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Predictable Morphometric Parameters for Rupture of Intracranial Aneurysms – A Series of 142 Operated Aneurysms

İntrakraniyal Anevrizma Rüptüründe Öngörülebilir Morfometrik Parametreler - 142 Ameliyat Edilmiş Anevrizma Serisi

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ABSTRACT

AIM: Intracranial aneurysm rupture is followed by high mortality and morbidity. In order to understand the aneurysm's natural course, it is necessary to recognize the predisposing factors for the rupture.

MATERIAL and METHODS: Analysis included 142 operated aneurysms (94 hemorrhaging and 48 unruptured) in the period from 2008 to 2010.

RESULTS: The ratio between the width of the aneurysm neck and diameter of the carrying blood vessel – artery in ruptured aneurysms (OR) was 1.58±0.61, and in unruptured aneurysms 1.14±0.52 (p<0.01). Aspect ratio of ruptured aneurysm was 1.89 ± 0.59, and in unruptured 1:33 ± 0.17. The angle of inclination of ruptured aneurysms was 139.22 ± 21.53, while in unruptured aneurysms it was 101.73 ± 21.26.

CONCLUSION: Based on the results of our research, a predictive model of morphometric characteristics of the vessel bearing the aneurysm to rupture can be identified: an irregular shape of the aneurysm, AR> 1.6, OR> 1.5 and inclination angle >135 deg.

KEYWORDS: Intracranial aneurysm, Risk factors, Morphometric parameters

ÖZ

AMAÇ: İntrakraniyal anevrizma rüptürü sonrasında yüksek mortalite ve morbidite görülmektedir. Anevrizmanın doğal seyrini anlamak için rüptüre yatkınlık oluşturan faktörleri tanımak önemlidir.

YÖNTEM ve GEREÇLER: Analize 2008-2010 arasında 142 ameliyat edilmiş anevrizma (94 kanayan ve 48 rüptür olmamış) dahil edildi.

BULGULAR: Anevrizma boynu genişliği ile taşıyan kan damarı - arter çapının arasındaki oran (OR) rüptüre olmuş anevrizmalarda 1,58±0,61 ve rüptüre olmamış anevrizmalarda 1,14±0,52 (p<0,01) şeklindeydi. Aspekt oranı rüptüre olmuş anevrizmalarda 1,89 ± 0,59 ve rüptüre olmamış anevrizmalarda 1,33 ± 0,17 şeklindeydi. İnklinasyon açısı rüptüre olmuş anevrizmada 139,22 ± 21,53 ve rüptüre olmamış anevrizmalarda 101,73 ± 21,26 şeklindeydi.

SONUÇ: Araştırmamızın sonuçları temelinde rüptüre olacak anevrizmayı taşıyan damarın morfometrik özelliklerinin prediktif bir modeli tanımlanabilir: Anevrizmada düzensiz şekil, aspekt oranı >1,6, OR >1,5 ve inklinasyon açısı >135 derece.

ANAHTAR SÖZCÜKLER: İntrakraniyal anevrizma, Risk faktörleri, Morfometrik parametreler

INTRODUCTION

Intracranial aneurysms are relatively frequent and occur according to autopsy and angiographic data in 2-5% of the general population (30). Most patients with ruptured aneurysms are between 30 and 60 years of age (annual incidence 10-22/100000 inhabitants), and the mortality rate in those cases is about 50% in the first month after the rupture (18, 22).

