Title page

Title

Cerebral aneurysm morphology before and after rupture: nation-wide case series of 29 aneurysms.

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Abstract

Background and Purpose—Using post-rupture morphology to predict rupture risk of an intracranial aneurysm (IA) may be inaccurate because of possible morphological changes at or around the time of rupture. The present study aims at comparing morphology from angiograms obtained prior to and just after rupture and to evaluate whether post-rupture morphology is an adequate surrogate for rupture risk.

Methods—Case series of 29 aneurysms from a nation-wide retrospective data collection. Two neuroradiologists that were blinded to pre- versus post rupture images assessed pre-defined morphological parameters independently and reached consensus regarding all measurements. Pre-rupture morphology and respective changes after rupture were quantified and linked to risk factors as well as to the risk of rupture according to the PHASES and unruptured IA treatment (UIAT) scores.

Results—All one-dimensional parameter medians were significantly larger after rupture, except neck diameter. Number of aneurysms with daughter sacs was 9 (31%) before and 17 (59%) after rupture (*P*=0.005). Aneurysm growth from the images prior to and just after rupture increased with the time elapsed between images. Aneurysms in patients with hypertension were significantly larger at diagnosis. Pre-rupture morphology did not differ in relation to smoke status. Clinical risk factors were not significantly associated with morphological change.

Conclusions—The changes in aneurysm morphology observed after rupture reflect the compound effect of time with successive growth and formation of irregularities, and the impact of rupture per se. Post-rupture morphology should not be considered an adequate surrogate for the pre-rupture morphology in the evaluation of rupture risk.

Introduction

Subarachnoid hemorrhage (SAH) causes loss of potential life years at a proportion similar to ischemic stroke and intracerebral hemorrhage.[1, 2] The prevalence of intracranial aneurysms (IA) is estimated to around 2-3.5% in a normal population.[3, 4] Ruptured aneurysms are the source of 80% of SAH. The SAH incidence is 10 per 100 000 person years, implying that many IA never rupture.[5] The optimal management of a diagnosed, unruptured IA remains controversial, and the risks of preventive intervention have to be weighed against the unknown risk of rupture for the individual aneurysm.[6] Therefore, tools have been developed to establish the risk of IA rupture (such as PHASES[7]) and to ease the decision-making in the management of unruptured IAs (such as UIATS[8]).

Aneurysm size is often applied in the clinical decision-making as it has shown to be a significant predictor of rupture.[7] On the other hand, rupture is a multi-factorial end-point and cannot be exactly determined by aneurysm size alone.[9] Hence, larger aneurysms carry a higher risk of rupture, but nevertheless a large amount of SAHs are caused by small aneurysms.[10-12] Aneurysm morphology expressed as aspect ratio and bottleneck factor determines the hemodynamics that may affect the risk of rupture. Several studies showed significant morphological differences between ruptured and unruptured aneurysms.[9] However, applying results from these studies on unruptured aneurysms to determine their risk of rupture critically relies on the premise that post-rupture morphology is not significantly different from that prior to rupture.[9] Recent case reports and small studies with 1-13 aneurysms indicate that this assumption does not hold.[13-16]

The aim of the present study is to describe the changes in morphology and morphological indices occurring between images obtained prior to and just after rupture of an aneurysm and to evaluate whether post-rupture morphology is an adequate surrogate for risk of rupture.

Patients and Methods

Study Design, Patient Selection and Data Extraction

The study is a nation-wide retrospective data collection from the four neurosurgical centers treating all IA and SAH in Norway. We searched electronic health records using codes from the International Classification of Diseases, version 10 (ICD-10), to identify patients diagnosed with unruptured IA, that later were hospitalized with SAH. We created lists of patients diagnosed with I67.1 (cerebral aneurysm, unruptured) between October 1st, 2003 and October 1st, 2013. Of these patients, we identified those being subsequently hospitalized with I60.0-I60.9 (non-traumatic subarachnoid hemorrhage).

