Comparison of morphologic features of intact and ruptured aneurysms of infrarenal abdominal aorta

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Introduction: **Endovascular aneurysm repair (EVAR) has been suggested as a technique to improve outcome of ruptured abdominal aortic aneurysm (AAA). Whether this technique becomes an established treatment will depend, in part, on the anatomy of ruptured AAA.**
Methods: **The anatomy of intact and ruptured AAA seen in a university department of vascular surgery over 5 years was reviewed. Aneurysm anatomy was assessed with spiral computed tomographic angiography. Suitability for EVAR was assessed from the dimensions of the proximal neck and common iliac arteries. Neck length less than 15 mm, neck width greater than 30 mm, and common iliac artery diameter greater than 22 mm were declared unsuitable for EVAR.**
Results: **Three hundred sixty-three patients with intact AAA and 46 with ruptured AAA were identified. Larger intact aneurysms were significantly associated with longer renal artery-bifurcation distance and more complex proximal neck architecture. In this sample, patients with ruptured AAA were more likely to have larger aneurysms with shorter and narrower proximal necks. Significantly more intact aneurysms were morphologically suitable for endovascular repair compared with ruptured AAA (78% vs 43%; $P < .001$).**
Conclusions: **Ruptured AAA are less likely to be suitable for endovascular repair than are intact AAA, most probably because of larger diameter at presentation. Open repair will likely remain the treatment of choice in most patients with ruptured AAA, because of current morphologic constraints of endovascular repair. (J Vasc Surg 2003;38:88-92.)**

The anatomy of abdominal aortic aneurysms (AAA) has come under greater scrutiny since introduction of endovascular aneurysm repair (EVAR). To ensure successful aneurysm exclusion, this technique requires accurate measurement of a number of morphologic variables. More recently, endovascular repair has been proposed as a method to reduce morbidity and mortality from ruptured AAA.[1] Case reports have demonstrated the feasibility of the technique, and studies with selected patients have shown encouraging results.[2,3]

Whether this new approach to ruptured AAA becomes more widely adopted will depend, in part, on the morphologic suitability of ruptured aneurysms for EVAR. It has been suggested that larger aneurysms, which are more likely to rupture, have more adverse anatomic features.[4] No study to date has examined the structure of ruptured AAA, and there are little data comparing ruptured versus intact AAA.

This study explores the anatomy and relationship of a population of intact and ruptured AAA as assessed with spiral computed tomographic angiography (CTA).

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Competition of interest: none.
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Published online May 29, 2003.

0741-5214/2003/$30.00 + 0
doi:10.1016/S0741-5214(03)00079-X

METHODS

Scans were reviewed for all patients who underwent morphologic assessment of intact AAA with spiral CTA over 5 years (1996-2002) at a university department of vascular surgery. Patients were not routinely screened for AAA and underwent spiral CTA only if the abdominal aorta measured 5.0 cm or greater at ultrasonography. On the whole, aneurysms were discovered incidentally at physical examination. The threshold for surgical treatment of AAA in our institution is diameter of 5.5 cm, unless there is evidence of rapid growth greater than 5 mm over 6 months or the aneurysm is symptomatic. None of the study aneurysms were symptomatic. During the same period, a number of patients were admitted with a suspected diagnosis of ruptured AAA, which was confirmed either at spiral CTA, laparotomy, or autopsy. Patients underwent spiral CTA selectively at the discretion of the vascular surgeon. This sample of patients provided the study group for analysis of ruptured AAA anatomy.

All patients underwent spiral CTA performed according to standard local protocol. Scans were obtained from upper L1 to the symphysis pubis to ensure coverage of the aneurysm from the visceral aorta to the external iliac arteries, with 5 mm collimation, 3 mm index, 1.5:1 pitch, and exposure factors of 120 kVp and 225 mA. Contrast material (100 mL of iohexol) was administered with pump injection, with a typical delay of 20 seconds, at a rate of 3 mL/s.

All aneurysms were infrarenal. Aneurysms with suprarenal aortic diameter greater than 35 mm were not included in the study. Data collected for each patient included maximum aneurysm diameter, proximal neck length (low-

Table I. Morphologic features of 363 intact abdominal aortic aneurysms

Variable	*Mean (mm)*	*SD (mm)*	*Minimum (mm)*	*Maximum (mm)*
Aneurysm diameter	66	12	32	120
Neck length	28	16	0	82
Neck diameter	26	4	15	50
RA-bifurcation distance	135	20	65	215
Right CIA length	57	16	12	105
Left CIA length	57	17	5	134
Right CIA diameter	20	9	8	70
Left CIA diameter	18	9	6	82
Right EIA diameter	9	2	3	29
Left EIA diameter	9	2	5	14

RA, Renal artery; *CIA,* common iliac artery; *EIA,* external iliac artery.