The hemorrhaging from an intracranial aneurysm is a consequence of the weakness of the aneurysmal wall and the influence of vibrations (systolic impacts of the blood wave, turbulent movement of the blood inside the aneurysmal cavum and vibrating movements during the passage of the systolic wave through the brain's blood vessels). Other important factors for the rupture are the sudden increase of the arterial pressure and the increase of the intracranial volume. The studies of Hassan and Cebral focused in particular on the above mentioned problem (5,6,10). It was discovered that the geometric – morphometric parameters have a great significance in the hemodynamics of the intracranial blood vessels and aneurysms, as well as their rupture. These parameters include the inclination angle of the blood vessel, its shape and its diameter at the level of separation of the aneurysm (1,8,31). Their study showed that the main points in the identification of the predisposing factors for ruptured aneurysm refer to the shape and diameter of the aneurysm (2-4, 22). In regards to the relative ratios, the Aspect Ratio (AR) was examined, i.e. the ratio between the maximum height of the aneurysm and the diameter of the aneurysm neck (8, 28, 29). The fact that it was not possible to assess topometric parameters of the blood vessel and their ratio in an aneurysm was a limiting factor in their study. Only with the development of computer protocols and the use of angiographic equipment were the conditions were created to develop this field further and extend the studies. Also, with the introduction of the rotational 3D angiography technology into clinical practice, an image with a higher resolution was obtained. With this progress it was possible to conduct a detailed survey of the spatial reconstruction with the free rotation at the selected point, which at the same time allowed doing an easier and more precise morphometric analysis. Using these technological advancements, Rohde et al. were able to give a detailed analysis and assessment of the irregularity of the intracranial aneurysm using rotational 3D angiography and Fourier's results. The aim of Rohde's research and analysis was to identify whether those aneurysms were lobular or daughter aneurysms. Up until that date conventional angiography was insufficient to make this differentiation (19). Dhar et al. performed a detailed analysis of the morphometric ratios of the aneurysm and this particular type of procedure was previously not possible with conventional angiography (8). In addition, this new technology allowed for the calculation of the inclination angle of the blood stream, as well as the measuring of the precise ratio of the blood vessel's parameter and the aneurysm neck. All this data is important to determine the predisposing factors for intracranial aneurysm rupture.

MATERIAL and METHODS

The aim of our performed study was on one hand to determine the optimal treatment – direct surgery/endovascular obliteration - and on the other hand to evaluate the risk of rupture detected accidentally or the rupture in associated aneurysms. The study is based on the morphometric analysis of aneurysm and the identification of predictive factors in the blood vessel bearing the ruptured aneurysm.

The study included 94 patients with proven spontaneous subarachnoid hemorrhage caused by rupture of intracranial aneurysms of the anterior segment. These patients were treated at the Neurosurgical Clinic of the Clinical Center in Serbia in the period from January 2008 to December 2010. The analysis included patients who met the following criteria: clinical, lumbar puncture (LP) and computerized tomography of endocranium (CT), verified attack of spontaneous subarachnoid hemorrhage (SAH), one or more verified aneurysms of the anterior segment blood vessels of the base of the brain using digital subtraction angiography (DSA), and operated or embolized aneurysm. The analysis used angiographic findings, the spatial reconstruction of blood vessels of the brain based on the original software provided by the manufacturers (Siemens AG, Axiom Artis), and previous computer models that were developed in our clinic (Figure 1), as well as intraoperative findings and complete medical records (13). To further extend the research we decided to take the results of a morphometric analysis of aneurysm, a comparative analysis of angiographic findings, and a comparison of the quality of angiography in relation to intraoperative findings and entered them into a form, which was specially created for this purpose. The data was then analyzed through descriptive (measures of central tendency and dispersion measures) and statistical facts.

For the study the following ratio data was used: The Ostium ratio (OR) is the ratio of the width of the aneurysm neck (dv) and the diameter of bearing blood court-artery (φ) and was measured in millimeters at the level of separation of