For the identified patients, we recorded age, sex, date of diagnosis of unruptured IA, date admitted for SAH, the reason for the aneurysm being conservatively managed. We also retrieved known risk factors such as hypertension, smoking, connective tissue disease, polycystic kidney disease, family history and/or prior aneurysmal SAH. We determined the PHASES[7] and UIATS[8] in all patients. The latest available pre- and the first available post-rupture angiograms were retrieved, from which a number of quantitative and qualitative features were determined. Patients were excluded if they had previous treatment of the aneurysm of interest, multiple aneurysms of which the ruptured aneurysm was difficult to identify, or image quality precluding reliable aneurysm measurements. Fusiform aneurysms were excluded.

The study was approved by the Northern Norway Regional Committee for Medical Research Ethics, which decided the study to be exempt from patient consent. The study is reported according to the STROBE guidelines.[17]

Measurement Process

Two neuroradiologists residing in different centers assessed the aneurysms, using measuring tools in Siemens syngo.via and syngo InSpace (Siemens Healthcare, Erlangen, Germany). The two observers measured all aneurysms independently according to a strictly defined measurement protocol, blinded to each other's results and with no prior information about aneurysm rupture state.

Initially, the observers interactively evaluated 3D volume rendering technique (VRT) images for general morphology such as smooth/irregular and numbers of daughter sacs (Figure 1A). The aneurysm neck was identified and multiplanar (MPR) cursors were aligned to define the aneurysm neck. The aneurysm was rotated until the maximum length and diameters were revealed. The resulting VRT projection was then converted to a thin slice maximum intensity picture (MIP) on which measurements were performed (Figure 1B).

We calculated intraclass correlation coefficient (ICC) to assess the absolute inter-rater agreement.[18] According to conservative criteria, values >0.81 represent substantial reliability.[19]

Mean ICC for all parameters except two was 0.88. Of the two with lower ICC, one parameter (minimal size) was excluded from further analyses, whereas the other (Neck) was redefined to increase precision. The final measurement guide is described below (see ‘Definition of parameters’).

The mean values between observers were chosen when inter-rater difference was <2 mm. In cases of ≥2 mm differences and for the redefined Neck parameter, values were settled by consensus.

Parameter Definitions

Size measurements

Definitions are illustrated in Figure 1C and 1D. All parameters must be fitted within the aneurysm sac. Maximal size is the maximal distance between any two points in the aneurysm sac, including the neck plane. Neck size is the largest observed diameter of the neck plane. Height is the orthogonal distance between the neck plane center and the aneurysm dome. Length is the greatest distance between the neck plane center and any point on the aneurysm dome, not necessarily orthogonal to the neck plane. Width L is the largest diameter that is orthogonal to Length. Width H is the largest diameter that is orthogonal to Height. When comparing digital subtraction angiography (DSA) with another image modality, the available DSA projections dictated which projections were used from the other modality.

Indices

Aspect ratio was calculated as the ratio between height and neck diameter, and the bottleneck factor was calculated as the ratio between Width L and neck diameter.[20]

Volume approximation

Three of the above measured diameters were used to mathematically approximate the aneurysm volume. The conventional volume formula is $V=4/3\ \pi(A/2)\ (B/2)\ (C/2)$. We replaced A, B, and C with Maximal size, Length and Width L, respectively. This approximation technique has been shown to underestimate but still correlate with other methods of volume measurements.[21]

Additional registrations

We registered aneurysm location, relation to parent artery (bifurcation or sidewall aneurysm), surface quality (smooth or irregular), and the presence as well as number of daughter sacs protruding from the aneurysm wall.

Statistical Analysis

The data were analyzed with Stata for Mac (version 14; StataCorp LP, TX, USA) and SPSS for Windows (version 24; IBM, NY, USA). The variables' distribution was investigated visually with Q-Q plots, and numerically with Shapiro-Wilk test, and found to be non-parametric. Thus, paired continuous variables were compared using Wilcoxon signed-rank test, and paired nominal variables using McNemar's test. Independent continuous variables were compared using Mann Whitney U test, or Kruskal-Wallis test in cases of more than two groups. Categorical variables were compared using Chi squared test. A P Value of < 0.05 was assumed statistically significant.

Results

The search identified 52 patients with confirmed aneurysmal SAH, originating from aneurysms that were recognized prior to rupture but not repaired. Of these, 23 were excluded (nine were fusiform and 14 due to missing or poor images). The remaining 29 patients were included in the study.