Table II. Correlation between maximum aneurysm diameter and other morphologic variables

Variable	*Pearson correlation coefficient*	P
Neck length	−0.07	.16
Neck diameter	0.13	.01
RA-bifurcation distance	0.38	<.01
Right CIA length	0.02	.69
Left CIA length	0.07	.16
Right CIA diameter	0.02	.70
Left CIA diameter	0.01	.87
Right EIA diameter	0.05	.38
Left EIA diameter	0.13	.02

RA, Renal artery; *CIA,* common iliac artery diameter; *EIA,* external iliac artery diameter.

est renal artery to aneurysm proper), neck diameter, lowest renal artery-aortic bifurcation distance, common iliac artery (CIA) length, CIA diameter, and external iliac artery diameter (EIA). In 60 patients, spiral CTA did not extend to include the EIA.

Aneurysms were deemed suitable for endovascular repair if aortic neck length was 15 mm or greater and diameter of the neck was 30 mm or less. CIA diameter greater than 22 mm was considered unsuitable for implantation of a standard iliac limb of an endovascular graft.

Morphologic variables were compared with the Pearson correlation coefficient and linear regression. Independent group t tests were used to test mean differences in morphologic variables between ruptured and intact aneurysm groups. Logistic regression was used to discriminate between groups. Statistical calculations were performed with SPSS version 10.1.4 (SPSS, Chicago, Ill).

RESULTS

Intact aneurysms. Records for 363 patients with intact AAA were reviewed. Three hundred thirty-four patients (92%) were men. Mean age was 72 years (SD, 6.7 years). Morphologic features of the 363 intact aneurysms are shown in Table I. In this sample, as aneurysm diameter increased, all other morphologic variables increased in size, except for neck length, which tended to decrease. However, only neck diameter, renal artery-bifurcation distance, and left EIA diameter increased significantly (Table II). The correlation between aneurysm diameter and renal artery-bifurcation distance was moderately large (r = .38; P < .001), whereas the correlation between aneurysm diameter and neck diameter was smaller (r = .13; P = .01). A simple linear regression model demonstrated that increasing aneurysm diameter by 1 mm resulted in a modest but significant increase in neck diameter of 0.05 mm, (95% confidence interval [CI], 0.01-0.08 mm) and left EIA diameter of 0.02 mm (95% CI, 0.001-0.039 mm). Renal artery-bifurcation distance increased more dramatically, by 0.62 mm (95% CI, 0.46-0.78 mm) for every 1 mm of aneurysm diameter (Table III).

When all other morphologic variables were included in multiple linear regression analysis, aneurysm diameter was still found to be a significant predictor of both renal artery-bifurcation distance and left EIA diameter. However, aneurysm diameter no longer had a statistically significant effect on neck diameter. Conversely, neck length now appeared to be significantly affected by aneurysm diameter. In other words, as aneurysm diameter increased, neck diameter increased in isolation and neck length tends to decrease. But these two neck measurements have a negative relationship with each other, and therefore together have a confounding effect on aneurysm diameter.

Ruptured aneurysms. One hundred ninety-three patients were admitted with confirmed ruptured AAA. Mean age was 76 years (SD, 8.5 years). One hundred forty-six patients (76%) were men. Spiral CTA was performed in 46 patients (34 men; mean age, 76 years [SD, 7.6 years]). Morphologic features of ruptured AAA are included in Table IV.

Comparison of intact and ruptured aneurysms. Mean diameter of ruptured AAA was 78 mm, significantly larger than the 66 mm for intact AAA (t = 5.1; P < .001). Mean neck length was significantly shorter in the ruptured group (mean difference, 9.9 mm; t = 4.0; P < .001), and neck diameter was slightly smaller (mean difference, 1.7 mm; t = 2.0; P = .05). No other variables were significantly different between the two groups.

Three variables were significant predictors of either ruptured or intact AAA: aneurysm diameter, neck diameter, and neck length (Table V). Patients with ruptured AAA were more likely to have larger aneurysms with shorter and narrower proximal necks.

With the criterion of neck length 15 mm, significantly more intact aneurysms, 315 of 363 (87%) had a proximal landing zone of suitable length for EVAR, whereas only 23 of 46 ruptured aneurysms (50%) were suitable for EVAR (P < .001). When anatomic criteria were extended to include neck length 10 mm, 3 additional ruptured AAA could potentially be treated, increasing the overall total to 26 (57%). With neck diameter 30 mm or less as the cutoff, 313 intact aneurysms (86%) and 38 ruptured aneurysms (85%) were suitable for EVAR (P = 1.0).