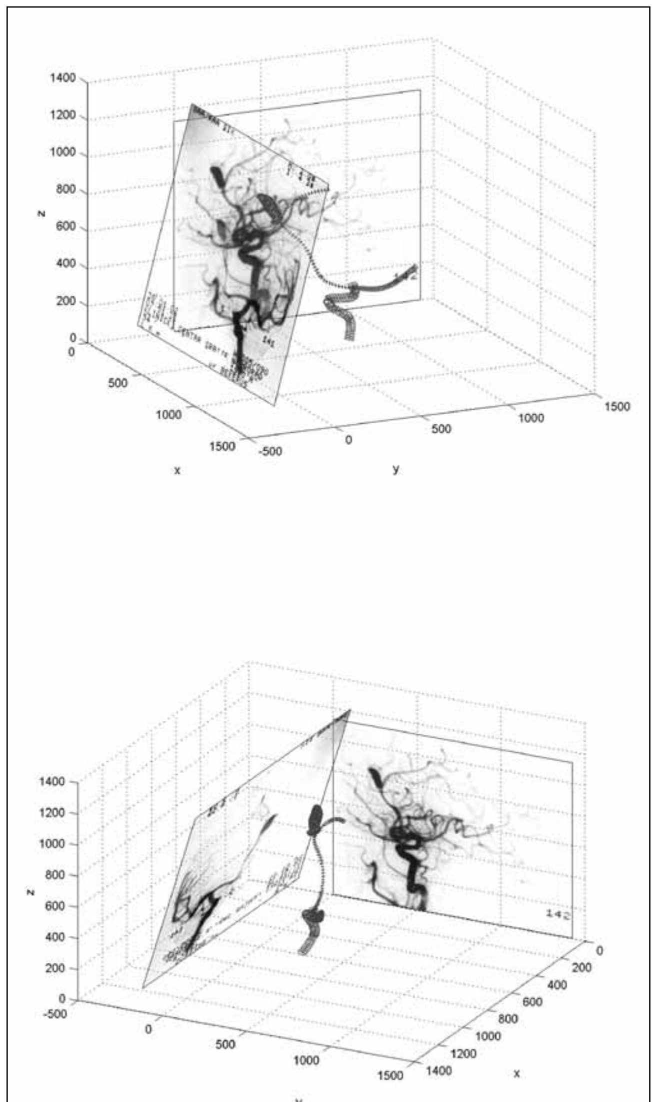

Figure 1: Spatial reconstruction of aneurysm of Pericalosal artery.

the artery aneurysms. The Aspect ratio (AR) is the ratio of the height of the aneurysm (ha) and the width of its neck (dv). The measured values are in millimeters.

$$OR = \frac{d_v}{\varphi} \qquad AR = \frac{h_a}{d_v}$$

Parametric (t-test) and nonparametric tests of difference (χ2, and Median test) were used for the analytical statistics.

RESULTS

The observed group included 94 patients of both sexes (62 women and 32 men), with an average age of 50.39±8.25 years. The average age of the female patients was 52.15±6.64 years and the average age of a male patient 46.84±9.96 years. The youngest patient was a 21-year-old and the oldest was 72 years of age. The median was 51 years (Med_m=47, Med_f =52). In the observed group of patients 142 were diagnosed with intracranial aneurysms of the carotid area, out of which 94 (66.2%) aneurysms were caused by a spontaneous subarachnoid hemorrhage. In Table I aneurysms are presented by location.

The type of aneurysms were divided into saccular, elongated, saddlebags, and irregularly shaped aneurysms. Table II shows the distribution of aneurysms according to the shape of ruptured and unruptured aneurysms. In both groups it is the saccular aneurysm that dominated (p<0.01, DF=3, unruptured χ2=114167, ruptured χ2=113,138).

The angle of inclination

The average value of the angle between the carrying vessel and the central line blood flow in the aneurysm (the angle of blood flow) in our group was 130.82±26.52. In aneurysms that have ruptured the average value of the angle was 139.22±21.53, whereas in the unruptured aneurysms the value was much smaller at 101.73±21.26, (p<0.01, t=7844, DF=140).

The largest diameter of the aneurysm

The largest diameter of the aneurysm was measured on 3D reconstructions. The average value of the maximum diameter of aneurysms was 1.11±6.98 mm. In ruptured aneurysms, this value was 11.66 ± 6.87 mm, and in unruptured 8:55 ± 5.11 mm. Because of the fact that the CV in both groups was more than 0.3, testing was done by the median difference test. Significant differences were found between the major diameters of ruptured and unruptured aneurysms (p <0.01, χ2 = 6849, do = 1). Table III presents the distribution of aneurysms in 6 groups (according to the largest diameter in steps of 5 mm).