Eight of the 29 patients were men (28%). Mean age at time of SAH was 67 years (standard deviation [SD], 9.3). Median time span between imaging prior to and just after rupture was 12 months (range, 0.3-96 months). The combination of image modalities before and after rupture was CTA and CTA for 16 patients (56%), CTA and MRA for eight patients (28%), CTA and 2D DSA for two patients (7%), and MRA and 2D DSA for three patients (10%).

Table 1 summarizes patient- and aneurysm characteristics at baseline, as well as risk of rupture expressed by PHASES risk score and treatment recommendations according to the UIAT score. The 5-year risk of rupture exceeded 1% (PHASES $\geq$ 5) in 79% of the patients and 5% (PHASES $\geq$ 10) in 38% of the patients. The UIAT score was indeterminate in 35% of the cases and favored conservative management in 31% of the patients. The UIAT score favoring aneurysm repair tended to be higher for aneurysms that ruptured within three months (median, 14 [range, 5-16]) compared to aneurysms with longer time between images (median, 10 [range 5-20], *P*=0.07). Online Supplement Table provides aneurysm location, maximal aneurysm size, PHASES and UIAT scores, and the reason for not performing aneurysm repair for each individual aneurysm.

Morphological Change

Table 2 lists the morphological parameters from imaging prior to and just after rupture. All one-dimensional parameter medians were statistically significantly larger after rupture, except neck diameter. Median aspect ratio before rupture was 1.5 (range, 0.8-4.0), compared to 1.9 (0.8-6.7) after rupture (*P*=0.008). Median bottleneck factor was 1.5 (range, 0.9-4.0) before and 1.5 (0.7-6.2) after rupture (*P*=0.068). Number of aneurysms with ≥ 1 daughter sac was 9 (31%) before and 17 (59%) after rupture (*P*=0.005). Figure 2 illustrates a typical change from pre- to post-rupture image.

The magnitude of change was clearly dependent on the time elapsed between the image prior to and just after rupture, visualized in Figure 3. Seven aneurysms (24%) ruptured within three months after the last image. Though median change in aspect ratio for this subset was only 0.10, the range from -0.45 to 0.95 (corresponding to -18 to 98%) demonstrates that we also observed relatively large morphological change within short time spans. We observed a new daughter sac in one of these seven aneurysms after rupture (number of days between images for this particular aneurysm was 18). Change in the morphological indices, however, was not dependent on time elapsed between images.

Morphology and Change in relation to Clinical Risk Factors

In hypertensive patients, aneurysms were significantly larger at diagnosis (median maximum size 12.85 mm [range, 3.4-12.3] in hypertensive versus 6.95 mm [2.8-33.4] in non-hypertensive, *P*=0.041). Indices and presence of daughter sacs were not significantly different. Changes in morphology from before to after rupture were not significant, except for neck diameter, which tended to increase in hypertensive patients (0.3 mm [-1.8-3.7]) and decrease (-0.4 mm [-2.9-0.5]) in non-hypertensive patients (*P*=0.047).

Between current and former/never smokers, there was neither a significant difference in morphology prior to rupture, nor a significant change in morphology after rupture. These findings were also true when excluding aneurysms that ruptured after a short observation period (< 3 months).

Discussion

The core finding of the present study is that aneurysm morphology had changed between imaging prior to and just after aneurysm rupture. The observed changes increased with the time elapsed between imaging, though gross changes also occurred within short time spans. Change occurred in a non-uniform manner, signified by changes in aspect ratio and fraction of aneurysms with daughter sacs.

Post-Rupture Morphology As Surrogate for Pre-Rupture Morphology

The present findings do not support the assumption that post-rupture morphology is representative for the pre-rupture morphology.[9] The fraction of aneurysms with blebs increased from 31% before to 59% after rupture. Consistent with the present study, a recent literature review reported that 17 of 23 aneurysms increased in size around time of rupture, and a case series in the same work showed presence of new daughter sacs after rupture in 5 out of 6 patients.[16] However, aneurysm morphology just after rupture will be subjected to the impact of the rupture per se plus any change that may have occurred along the evolution of the specific aneurysm, or even in the short time span between rupture and post-rupture imaging. In a meta-analysis including 4972 unruptured aneurysms, 9% of aneurysms enlarged within a mean follow-up time of 2.8 patient-years.[22] Accordingly, our data do not reveal what occurs during the exact moment of rupture, but rather support the notion that aneurysms grow over time, with periods with and without growth, and an inconstant risk of rupture over time.[23-25]