Table III. Simple regression estimates of morphologic variables of intact aneurysms

Variable	*Estimate of aneurysm diameter (mm)*	*SE*	P	*95% confidence interval*	*Adjusted* R^2
Neck diameter	0.05	0.02	.01	(0.01-0.08)	.02
RA-bifurcation distance	0.62	0.08	<.01	(0.46-0.78)	.14
Left EIA diameter	0.02	0.01	.02	(0.004-0.039)	.02

RA, Renal artery; *EIA,* external iliac artery.

Table IV. Morphologic features of 46 ruptured abdominal aortic aneurysms

Variable	*Mean (mm)*	*SD (mm)*	*Minimum (mm)*	*Maximum (mm)*
Aneurysm diameter	78	15	40	103
Neck length	18	18	0	59
Neck diameter	24	6	16	42
RA-bifurcation distance	139	19	98	183
Right CIA length	58	14	37	91
Left CIA length	61	21	27	156
Right CIA diameter	18	6	9	35
Left CIA diameter	16	6	9	42
Right EIA diameter	9	2	4	15
Left EIA diameter	9	2	6	14

RA, Renal artery; *CIA,* common iliac artery diameter; *EIA,* external iliac artery diameter.

Table V. Results of logistic regression for prediction of membership to either intact or ruptured abdominal aortic aneurysms

Predictor	*Adjusted odds ratio*	*95% confidence interval*
Constant	0.11	
Aneurysm diameter	1.07	(1.04-1.09)
Neck diameter	0.95	(0.93-0.98)
Neck length	0.87	(0.81-0.95)

When using current anatomic constraints of the proximal neck (combining neck length and diameter measurements), 282 intact AAA (78%) and 20 ruptured AAA (43%) were morphologically suitable ($P < .001$). Extending the criteria to include neck as short as 10 mm increased eligibility rate to 23 (50%) ruptured aneurysms.

There was no statistical difference between the two groups with reference to presence of unilateral or bilateral CIA aneurysms. Bilateral CIA aneurysms were present in 11% of the intact group and 9% of the ruptured group ($P >$ .6). Use of a conventional bifurcated endograft was not possible in 157 intact AAA (43%) and 15 ruptured AAA (33%), because of presence of a unilateral CIA aneurysm ($P = 0.2$).

DISCUSSION

Spiral CTA is an established technique for interpretation of intact AAA anatomy. It is now frequently used as the sole examination for planning of endografts in intact aneurysms.[5] Similarly, our group found spiral CTA reliable for planning of endografts in ruptured AAA.[6]

Concerns have been expressed regarding the potential for treatment delay associated with this imaging method in patients with ruptured AAA,[7] especially if the aneurysm is morphologically unsuitable for EVAR. Nevertheless, it has been suggested that hemodynamically stable patients being considered for open surgery may benefit from the results of spiral CTA.[8] Spiral CTA findings confirm the presence of a suprarenal component to an aneurysm and extension of aneurysmal disease into the iliac arteries, and may exclude other causes of abdominal pain, and hence management may be altered. In a prospective series, Willmann et al[9] established that sufficiently accurate data could be acquired from spiral CTA with mean overall acquisition and three-dimensional image reconstruction time of 15 minutes, significantly shorter than the 63 minutes reported by another author in an earlier report.[8] Whether such delay will affect overall patient outcome with the endovascular approach remains to be determined.

An important limitation of the current study is that it is retrospective. Patients underwent spiral CTA at the discretion of the vascular surgeon, and tended to be hemodynamically stable or were being considered for EVAR. Indeed, spiral CTA was performed in only 24% of patients with ruptured AAA over the 5-year study. Therefore the sample of ruptured AAA is selective and, in theory, could represent aneurysms with morphologic features different from those of the whole population of ruptured AAA. That said, "stable" patients who were selected for the study are precisely those who are likely to be offered EVAR, and therefore this group is of high clinical relevance.

This study demonstrated in intact aneurysms that an increase in maximum diameter of the aneurysm increases the length of the aneurysm (renal artery-bifurcation) and neck diameter. There is no obvious explanation why left EIA diameter should increase with aneurysm diameter, but is probably due to sampling variability. In the multiple regression model, neck length was inversely related to aneurysm diameter, but there was no significant effect on neck diameter. In essence, larger aneurysms are more likely to have more complex aortic neck anatomy. Endovascular repair is therefore likely to be more technically challenging and less appropriate in larger aneurysms. Similarly, Bayle et al[10] demonstrated an inverse relationship between aneurysm diameter and neck length in intact AAA.

