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The aspect ratio (dome/neck) of ruptured and unruptured aneurysms

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Object. In this retrospective study the authors examined the aspect ratio (AR; the maximum dimension of the dome/width of the neck of an aneurysm) and compared the distribution of this ratio in a group of ruptured and unruptured aneurysms. A similar comparison was performed in relation to the maximum dimension of the aneurysm alone. The authors sought to evaluate the utility of these measures for differentiating ruptured and unruptured aneurysms.

Methods. Measurements were made of 774 aneurysms in 532 patients at three medical centers. One hundred twenty-seven patients harbored only unruptured lesions, 290 only ruptured lesions, and 115 both ruptured and unruptured lesions. Cases were included if angiograms were available for measurement and the status of the individual patient's aneurysm(s) was known.

The odds of a lesion falling in the ruptured aneurysm group increased with both the lesion's maximum size and the AR. The odds ratio for rupture rose progressively only for the AR. The distribution curves showed that ruptured aneurysms were larger and had greater ARs. The mean size of unruptured aneurysms was 7 mm and that of ruptured ones was 8 mm; the corresponding mean ARs were 1.8 and 3.4, respectively. The odds of rupture were 20-fold greater when the AR was larger than 3.47 compared with an AR less than or equal to 1.38. Only 7% of ruptured aneurysms had an AR less than 1.38 compared with 45% of unruptured lesions.

Conclusions. The AR is probably a useful index to calculate. A high AR might reasonably influence the decision to treat actively an unruptured aneurysm independent of its maximum size. Prospective studies are warranted.

Key Words • aspect ratio • dome/neck ratio • ruptured aneurysm • unruptured aneurysm • subarachnoid hemorrhage

On the basis of experimental studies showing an increased tendency for bleb formation and dumbbell shapes in aneurysms having sluggish flow, Ujiie and colleagues[6] hypothesized that flow stagnation might precipitate aneurysm rupture. Such a condition is more likely to occur in aneurysms having a long depth in relation to a small orifice. These authors considered that this ratio might be a better geometric index than maximum size alone in determining intraarterial flow and, thus, the tendency to rupture. In 207 aneurysms, 80% of 129 ruptured ones had an AR greater than 1.6, whereas almost 90% of 78 unruptured ones had an AR less than 1.6. The ratio of male to female patients harboring these lesions was 1:1.75. The mean size of ruptured aneurysms in that study was 8.7 mm and that of unruptured lesions was 5.8 mm. In discussing this report, Dickey and Kailasnath[3] suggested that a cumulative rupture risk and the existence of apparent threshold values are population dependent and cannot be generalized freely to groups outside the targeted population of the study because of differences in the distribution of variables of interest.

Abbreviations used in this paper: AR = aspect ratio; CI = confidence interval; ICA = internal carotid artery; OR = odds ratio; PCoA = posterior communicating artery; ROC = receiver operating characteristic.

The AR (referred to as the dome/neck ratio) has gained the attention of interventional radiologists because a low ratio is generally associated with greater technical difficulty and poorer results from coil application. Using Guglielmi Detachable Coils, Debrun, et al.,[1] achieved total occlusion in two (40%) of five aneurysms with an AR less than 2 and in 13 (59%) of 22 aneurysms with an AR of 2 or greater.

We explored the potential utility of this parameter in a cohort of patients with aneurysms.

Clinical Material and Methods

Patient Population

Patients were retrospectively selected for this study based on the availability of angiograms and a clear diagnosis of an unruptured or ruptured aneurysm. Patient age and sex, and the location of the aneurysm were also recorded, but were missing in 99, two, and six cases, respectively. Five hundred thirty-two patients with 774 aneurysms were included from three centers. The sex distribution in these patients was 29% male and 71% female, a distribution that did not differ significantly among centers. One hundred twenty-seven patients harbored unruptured aneurysms alone, 290 ruptured aneurysms alone, and 115 both ruptured and un-