The low rate of rupture of small aneurysms in the International Study of Intracranial Aneurysms (ISUIA) led some authors to speculate that aneurysms shrink after rupture.[14, 26] Aneurysms in the present study that ruptured within three months after the pre-rupture image showed less change in morphology (or even shrunk in some of the parameters) than those that had ruptured after longer time intervals. One could assume that the changes in this subgroup were more subjected to the effect of the rupture per se than those we observed in the other aneurysms. Though the changes are too small to rule out measurement uncertainty, one can speculate that rupture may cause a slight deflation of aneurysms. Three of the aneurysms ruptured after 9, 16, and 22 months after the last pre-rupture scan, respectively, and also showed a decrease in Maximum size; one could speculate that these were stable aneurysms without growth during the time-span, and that the observed change was caused by the rupture. However, the number of aneurysms is too small to allow for conclusions.

Risk of Rupture

An aspect ratio above 1.6 has been considered as a predictor for future rupture, and is also included in the UIAT score.[8] We are not aware of suggested cut-off values for bottleneck factor.

Although such thresholds have been criticized and are affected by measurement methodology,[20] we note with interest that 15 (52%) of the 29 aneurysms in our material fell below these limits before rupture, whereas 10 (35%) did so after rupture. Since the mean values increased for all parameters except neck diameter, any change would tend to increase aspect ratio and bottleneck factor. Thus, the higher aspect ratio and bottleneck factor seen in ruptured aneurysms in other studies may simply be the effect of change over time, or the rupture itself.[27]

Maximal aneurysm diameter is perhaps the most common denominator for determining the risk of rupture and is incorporated into the PHASES[7] and UIAT[8] scores. The fact that even very small aneurysms rupture is well established.[28, 29] Close to one third (28%) of our aneurysms were < 7 mm and still ruptured. The size of our aneurysms did not predict the time span to rupture. One reason may be an overrepresentation of small aneurysms within the population of unruptured IAs, and another may be that aneurysms grow in a non-linear fashion.[23, 24]

Size is only one indicator of the multifactorial causes for aneurysm rupture. PHASES and UIAT scores incorporate a wide array of factors supposedly influencing the risk of aneurysm rupture; still, in merely about one third of our cases, the UIAT would have favored aneurysm repair. In 20% of cases, the PHASES score indicated a 5-year cumulative rupture risk of less than 1%. On the other hand, the UIAT scores favored repair or suggested special consideration due to indetermination regarding treatment in 70% of patients. According to PHASES, 38% of the patients exceeded a 5-year risk of rupture of 5%. Though our retrospective study aims to compare pre- and post-rupture imaging, we note that the majority of the included patients may have required treatment.

Aneurysm growth is a strong risk factor for rupture,[22, 24, 30-32] possibly increasing risk 12- to 24-fold.[30, 31] Growth rate and risk of growth increases with increased aneurysm size. However, growth can occur at all aneurysm sizes, warranting follow-up imaging of conservatively managed aneurysms, including aneurysms < 7 mm.[24, 25, 27, 29-31] In a systematic review of 30 unruptured aneurysms <7 mm followed with serial imaging for a median of 6.5 years, 27 (90%) enlarged before rupture.[24] Thus, assuming that at least substantial parts of the changes we observe in our study are pre-rupture changes, our study sample consists of aneurysms of a high rupture risk. Still, aneurysm growth is only one marker of increased risk, and rupture can occur without growth.[24, 25]

Smoking and hypertension are other well established independent risk factors for aneurysm rupture.[8, 33] Morphological changes, however, were similar for patients with and without these risk factors. Thus, in our material, the presence or absence of smoking and hypertension did not influence whether post-rupture morphology was representative of that prior to rupture.

Studies comparing unruptured aneurysms with aneurysms presenting after rupture have generated important hypotheses about pathophysiology and risk factors for growth and rupture.[34] With the addition of the present study to existing data, we argue that the post-rupture morphology should not be considered a good surrogate in the evaluation of risk of rupture. Morphological and hemodynamic rupture predictors should be validated in studies of pre-rupture aneurysms.