Overall, ruptured AAA were larger than intact AAA, which has been recognized for many years and has become the basis on which decisions to operate are based.[11,12] More interesting is that ruptured AAA had significantly shorter proximal necks. In this series, 43% of ruptured aneurysms could potentially be treated with endovascular methods, on the basis of spiral CTA assessment of the proximal neck. The only consecutive small series of spiral CTA reported to date in patients with ruptured AAA corroborates these results, finding that EVAR could be successfully performed in 43% of patients with ruptured AAA.[9]

Previous work from our institution found that 20% of CIA were aneurysmal in patients with AAA, with a definition of CIA diameter greater than 24 mm.[13] In the current series, the presence of CIA aneurysms (diameter >22 mm) did not differ between the two groups. Unilateral CIA aneurysms were present in 43% of patients with intact AAA and 33% of patients with ruptured AAA. Bilateral CIA aneurysms occurred in 11% of patients with intact AAA and 9% of patients with ruptured AAA. These findings concur with previous studies, which show that most aneurysms are unsuitable for endovascular repair on the basis of proximal aortic neck anatomy.[14]

In a recent paper,[15] only 30% of aneurysms in an unselected population with intact AAA were found to be entirely suitable for endovascular repair, significantly less than found in our series of intact or ruptured AAA. Woodburn et al[15] suggest that previous reported eligibility rates of 60% reported by tertiary referral centers were a direct result of deploying stent-grafts in aneurysms with unfavorable anatomy. Expanding the criteria to repair aneurysms with more difficult anatomy is feasible. However, it must be remembered that the goal of EVAR for ruptured AAA differs from that for intact AAA. The management goal of ruptured AAA is to reduce perioperative mortality; long-term durability of the repair is of secondary importance. Wolf et al[16] found that simply increasing experience in their endovascular program enabled them to treat more difficult cases, improving overall eligibility rates from 54% to 63%. Specifically, Greenberg et al[17] demonstrated that it is technically possible to exclude aneurysms, at least in the short term, with a proximal neck as short as 5 mm. During complex endovascular aneurysm surgery frequent intraoperative technical problems are encountered, but these can usually be resolved with additional endovascular techniques, performed by an experienced team.[18,19] Although definitive endovascular repair may not be possible in a percentage of patients, this should not be interpreted to mean that the endovascular technique cannot be a useful adjunct to open repair. In particular, use of an aortic balloon may be helpful in gaining early and safe hemorrhage control.[20]

Despite these encouraging reports, other authors have published more cautionary data. Specifically, the Australasian experience demonstrated that breaching the proximal neck length criterion resulted in a fourfold increase in endoleak, and combined deviations from the manufacturer's guidelines multiplied the effect.[21] Moreover, the consequences of endoleak and subsequent adjunctive procedures required to ensure aneurysm exclusion are not without their own complications. Both endoleak and secondary procedures are associated with significant morbidity and mortality after EVAR of ruptured AAA.[6]

The most appropriate endovascular graft for management of aneurysms, both intact and ruptured, continues to be debated. The aortouniiliac configuration provides greatest scope for the largest number of aneurysms, because of its ability to accommodate adverse iliac features, and is particularly attractive when the number of aneurysms treatable is likely to be at a premium.[22,23] Another attractive feature of this configuration in the emergency setting is ease and rapidity of deployment.[24] In the emergency setting, grafts should be available in a variety of sizes and preferably should be able to seal short necks.

In conclusion, larger aneurysm diameter is associated with longer renal artery-bifurcation distance (in itself, not an adverse morphologic feature) and more complex neck anatomy. In this series significantly more intact aneurysms were morphologically suitable for endovascular repair. Overall, 43% of ruptured aneurysms had a suitable proximal implantation site for an endovascular graft, significantly less than the 78% of intact aneurysms that were eligible ($P <$ .001). It is probable that ruptured AAA are morphologically less likely to be suitable for EVAR because of their larger diameter at presentation, although individual aneurysms, whether intact or ruptured, cannot be excluded from EVAR on the basis of aneurysm diameter alone.

On the basis of results of this study, one of the desirable properties of an endovascular graft intended for management of ruptured AAA is that it can be used with complex neck morphology, in particular, short neck.

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Submitted Oct 2, 2002; accepted Dec 17, 2002.