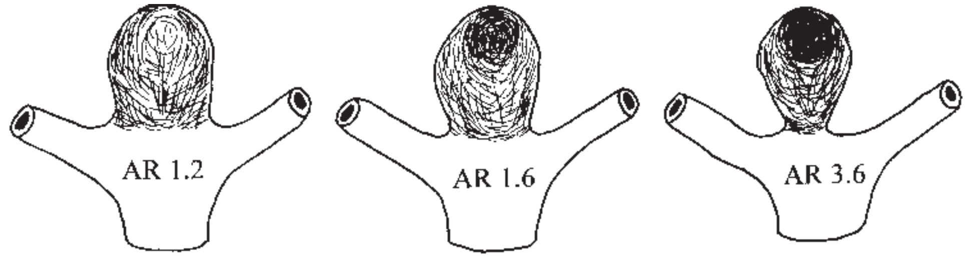

FIG. 1. Drawings of representative ARs (1.2, 1.6, and 3.6). An AR of 3.6 is much more likely to be associated with a ruptured aneurysm than an AR of 1.2, even if both have the same maximum size.

ruptured lesions. The mean age of the patients was 50.6 years and the median age was 50 years. The number of aneurysms per patient were one in 361, two in 126, three in 29, four in 13 patients, and five, seven, and 10 in one patient each.

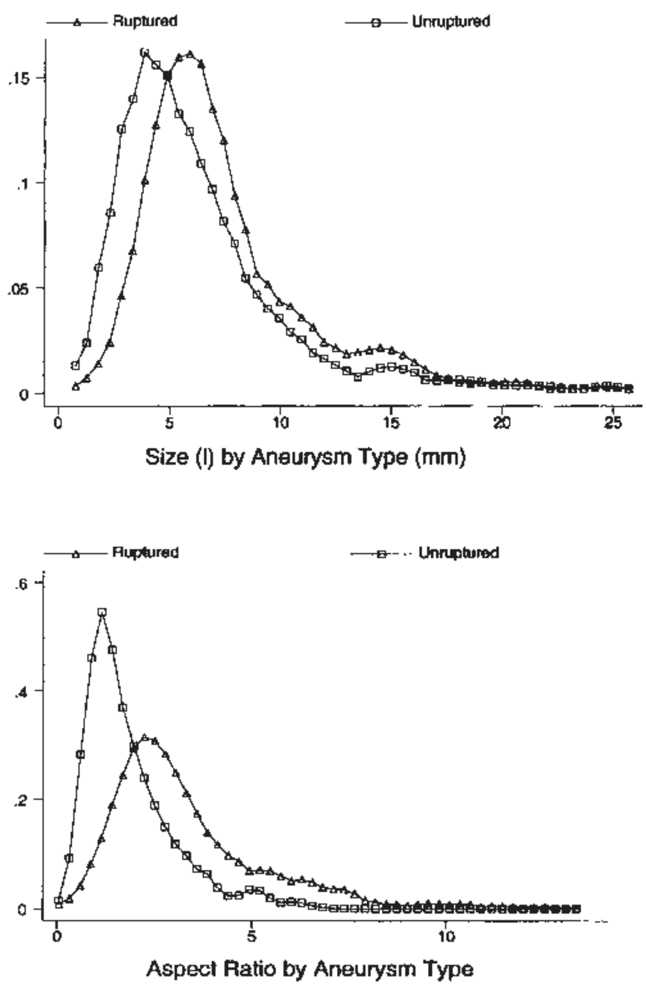

FIG. 2. Kernel density plots. *Upper:* Plot for maximum linear dimension of the aneurysm (size [1]), excluding patients with aneurysms larger than 25 mm. The numbers on the y axis represent the relative frequencies per millimeter of aneurysm size. The area under each curve is equal to 1. *Lower:* Plot for the AR in the same group of patients. The numbers on the y axis represent the relative frequencies per unit of AR.

In patients with multiple aneurysms, the aneurysm that ruptured was determined using standard radiological and clinical methods such as the following: the pattern of blood on a computerized tomography scan; the relative size, site, and loculations on an angiogram; and the operative and/or autopsy findings.

Angiographic Examination

In this retrospective study no precise protocol was used to obtain the angiograms. Measurements of lesions on angiograms were performed by experienced research associates. Examples of different ARs are shown in Fig. 1. The presence of loculations or multiple lobes was not considered in the analysis.