Ostium ratio (OR)

The mean value of the ratio between the aneurysm neck width and the diameter of the carrying blood vessel - artery for ruptured aneurysms was 1.68333±0.18591. For unruptured aneurysms the mean value was 1.04643±0.20758. A statistically significant difference was observed in the much higher mean value in ruptured aneurysms (p<0.01, t=17.90442, DF=140).

The mean values of the ratio between the aneurysm neck width and the diameter of the carrying blood vessel for ruptured/unruptured aneurysm for each artery (ACM, ACoA, ACI and AP-ACA complex) are shown in Table IV.

We tested the contrast ratio neck diameter with a diameter of an aneurysm carrier vessel for each of the arteries of the carotid siphon and obtained the following results: for internal carotid artery: t=8.89759, DF=44, p<0.01; for the middle cerebral artery: t=6.80889, DF=46, p<0.01; for the anterior communicating artery: t=7.37883, DF=37, p<0.01; and for the anterior cerebral artery with artery pericalosal: t=6.75312, DF=7, p<0.01. All these values indicate that the Ostium ratio gives a statistically significant parameter for the predisposition of ruptured intracranial aneurysms.

Aspect ratio (AR)

Aspect ratio in the ruptured aneurysm was 1.89±0.59, and for unruptured 1.33±0.17. There was a statistically

Table I: Distribution of Aneurysms by Presented Localisation

Artery	Nº
ICA	46
PA-ACA	9
AcoA	39
MCA	48

***MCA** – middle cerebral artery, **ACoA** – anterior communicant artery, **ICA** – internal carotid artery, **PA-ACA** – pericalosal-anterior cerebral artery complex.*

Table II: Distribition of Aneurysms according to the Shape

Shape of aneurysm	Ruptured	Unruptured	Nº
Saccular	61	44	105
Saddlebags	11	0	11
Elongated	14	1	15
Irregular	8	3	11
Σ	94	48	142

Table III: Distribution of Aneurysms according to the Largest Diameterin Steps of 5 mm

Diameter of aneurysm	Ruptured	Unruptured	Nº
≤ 5 mm	5	20	25
6-10 mm	54	13	67
11-15 mm	14	9	23
16-20 mm	9	3	12
21-25 mm	4	1	5
> 25 mm	8	2	10
Σ	94	48	142

Table IV: Mean Values of OR for Ruptured Aneurysms

	Ruptured			Unruptured		
Artery	**OR**	**SD**	**Nº**	**OR**	**SD**	**Nº**
MCA	1.66129	0.24946	31	1.04054	0.17641	17
ACoA	1.86667	0.29103	28	1.13636	0.30001	11
PA-ACA	1.57	0.09798	5	0.875	0.15	4
ICA	1.60678	0.31721	30	1.03625	0.12708	16

***MCA** – middle cerebral artery, **ACoA** – anterior communicant artery, **ICA** – internal carotid artery, **PA-ACA** – pericalosal-anterior cerebral artery complex.*

Table V: Mean Values of AR for Ruptured Aneurysms

	Ruptured			Unruptured		
Artery	**AR**	**SD**	**Nº**	**AR**	**SD**	**Nº**
MCA	2,09	0.83	31	1.34	0.17	17
ACoA	1,69	0.29	28	1.32	0.13	11
PA-ACA	2,09	0.18	5	1.28	0.04	4
ICA	1,74	0.25	30	1.31	0.16	16

***MCA** – middle cerebral artery, **ACoA** – anterior communicant artery, **ICA** – internal carotid artery, **PA-ACA** – pericalosal-anterior cerebral artery complex.*

significant difference in favor of ruptured aneurysms ($p<0.01$, $t=5.384$, $D=183$). Table V presents the values of AR according to the localization of the aneurysm. The Aspect ratio for each of the arteries of the carotid siphon have been tested: internal ICA $t=6.02$, $DF=44$, $p<0.01$; MCA statistical analysis showed $\chi 2=5.29$, $DF=1$, $p<0.05$ (Median test, $CV>0.3$, Mood's formula); ACoAt=3.28, $DF=37$, $p<0.01$ and the PA-ACA complex $t=9.76$, $DF=7$, $p<0.01$. All these values indicate that the AR shows a statistically significant parameter for the predisposition for ruptured intracranial aneurysms.