Limitations

The present material is subjected to selection bias since the included patients were selected to conservative management, except those that either refused treatment or experienced SAH while waiting for aneurysm repair. A number of factors can affect the rupture risk: The included patients are somewhat older and possibly more comorbid than the expected average of SAH patients. The fraction of smokers in our material is somewhat lower than the country average (less than half versus two-thirds, respectively), and the fraction of patients with multiple aneurysms is higher than what is commonly found in clinical series.

A length time bias may pertain to the included aneurysms, as other more rupture-prone aneurysms might have ruptured early on in their pathogenesis, never being diagnosed before rupture. Also, patients with a recognized IA that succumbed to their aneurysm without reaching a hospital are not part of this study. Still, we regard the external validity as high, since none of the clinical risk factors were statistically significantly associated with morphological change. However, the retrospective nature of the study reduces the accuracy of the patient risk factors recorded. The study sample is small and does not allow for definite conclusions, but pre- and post-rupture angiograms of IAs are exceedingly rare, making adequately powered enquiries into this matter difficult. This study thus contributes to shed light onto an area that is very rarely available for investigation.

The neck diameter definition used in this study is the maximal neck size. This definition provided the highest inter-rater reliability, but reduces comparability with studies employing average or minimal neck diameter definitions. To answer our study question, the inter-rater reliability was paramount. Manual measurements can introduce inter-rater discrepancies. Strict parameter definitions guided the measuring process to counter error. The intra-class correlation coefficient demonstrated substantial agreement between the two raters.

Finally, 45% of the cases were evaluated with different image modalities, introducing technical limitations in measurement precision. However, other studies have shown that different modalities can be reliably compared.[35] Moreover, image quality, CTA and MRA slice thickness, as well as radiocontrast filling effects introduce variability. This variability may be assumed to be of the same magnitude like the one meeting the clinician in every day practice when evaluating serial imaging in a patient. The observed changes in the present study are of such a magnitude that they still would be consistent even after considering a margin for measurement errors.

Conclusion

Aneurysm morphology was significantly different after rupture as compared to before rupture. To an extent, changes had occurred in a non-uniform manner. The changes observed after rupture reflect the compound effect of time with successive growth and formation of irregularities, and the impact of rupture per se. Post-rupture morphology should not be considered a good surrogate in the evaluation of risk of rupture.

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Disclosures

None.

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Figure Legends

Figure 1. Aneurysm measurement method. (A) Volume rendering technique (VRT) image for assessment of general morphology and identification of optimal measurement planes.
(B) Maximum intensity picture (MIP) for measurements. (C) and (D) Illustrations of parameter definitions.

Figure 2. Volume rendering technique (VRT) images of one aneurysm before and after rupture. Height and Maximal size measurements are shown. (A) Before rupture. (B) After rupture. Maximal size is increased and a daughter sac has developed.

Figure 3. Difference between pre- and post-rupture measurements of the one-dimensional parameters Maximal size, Height, Neck and Length, categorized in accordance with the time elapsed between images. *P* Values from independent samples Kruskal-Wallis test.

Table 1. Patient and Aneurysm Characteristics.

Characteristic	No	(%)
Patients		
No. of patients	29	(100)
Sex, male	8	(28)
Age at time of SAH, years, mean (±SD)	67.2	(9.3)
Hypertension	21	(72)
Multiple aneurysms	12	(41)
Smoking		
Current	13	(45)
Former	3	(10)
Never	13	(45)
PHASES 5-year rupture risk, median (range)	8	(3-16)
> 1% risk, no. (%)	23	(79)
> 5% risk, no. (%)	11	(38)
UIAT score		
Favored repair	10	(35)
Indeterminate	9	(31)
Favored conservative management	10	(35)
Aneurysms		
No. of aneurysms	29	(100)
Location*		
Anterior	26	
Posterior	3	
Time between images, months, median (range)	12	(0.26-96.2)

*Anterior: anterior cerebral artery, anterior communicating artery, middle cerebral artery and internal carotid artery. Posterior: basilar artery, posterior cerebral artery, posterior communicating artery.

Table 2. Morphological Parameters Before and After Rupture.