Statistical Analysis

A spreadsheet with statistical functions (Microsoft Excel; Microsoft Corp., Redmond, WA) was used for preliminary calculations; all other analyses were performed using a statistical software package (STATA version 7; Stata Corp., College Station, TX). Smoothed estimates of the distribution of aneurysm sizes and ARs in ruptured and unruptured lesions were derived using the kernel density estimator (KDENSITY) provided with the STATA statistical software. Logistic regression analyses[4] of the influence of size and AR on rupture status, adjusted for patient sex and age, and aneurysm location, were performed. Robust standard errors were used to account for the potential correlation among multiple aneurysms in the same patient. The probability of an aneurysm being a ruptured one was calculated by first categorizing aneurysms by size or AR into four groups according to the 25th, 50th, and 75th percentiles of the respective distribution. Due to a digit preference, the categorization by size did not result in numerically equal frequencies in the four categories of size.

To compare the utility of aneurysm size and AR more fully for discriminating between ruptured and unruptured aneurysms, we performed an ROC analysis. The ROC analysis is commonly used when evaluating diagnostic tests.[5] The ROC curve is used to plot sensitivity (in our case, the proportion of ruptured aneurysms with a size [or AR] greater than a given cutpoint) against 1 − specificity (1 − proportion of unruptured aneurysms with values below the cutpoint), as the cutpoint is varied continuously from larger to smaller values. Thus, for large values of the cutpoint, the sensitivity will be low (if larger values correspond to a greater risk), but the specificity will be high. As the cutpoint is progressively decreased, the sensitivity increases and the specificity decreases. Thus, the curve is used to plot the

TABLE 1

*Summary of aneurysm sizes and ARs**

Type of Lesion	No. of Lesions	Mean	Median	SD	Min	Max
aneurysm size (mm)†						
UAs	365	7.0	5	5.7	1.5	43
RAs	409	8.0	7	5.3	1.5	50
all	774	7.5	6	5.5	1.5	50
AR						
UAs	361	1.8	1.5	1.1	0.4	6.5
RAs	406	3.4	2.8	2.1	0.4	13
all	767‡	2.7	2.2	1.9	0.4	13

* RA = ruptured aneurysm; SD = standard deviation; UA = unruptured aneurysm.

† Maximum linear dimension of aneurysm.

‡ In seven patients data on aneurysm neck widths were unavailable.

TABLE 2

Frequency of rupture by aneurysm size and AR

Parameter	No. of UAs (%)	No. of RAs (%)	OR
size (mm)*			
≤4	130 (66.7)	65 (33.3)	reference
>4 to ≤6	98 (42.1)	135 (57.9)	2.76
>6 to ≤8.2	58 (37.7)	96 (62.3)	3.31
>8.2	79 (41.1)	113 (58.9)	2.86
AR†			
≤1.38	162 (84.4)	30 (15.6)	reference
>1.38 to ≤2.24	99 (51.8)	92 (48.2)	5.02
>2.24 to ≤3.47	62 (32.5)	129 (67.5)	11.2
>3.47	38 (19.7)	155 (80.3)	22.0

* $\chi^2 = 40.57$, $p < 0.001$, indicating size is associated with rupture status.

† $\chi^2 = 183.43$, $p < 0.001$, indicating that the AR is associated with rupture status.

tradeoff between sensitivity and specificity, and the closer the curve is to the upper left-hand corner of the plot the better the discrimination. A convenient summary measure is obtained by calculating the area under the ROC curve. This area ranges between 0.5 and 1, with 0.5 reflecting a test that is no better than flipping a coin and 1 corresponding to a perfect test. The areas were estimated using a nonparametric approach and compared using a method, described by DeLong, et al.,[2] for comparisons involving correlated ROC curves arising when the curves are determined from the same sample, as is the case here.

Results

The smoothed distributions of ruptured and unruptured aneurysms according to maximum size and AR are shown in Fig. 2. Descriptive statistics for aneurysm size and AR are shown in Table 1.

In univariate analyses, in which logistic regression was used to model the probability that an aneurysm is ruptured, we analyzed the effects of patient age and sex, and aneurysm location, size, and AR. Patient age had no statistically significant effect on the risk of rupture, but sex did ($p < 0.001$). On average the odds of finding a ruptured aneurysm in a female patient was 55% that in a male patient. Different locations had different odds of rupture. Using the cavernous ICA as a reference, the odds were 5.3-fold greater for aneurysms of the posterior circulation ($p = 0.003$), 4.4-fold greater for those on the PCoA ($p = 0.007$), 4.4-fold greater for those on the anterior communicating artery ($p = 0.006$), 2.7-fold greater for those on the middle cerebral artery ($p = 0.066$), and 2.1-fold greater for those on the ophthalmic segment of the carotid artery ($p = 0.2$).

