Clinical Neurology and Neurosurgery 186 (2019) 105506

Contents lists available at ScienceDirect

Clinical Neurology and Neurosurgery

journal homepage: www.elsevier.com/locate/clineuro

Treatment allocation of ruptured anterior communicating artery aneurysms: The influence of aneurysm morphology

Marvin Darkwah Oppong[a,*], Cornelius Deuschl[b], Daniela Pierscianek[a], Laurèl Rauschenbach[a], Mehdi Chihi[a], Alexander Radbruch[b], Philipp Dammann[a], Karsten H. Wrede[a], Neriman Özkan[a], Oliver Müller[a], Michael Forsting[b], Ulrich Sure[a], Ramazan Jabbarli[a]

[a] Department of Neurosurgery, University Hospital, University of Duisburg-Essen, Essen, Germany
[b] Institute for Diagnostic and Interventional Radiology, University Hospital, University of Duisburg-Essen, Essen, Germany

ARTICLE INFO

Keywords:
Aneurysm
Anterior communicating artery
Subarachnoid hemorrhage
Treatment allocation
Microsurgical clipping
Endovascular coiling

ABSTRACT

Objectives: Since publication of the ISAT study, the majority of neurovascular centers adhere to “coil first” policy for patients with subarachnoid hemorrhage (SAH). However, final allocation in favor of coiling or clipping is based on anatomic features of ruptured intracranial aneurysms with respect to clinical characteristics of SAH. In this study, we analyzed the parameters relevant for treatment allocation of ruptured anterior communicating artery aneurysms (AComAA).

Patients and methods: From our institutional SAH database, all cases with ruptured AComAA, which underwent diagnostic subtraction angiography (DSA) with subsequent treatment allocation, were included. The radiographic features of AComAA were collected from pre-treatment DSA. In addition, demographic, clinical and radiographic parameters of SAH were recorded. The variables selected through univariate analyses were subsequently evaluated using multivariate regression analysis.

Results: Of 300 SAH patients in the final analysis, the majority of the cases underwent endovascular coiling (n = 221, 73.7%). The following aneurysm features were associated with treatment modality in the univariate analysis: maximal sack size ($p = 0.034$), perpendicular height ($p = 0.007$), aspect ratio ($p < 0.001$) and sack/neck-ratio ($p = 0.001$). Accordingly, the following cutoffs for these variables were defined upon the receiver operating characteristics curves: 5 mm for sack size, 6 mm for perpendicular height, 1.6 for aspect ratio and sack/neck-ratio. In the multivariate analysis, aspect ratio of 1.6 was the only independent predictor of treatment allocation ($p = 0.005$; aOR = 2.57; 95% CI 1.33–4.96), which remained significant ($p = 0.003$; aOR = 2.77; 95% CI 1.41–5.45) after adjusting for patients’ age, WFNS & Fisher grades, as well as intracerebral hematoma volume.

Conclusion: Although not-routinely assessed during initial allocation treatment, our retrospective analysis proved that aspect ratio is a reliable predictor of treatment allocation of ruptured AComAA. Except for large space-occupying ICH commonly obligating the microsurgical treatment, other clinical and radiographic characteristics of SAH do not seem to be of clinical relevance for the selection of treatment modality.

1. Introduction

Since the publication of the ISAT [25], there has been a major paradigm shift towards endovascular treatment for intracranial aneurysms (IA) not located at the middle cerebral artery [21]. However, final treatment allocation in favor of clipping or coiling is the matter of an interdisciplinary consensus based on anatomic features of the ruptured IA with respect to radiographic/clinical/demographic characteristics of subarachnoid hemorrhage (SAH). The anterior communicating artery (AComA) is one of the most common sites not only for IA but also of rupture in case of SAH [25,28]. Improvement in endovascular treatment modalities and techniques made a greater amount of IA at this location suitable for endovascular treatment than during the early post-ISAT era or during the BRAT [27]. Nonetheless there still is a significant portion of AComA aneurysms (AComAA) that are considered as not suitable for this type of treatment.

In particular, small aneurysm size and low sack/neck ratio have been mentioned as radiographic parameters making IA less suitable for

* Corresponding author at: Department of Neurosurgery, University Hospital Essen, D-45147 Essen, Germany.
E-mail address: marvin.darkwahoppong@uk-essen.de (M. Darkwah Oppong).

https://doi.org/10.1016/j.clineuro.2019.105506
Received 22 June 2019; Received in revised form 19 August 2019; Accepted 30 August 2019
Available online 30 August 2019
0303-8467/

endovascular treatment [26,9]. Furthermore, clinical factors like patients´ age [9], presence of a large intracerebral hematoma (ICH) [26] or IA dome projection [30] have been mentioned as factors influencing treatment decision.

The aim of this study was to identify the factors relevant for treatment allocation of ruptured AComAA. Using a large monocentric post-ISAT SAH database, we evaluated the role of demographic, clinical and radiographic features of ruptured AComAA and SAH in the treatment decision, with special emphasis on anatomic characteristics of IA. In addition, we addressed the impact of the radiographic features of AComAA on the treatment success and functional outcome of SAH patients.