	Before Rupture, median (range)		After Rupture, median (range)		*P* Values*
1D parameters, mm					
Maximal diameter	10.0	(2.8-33.4)	12.1	(3.5-40.2)	**<0.001**
Neck diameter	5.6	(1.9-12.8)	5.4	(2.1-13.1)	0.79
Length	9.6	(2.7-25.4)	11.1	(3.5-40.2)	**0.003**
Width L	8.6	(2.5-28.0)	9.4	(2.1-37.0)	**0.024**
Height	9.6	(2.7-25.4)	9.1	(2.6-40.2)	**0.035**
Width H	8.4	(2.5-28.0)	9.6	(2.1-37.0)	**0.002**
2D parameters					
Aspect ratio	1.5	(0.8-4.0)	1.9	(0.8-6.7)	**0.008**
Bottleneck factor	1.5	(0.9-4.0)	1.5	(0.7-6.2)	0.069
3D parameters					
Approximated volume (cm^3)	0.50	(0.01-11.2)	0.57	(0.02-31.3)	**0.001**
Wall characteristics					
Irregular, no. (%)	10	(35)	13	(45)	0.25 †
No. of blebs, median (range)	0	(0-2)	1	(0-5)	**0.001**
Aneurysms with blebs, no. (%)	9	(31)	17	(59)	**0.005**

* *P* Value for the difference before and after rupture; Wilcoxon signed-rank test. *P* Values < 0.05 considered statistically significant and bolded.

† related samples McNemar test.

Online Supplement

CEREBRAL ANEURYSM MORPHOLOGY BEFORE AND AFTER RUPTURE:
NATION-WIDE CASE SERIES OF 29 ANEURYSMS.

Table I. Location, Time Frame, Maximum Size, Risk Factor Scores and Reasons For Not Treating the Individual Aneurysm
References