DISCUSSION

In the last two decades the investigation of morphometric parameters of accidentally discovered intracranial aneurysms was started. The goal was to identify risk factors for rupture. During the investigations the shape and the diameter of the aneurysm have been looked at as well as the correlation of different diameters. With his research, Ujiie demonstrated the importance of AR as predisposing factors for rupture of intracranial aneurysms (28, 29).

Also, in the past 10 years other related factors have been studied including H with ratio and the Bottleneck factor (11). Recent studies increasingly point towards the importance of hemodynamics with several significant findings. The hemodynamics of the fluid is an important factor as well as the problem of the angle of the aneurysm and the angle of the blood stream (i.e. the angle between the bloodstream of the bearing artery and the bloodstream that enters the aneurysm). These aspects have been dealt with only in a few studies until now (1,31). Based on Bernoulli's Law the impacts of the systolic wave are transferred to the aneurysm wall according to the principle of transfer of hydraulic pressure in closed vessels. With turbulent blood movements inside an aneurysm, the pressure is increased in certain places. This causes the phenomenon of resonance to occur during the passage of the systolic wave through the cerebral arterial network. It is seen as a constant vibration. In this situation the height of the arterial pressure has direct influence on the intensity of these factors. The entrance of blood into the aneurysm almost exclusively develops during the systole, and the exit of blood is not pulsable (28).

The probability of rupture in the aneurysms is greater where the power of systolic pressure directly empties into the holdings (21). The risk of aneurysm is also higher in a blood vessel with unusual flow (12). An aneurysm at bifurcation has a higher risk of rupture because the shock waves are direct systolic (27). This indicates that it is more important to watch the blood stream and the angle between this blood stream and the one that is entering the aneurysm than the angle that anatomically closes the aneurysm in the carrying blood vessel (7, 8).

Another study of computerized simulations done by Szikora's and associates pointed out the great importance of the blood flow and the geometry of the aneurysm for a risk in rupture (24). Aneurysms can be of very different shapes, ranging from relatively proper spheres, ellipsoids with different forms, from unusual similar to long warm shapes to the ultimate multilobular irregular shapes. For each analysis in our study, aneurysms were divided into four groups: saccular (relatively regular spheres and ellipsoids with difference in diameter), oblong (ellipsoids warm shapes and large differences in diameter), bisaccular - saddlebags (made up of two spheres or ellipsoids) and irregular (mostly multilobular). Saccular aneurysms are the dominant type of aneurysms in literature findings, and usually they are expected to be the most common aneurysms in the ruptured group (61/94) and in the unruptured group (44/48) of aneurysms (4). And if other forms occur less often, what stands out is the fact whether they where ruptured or unruptured. Irregular aneurysms in the observed series were found in 8 cases of ruptured aneurysms and in 3 cases of unruptured. An oblong aneurysm was found in 14 cases in ruptured and only in one case in unruptured. Saddlebag aneurysms were found in 11 cases of ruptured aneurysms and in the unruptured group of observed patients, none was found. These data indicate the great importance of the shape of aneurysms, because obviously some forms correlate highly with the rupture of the aneurysm.

In another study, Beck and his associates stressed the importance of irregular shapes (primarily multilobar aneurysm) as predisposing factors for aneurysm rupture (3). A number of scientists consider that the bisaccular and the mulitilobular appearance of aneurysm are of secondary importance. In their opinion, lobes form in a later stage during the development and growth of the aneurysm (9, 16).