The risk of rupture increases with the size of an aneurysm.[1] Aneurysms with sizes in the three higher percentile groups had a significantly ($p < 0.001$) greater chance of being ruptured lesions than those with sizes in the 0 to 25 percentile group. This was also true for the corresponding AR groups (Table 2). For size, however, the risk of rupture was similar in the three higher percentile groups, whereas for the AR there was a steady increase in risk with increasing AR. Only 30 (7%) of 406 ruptured aneurysms had ARs equal to or less than 1.38 compared with 162 (45%) of 361 unruptured ones.

Multivariate analysis of the effects of aneurysm size and other factors produced similar results to the univariate analysis. Adjusted for patient sex and the location and size of the aneurysm, patient age did not have a significant effect on the risk of aneurysm rupture ($p = 0.18$). Age was therefore dropped from the model and the results of fitting the final model, including patient sex and location and size of the aneurysm, are shown in Table 3. The OR for female patients relative to male ones was 0.52. Aneurysm locations had different odds of rupture, with the cavernous ICA being the lowest and all other sites having a higher risk. The odds of rupture were nearly threefold greater for the second quartile of size relative to the first, but the OR increased only slightly for the third and fourth quartiles (Fig. 3 *upper*).

In the multivariate analysis of the effects of the AR and other factors, patient age again did not reach statistical significance ($p = 0.075$) and was subsequently dropped from the model. In the final model (Table 4) the OR for female patients relative to male ones was 0.65 and was statistically significant. The effects of location were somewhat less than those shown in Table 3, with the only significant contrasts noted when the PCoA was compared with the cavernous ICA and when the posterior circulation was compared with the cavernous ICA. The AR exhibited a rather strong gradi-

TABLE 3

*Results of a multiple logistic regression analysis of the effect of aneurysm size and other factors on risk of rupture in 766 aneurysms**

Contrast	OR	SE	p Value	95% CI
sex				
female vs male	0.52	0.09	<0.001	0.37–0.73
location of aneurysm				
OphA vs cav ICA	2.38	1.37	0.134	0.77–7.38
ACoA vs cav ICA	5.06	2.83	0.004	1.69–15.1
MCA vs cav ICA	3.21	1.80	0.038	1.06–9.65
PCoA vs cav ICA	5.86	3.41	0.002	1.88–18.3
post circ vs ICA	5.83	3.37	0.002	1.88–18.1
size of aneurysm (mm)				
>4 to ≤6 vs ≤4	2.95	0.63	<0.001	1.94–4.47
>6 to ≤8.2 vs ≤4	3.66	0.89	<0.001	2.27–5.90
>8.2 vs ≤4	3.67	0.84	<0.001	2.34–5.75

* ACoA = anterior communicating artery; cav = cavernous; MCA = middle cerebral artery; OphA = ophthalmic artery; post circ = posterior circulation; SE = standard error.