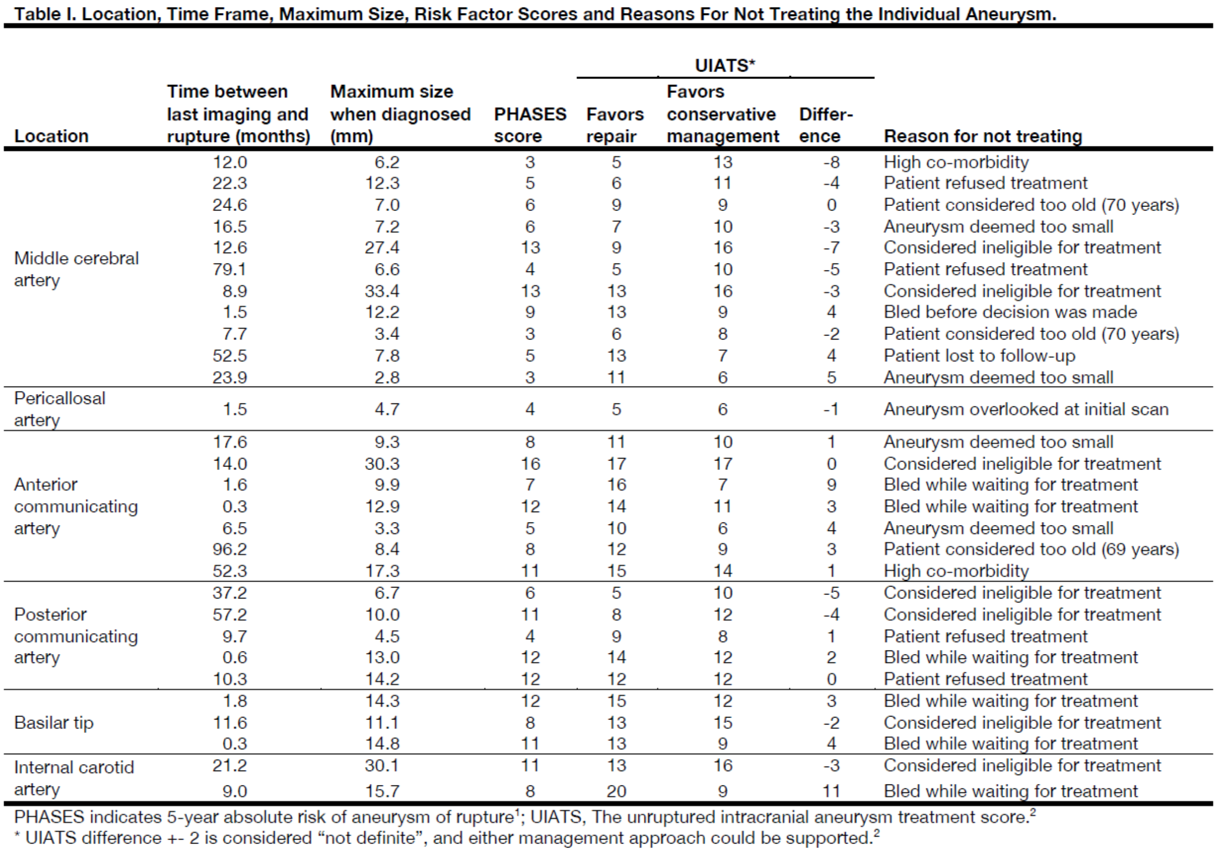

Table I. Location, Time Frame, Maximum Size, Risk Factor Scores and Reasons For Not Treating the Individual Aneurysm.

Location	Time between last imaging and rupture (months)	Maximum size when diagnosed (mm)	PHASES score	UIATS* Favors repair	UIATS* Favors conservative management	UIATS* Differ-ence	Reason for not treating
Middle cerebral artery	12.0	6.2	3	5	13	-8	High co-morbidity
	22.3	12.3	5	6	11	-4	Patient refused treatment
	24.6	7.0	6	9	9	0	Patient considered too old (70 years)
	16.5	7.2	6	7	10	-3	Aneurysm deemed too small
	12.6	27.4	13	9	16	-7	Considered ineligible for treatment
	79.1	6.6	4	5	10	-5	Patient refused treatment
	8.9	33.4	13	13	16	-3	Considered ineligible for treatment
	1.5	12.2	9	13	9	4	Bled before decision was made
	7.7	3.4	3	6	8	-2	Patient considered too old (70 years)
	52.5	7.8	5	13	7	4	Patient lost to follow-up
	23.9	2.8	3	11	6	5	Aneurysm deemed too small
Pericallosal artery	1.5	4.7	4	5	6	-1	Aneurysm overlooked at initial scan
Anterior communicating artery	17.6	9.3	8	11	10	1	Aneurysm deemed too small
	14.0	30.3	16	17	17	0	Considered ineligible for treatment
	1.6	9.9	7	16	7	9	Bled while waiting for treatment
	0.3	12.9	12	14	11	3	Bled while waiting for treatment
	6.5	3.3	5	10	6	4	Aneurysm deemed too small
	96.2	8.4	8	12	9	3	Patient considered too old (69 years)
	52.3	17.3	11	15	14	1	High co-morbidity
Posterior communicating artery	37.2	6.7	6	5	10	-5	Considered ineligible for treatment
	57.2	10.0	11	8	12	-4	Considered ineligible for treatment
	9.7	4.5	4	9	8	1	Patient refused treatment
	0.6	13.0	12	14	12	2	Bled while waiting for treatment
	10.3	14.2	12	12	12	0	Patient refused treatment
Basilar tip	1.8	14.3	12	15	12	3	Bled while waiting for treatment
	11.6	11.1	8	13	15	-2	Considered ineligible for treatment
	0.3	14.8	11	13	9	4	Bled while waiting for treatment
Internal carotid artery	21.2	30.1	11	13	16	-3	Considered ineligible for treatment
	9.0	15.7	8	20	9	11	Bled while waiting for treatment

PHASES indicates 5-year absolute risk of aneurysm of rupture[1]; UIATS, The unruptured intracranial aneurysm treatment score.[2]
* UIATS difference +- 2 is considered “not definite”, and either management approach could be supported.[2]

References

1. Greving JP, Wermer MJ, Brown RD, Jr., Morita A, Juvela S, Yonekura M, et al. Development of the PHASES score for prediction of risk of rupture of intracranial aneurysms: a pooled analysis of six prospective cohort studies. *Lancet Neurol*. 2014;13:59-66
2. Etminan N, Brown RD, Jr., Beseoglu K, Juvela S, Raymond J, Morita A, et al. The unruptured intracranial aneurysm treatment score: a multidisciplinary consensus. *Neurology*. 2015;85:881-889