De Rooij divided aneurysm in spherical and aspherical, which includes ellipsoid (oval and elongated) and multilobular aneurysms. In her opinion the predisposing factor of an aneurysm can be seen in its shape. In comparison with the spherical shape, the more irregular shape increases the risk of rupture (7). Also Frösén emphasizes in his study the importance of shape as a risk factor for rupture of intracranial aneurysms. According to him, a primarily bisaccular form is an important predisposing factor (9). Dhar and his colleagues determined the index of elliptic and the asphericity index of intracranial aneurysms using 3D angiography as a baseline for measurement. According to them, the risk of rupture is greater with the increase of these indexes (8). Rohde and his colleagues studied the shape and surface of the aneurysm using 3D rotational angiography and Fourier's analysis. The conclusion was that the great importance is the irregular anatomy. If it is found with unruptured aneurysm, it indicates a high percentage in the possibility of a rupture. Thanks to the well-developed software and the rotational angiography they were able to work on the assessment of irregularities to identify whether it is in a lobus or a daughter aneurysm. Conventional angiography is insuffcent to show this difference (19).

Pentimalli and his associates in their research demonstrated the relationship of apoptosis in ruptured aneurysms and shapes. In their study they mainly showed a significant increase in irregular forms of aneurysms. They often also brought in relation the apoptosis hemodynamic factors and the dynamics of fluids (blood) in aneurysms (15). According to them a constant distension of the wall in saccular aneurysms and mechanical pressure during the systolic pulse wave leads to a reduction in vasa vasorum aneurysm causing hypoxia, necrosis, and rupture of the aneurysm (14).

Taking all these findings and data in consideration, we were looking for another aspect to find predictable morphometric parameters for rupture of intracranial aneurysms. Separating primarily hemodynamic in relation to the anatomical substrate, it was decided that in our study the angle of blood flow will be measured, i.e. the angle of the blood stream within the aneurysm and the angle of the blood stream in the carrier blood vessel. The measurement was done in the same way as Dr Dhar and his collaborators: by the rotation of the reconstruction in space until the smallest angle of blood flow was measured. In addition to this, the angle between the lobules and the daughter aneurysm was compared. The average value of the angle in ruptured aneurysms was 139.22 $\pm$ 26.52, and with unruptured aneurysm it is significantly smaller amounting to 101.73 $\pm$ 21.26 ($p < 0.01$). An angle of less than 115° had 88,235% of unruptured aneurysms, and an angle of greater than 150 ° was observed only in 3 cases. In comparison to this result 86.869% of aneurysms that had ruptured had an angle of blood flow greater than 115°, so that this value can be taken as a threshold.

This value of threshold for the angle of blood flow is very close to the results obtained by Dhar et al. Their threshold is in smaller percentage 81.8%, amounting to 112° (8). These differences may be considered almost negligible due to the very close values. According to findings of Suga and his co-workers the highest risk of rupture carries a shaft angle of 160-170°. With shafts of 80-130° it comes to a depreciation of wave and rupture is extremely rare (23). In our study only three cases were found with an angle higher than 150 degrees, which obviously calls for necessary caution as the risk for a rupture is increased. In ruptured aneurysms the blood flow angle is usually higher than 135° degrees so the value indicated by Suga, can be lowered by 25 degrees, because these values clearly show a very high risk of rupture. The average value of the largest diameter of ruptured aneurysms in the observed group was 11.66 $\pm$ 6.87 mm, and unruptured 8:55 $\pm$ 5.11 mm ($p < 0.01$). In this group the aneurysms with diameter less than 5 mm amount to 41.67% of unruptured aneurysms, while ruptured make up only 5.32%. As we had in the observed group only a very small number of aneurysm bleeds, we can agree with Dr. Beck that it is difficult to determine the critical value of the diameter, meaning the smallest diameter, which is predisposed to rupture. In his group of small bleeding aneurysms the average diameter was 6.7 mm and 5.7 mm for unruptured ($p > 0.05$) (2). In the observed group, bleeding aneurysms of diameter 5-10 mm were present in 57.45% and with unruptured only in 27.1%. Looking at the aneurysm with a diameter of 5-14 mm the ruptured aneurysms will make up a great majority of them with 72.34% while in the case of unruptured aneurysms their occurrence is significantly smaller and it is 45.83%. These results are in accordance with the available literature findings, which indicate that the aneurysm with a diameter smaller than 5mm will rupture in only 2.5%. The rupture is most likely with the aneurysm of diameter 5-15 mm (41% for aneurysms 5-10mm in diameter and 87% for those with a diameter of 10-15 mm). As one might assume there were no significant differences between the diameters of aneurysms basins.