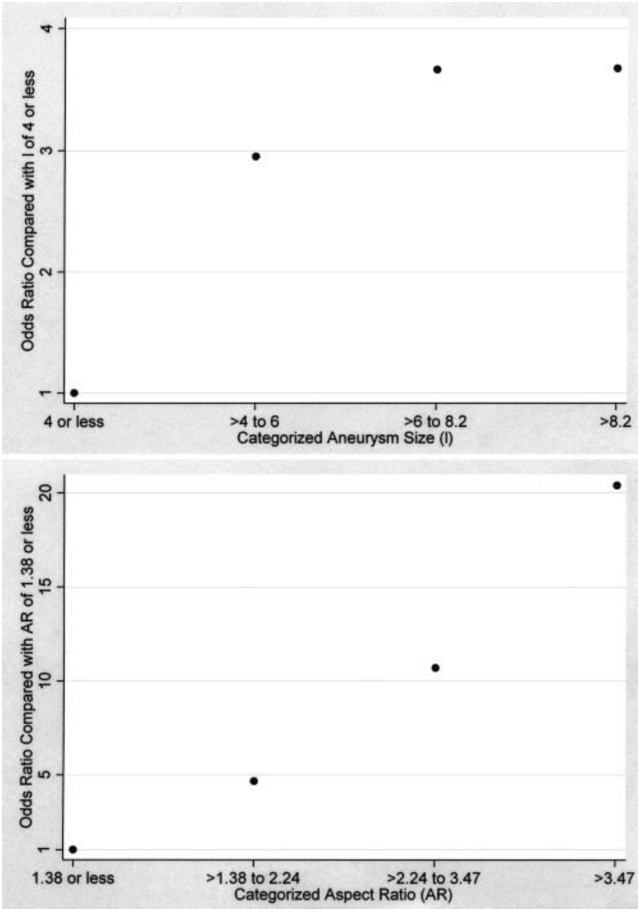

FIG. 3. Graphs demonstrating ORs associated with ruptured aneurysms. *Upper:* Adjusted for patient sex and the location of the aneurysm, the risk of rupture increases with the size of the lesion. Compared with aneurysms 4 mm or smaller, the ORs for the three larger categories of size were 2.95, 3.66, and 3.67 ($p < 0.001$ for all), but the differences among the three larger groups were small. *Lower:* Compared with aneurysms that have an AR 1.38 or less, the ORs for the three groups of lesions with higher ARs were 4.66, 10.7, and 20.4 ($p < 0.001$).

TABLE 4

Results of a multiple logistic regression analysis of the effect of the AR and other factors on risk of rupture in 759 aneurysms

Contrast	OR	SE	p Value	95% CI
sex				
female vs male	0.65	0.13	0.028	0.44–0.95
location of aneurysm				
OphA vs cav ICA	2.05	1.31	0.259	0.59–7.16
ACoA vs cav ICA	2.71	1.68	0.107	0.81–9.12
MCA vs cav ICA	2.15	1.34	0.217	0.64–7.27
PCoA vs cav ICA	4.02	2.58	0.030	1.14–14.1
post circ vs cav ICA	3.59	2.26	0.042	1.05–12.3
AR				
>1.38 to ≤2.24 vs ≤1.38	4.66	1.22	<0.001	2.79–7.79
>2.24 to ≤3.47 vs ≤1.38	10.7	2.85	<0.001	6.38–18.1
>3.47 vs ≤1.38	20.4	5.67	<0.001	11.8–35.2

TABLE 5

*Ruptured and unruptured aneurysms classified by size and rupture rate**

Parameter	UA	RA	Rupture Rate (%)†	NPV (%)	PPV (%)
size (mm)					
≤10	315	333	51.4	48.6	
>10	50	76	60.3		60.3
AR					
≤1.6	201	48	19.3	80.7	
>1.6	160	358	69.1		69.1

* In seven cases there were missing neck widths and thus the samples were 774 lesions for size measurements and 767 lesions for AR measurements. Abbreviations: NPV = negative predictive value; PPV = positive predictive value.

† The rupture rate is the number of ruptured aneurysms divided by the total number of aneurysms (including unruptured ones) in that group.

ent effect; the odds of rupture increased steadily with the AR (Fig. 3 *lower*).

The number of ruptured and unruptured aneurysms, as classified by their size and rupture rate (number of ruptured lesions/total number of aneurysms) in each size group (> or ≤ 10 mm), is given in Table 5. The chance that an aneurysm 10 mm or smaller was not ruptured (negative predictive value) was 48.6%, whereas the chance that an aneurysm larger than 10 mm was ruptured was 60.3% (positive predictive value). The negative predictive value for an AR of 1.6 or less (the cutpoint cited by Ujiie, et al.[6]) was 80.7% and the positive predictive value for an AR greater than 1.6 was 69.1%. Among aneurysms 10 mm or smaller with an AR higher than 1.6, 67.8% were ruptured; however, among similar lesions with a smaller AR only 19.3% were ruptured. Among aneurysms larger than 10 mm with an AR of 1.6 or less, only 19.4% were ruptured; at a higher AR, however, 75% of these lesions were ruptured (Table 6).

The results of the ROC analysis are depicted in Fig. 4. It is apparent that the curve for the AR dominates that for maximum size. The area under the ROC curve for the AR is 0.79 (95% CI 75–0.82), whereas that for aneurysm size is 0.62 (95% CI 0.58–0.66). The difference between these areas is highly statistically significant ($p < 0.001$). At a cutpoint of 1.6 for the AR, considered in Table 5, the sensitivity is approximately 88%, but the specificity is only 56%.

Discussion

It seems that tubular aneurysms are more likely to rupture than mushroom-shaped ones. Using contemporary angiographic equipment, which has built-in measurement capability, it would be easy to report the AR as well as the maximum size of an aneurysm.