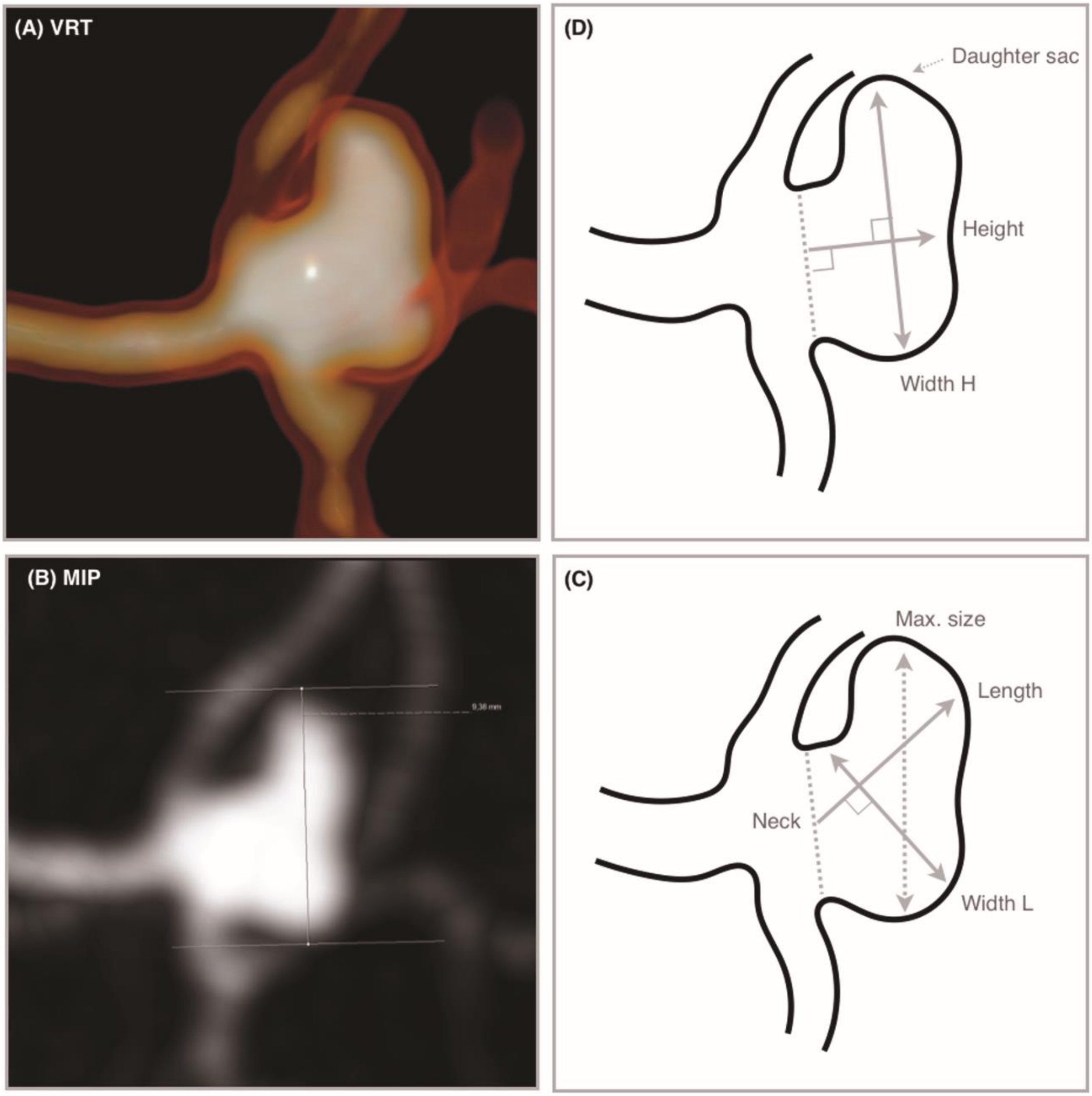
(A) VRT
(D)
Daughter sac
Height
Width H
(B) MIP
9,36 mm
(C)
Max. size
Length
Neck
Width L

Figure 2

Figure 3