In his study Sato points out the importance of the geometric aspect of the carrier vessel as a significant hemodynamic factor for intracranial aneurysm rupture (20). The SR factor is introduced representing the ratio of the caliber of the carrier vessel and the size of the aneurysm as a predisposing factor for aneurysm rupture (8,17,26,31).

Comparing the flow of fluids in rigid vessels, and in accordance to Bernoulli's law, the flow in the side court, which is separated from the main court depends on several factors, amongst which is the diameter of the main and the lateral vessel. Using this analogy, we assumed that with cerebral circulation, especially the circulation in intracranial aneurysms, legitimity exists. During our analysis of morphometric parameters of ruptured and unruptured intracranial aneurysms, we realized that there were significant differences in the values of the diameter of the aneurysm neck and the diameter bearing a blood vessel measuring it at the height of the separation of the aneurysm.

In the observed group mean value OR for the ruptured aneurysms was 1.683 ± 0.186, and for unruptured aneurysms it was 1.046 ± 0.208 ($p<0.01$). OR was considerably smaller in unruptured aneurysms than in hemorrhaging ones, and from a statistical point of view a highly significant difference between their values was found. OR is bigger in ACoA aneurysms then in others, but there is no statistically significant difference between them. An explanation for this could be found in the anatomical specificity of the anterior communicating segment and relatively frequent physiological variations.

The AR - aspect ratio presents the ratio of the highest level of the aneurysm and the diameter of its neck. According to Ujiie, AR is a better index than the geometric size of the aneurysm for assessment of intra-aneurysmal flow. It does not find unruptured aneurysms with AR <1. In unruptured aneurysms, AR is 90% smaller than 1.6, and with ruptured AR > 1.6 is present in 79% of the ACA, 58% MCA, 85% ACII and 81% in other locations (29). According to Taman and associates unruptured aneurysms with AR> 1.6 are under high risk of rupture in the near future from the moment of diagnosis (25). In the observed group of patients with ruptured aneurysms AR was $1.89 \pm 0{:}58$ and for unruptured 1.33 ± 0.17. AR value <1.5 was found in ruptured aneurysms in only 10.59%, while with unruptured it was found in 80.64%. A slightly higher percentage of ruptured aneurysms with a value were found by Beck in almost 21% (2). AR> 1.6 has a high predisposition to rupture (28,32). In this series of ruptured aneurysms AR> 1.6 was found in up to 84.71% and unruptured in only 9.68%. This indicates that AR is a good predictive factor for predisposing rupture (29). Blood flow is turbulent and may lead to cell migration of the muscular middle layer of the vessel wall, which activates the enzyme matrix metalloproteinase (MMPs) and other proteolytic enzymes causing the degeneration and thinning the wall of the aneurysm (10, 16, 28). AR over 2.0 indicates a predisposition to developing thrombosis because the blood flow in the aneurysm is much slower. Reynold's factor in the systolic phase in the region of the dome of the aneurysm is about 250, which is compatible with the diastolic phase (28, 32).

CONCLUSIONS

Relatively few studies in the last 10 -15 years have dealt with the morphometric analysis, i.e. analysis of the geometry of the aneurysm. The reason for this lies primarily in the insufficiency of diagnostic equipment in the past. With the development of the computer protocol and the angiography equipment, opportunities for development in this area have been created. Also, quite a number of previous morphometric analysis ignored the mounting parameters of the blood vessel (the angle of the blood flow, the shape of the vessel and its diameter at the level of separation of the aneurysm). These factors proved to be important regarding the hemodynamic features of intracranial aneurysms and their rupture. Based on the results of our study, the predictive model can be extracted concluding the morphometric characteristics of the vessel bearing the aneurysm to rupture: an irregular shape of the aneurysm, AR> 1.6, OR> 1.5 and an inclination angle of> 135°.

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