In the past it has been recommended that unruptured aneurysms smaller than 10 mm should not be treated. If a male patient presented with an unruptured 7-mm aneurysm located along the posterior circulation, we would be more enthusiastic about intervention if the AR were 6 than if it were 1.3.

Our study does not permit us to establish an AR below which the chance of rupture is apparently negligible. We found that a fairly high percentage of unruptured aneurysms had a high AR. Will these be more prone to rupture in the

TABLE 6

Ruptured or unruptured aneurysms classified by size and AR

Aneurysm Size	AR ≤ 1.6	AR > 1.6
≤10 mm		
no. of UAs	176	137
no. of RAs	42	289
rupture rate (%)	19.3	67.8
>10 mm		
no. of UAs	25	23
no. of RAs	6	69
rupture rate (%)	19.4	75

future compared with unruptured aneurysms with a low AR? Prospective studies are required to determine whether unruptured aneurysms with a high AR are more likely to rupture than lesions that have the same size but a lower AR.

The limitations of this study include its retrospective nature, measurements made by different observers, a subjective bias in determining aneurysm dimensions, and the special patient populations resulting from the selection and referral bias. A relatively large percentage of patients harbored multiple aneurysms. Despite these considerations, that of our patients was similar to that of patients in very large studies, as was the mean size of the ruptured aneurysms.

Another potential source of bias is that, in patients with multiple ruptured and unruptured aneurysms, it is not always possible to identify with certainty which aneurysm has ruptured. It should be noted, however, that a misassignment in such a case would apply to the calculation of the AR as well as the aneurysm size. Furthermore, an analysis of data including only patients with single or multiple unruptured aneurysms (503 lesions) gave results that favored the AR even more as a better discriminator than aneurysm size (data not shown).

What seems to separate unruptured from ruptured aneurysms most effectively? A size smaller than or equal to 10 mm is associated with a rupture rate of 51% and an AR smaller than or equal to 1.6 with a rupture rate of 19%. A size greater than 10 mm is associated with a rupture rate of 60% and an AR ratio greater than 1.6 with a rupture rate of 69%. The cutoff AR of 1.6 has higher negative (81%) and positive (69%) predictive values than the size cutoff of 10 mm, for which the negative and positive predictive values are 49 and 60%, respectively (Table 4).

Our data show that 88% of ruptured aneurysms had an AR greater than 1.6 and that 56% of unruptured aneurysms had an AR of 1.6 or less. This compares with rates of 80 and 90%, respectively, in the study by Ujiie, et al.[6] The negative and positive predicted values in that study were 73 and 93%, respectively. In our study a low AR was more likely to be useful in ruling out aneurysm rupture (higher sensitivity and negative predictive value), but a high AR was more frequently associated with an unruptured aneurysm (lower specificity and positive predictive value).

Conclusions

We suggest that the AR is a useful measurement and it should be made routinely. It may assist in the difficult decision making regarding whether to treat unruptured aneurysms. It would be premature, however, to claim a true predictive value on the basis of retrospective data alone.

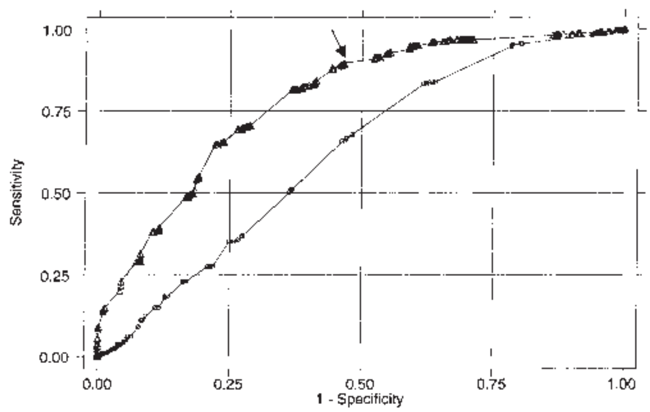

FIG. 4. Graph depicting the ROC curves for aneurysm size (the maximum dimension of the lesion) and AR. For the AR the *arrow* denotes the point on the curve corresponding to a cutpoint of 1.6. *Circles* designate aneurysm sizes and *triangles* ARs. The ROC area for aneurysm size is 0.6195; the ROC area for the AR is 0.7854.

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