting precision in estimation and power to detect associations with potential risk factor variables.

CONCLUSIONS

The average increase of the aortic neck diameter in our population was statistically significant albeit small, and seven (13%) of the patients in this study developed a clinically significant dilation over a time period of around 3 years. Certain anatomic properties of the aneurysm such as its size and shape may have an influence on the long-term stability of the proximal attachment site after endovascular aneurysm repair.

AUTHOR CONTRIBUTIONS

Conception and design: JF, WO, MB
Analysis and interpretation: JF, WO, AH, JC, RP
Data collection: JF, MB, BH, TLB
Writing the article: JF, WO, AH, JC, RP
Critical revision of the article: JF, WO, MB, BH, AH, JC, TB, RP
Final approval of the article: JF, WO, MB, BH, AH, JC, TB, RP
Statistical analysis: JF, JC
Obtained funding: WO
Overall responsibility: WO

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