2. Material and methods

The study presents a retrospective analysis based on our institutional database containing all consecutive patients with aneurysmal SAH treated between January 2003 and June 2016. The cases with ruptured AcomAA, that underwent digital subtraction angiography (DSA) with subsequent treatment allocation were included into the final analysis. The study protocol was approved by the institutional ethic review board. All patients or their relatives gave written consent within the treatment contract before inclusion into the database.

2.1. Treatment protocol

SAH patients were treated according to the internal treatment protocol in accordance with the current SAH guidelines [10,34]. All patients were admitted to our neurosurgical intensive care unit and received Nimodipine oral or via gastric tube for 21 days after bleeding event. Transcranial Doppler ultrasound was performed for a minimum of 14 days after bleeding. Acute hydrocephalus was treated by placement of an external ventricular drainage (EVD).

On the basis of the existing evidence [25,24] and institutional policy, ruptured AComAA were referred for coiling, if they were considered eligible for endovascular treatment without stent placement. The final decision in favor of coiling or clipping was made upon interdisciplinary consensus between the vascular neurosurgeon and the interventional neuroradiologist on duty. SAH patients with space-occupying ICH necessitating urgent decompression surgery underwent direct microsurgical clipping after diagnostic work-up with computed tomography angiography (CTA). These cases were excluded from the final analysis.

2.2. Data management

Demographic and clinical parameters were taken from digital/analog patients' charts. Initial clinical severity was estimated utilizing the World Federation of Neurosurgical Societies (WFNS) grading system [35]. For statistical analysis, we dichotomized the WFNS grade into poor (WFNS grade 4–5) and good (WFNS grade 1–3) clinical condition.

Radiographic features of SAH were taken from the pretreatment CT imaging. Radiographic severity of SAH was judged according to the original Fisher scale [15] with further dichotomization into high (Fisher scale 3–4) and low (Fisher scale 1–2) radiographic severity. Presence of an ICH and intraventricular hemorrhage (IVH) was noted as well. Volume of the ICH was calculated using the a*b*c/2 method [19]. Severity of IVH was measured according to the original Graeb score [16].

Aneurysmal radiographic characteristics were extracted from pretreatment 2D-DSA imaging by the first author (MDO). This included maximal aneurysm sack diameter in millimeter (mm) and aneurysm neck size in mm. Perpendicular height in mm defined as maximum perpendicular distance from the aneurysm neck to the dome of the IA (Fig. 1). Upon these parameters, we calculated the sack-neck-ratio and the aspect ratio (perpendicular height divided by neck size). The morphology of the IA was defined as irregular in case of presence of

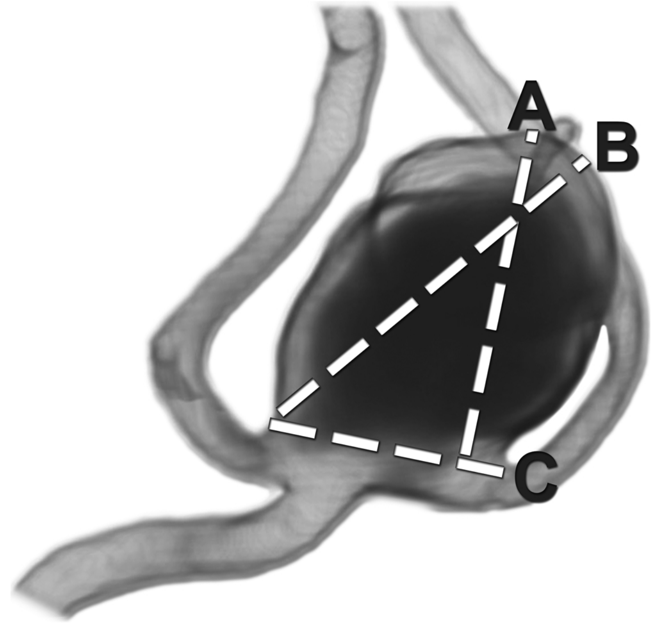

Fig. 1. Example of measurement of aneurysm dependent parameters on a DSA 3D reconstruction of an AComAA. A: Perpendicular height; B: Maximal aneurysm sack diameter; C: Neck diameter.
Abbreviations: AComAA Anterior communicating artery aneurysms; ; DSADigital substraction angiography

daughter aneurysm(s) (< 50% of IA size) or presence of more than one aneurysm lobe (> 50% of IA size). The direction of the aneurysm dome was divided into anterior and posterior projection (Fig. 2).

The diameter of the two A1 segments of the anterior cerebral artery was measured in mm just proximal to the cross section to the AComA. A1 segments were considered asymmetric, if the diameter of the smaller A1 segment was less than two-thirds of the diameter of the dominant side [23]. A1 segment not visible in the DSA was classified as aplastic. Furthermore, we calculated an A1/A1 ratio by dividing the diameter of the larger A1 segment by the lesser one as well as the difference between the two A1 diameters (in mm).

Success of treatment was judged separately for clipping and coiling cases:

Coiling cases were controlled with time of flight (TOF) and contrast enhanced (CE) magnetic resonance imaging (MRI) during initial hospitalization and after 6 month. Results were judged according to the grading system proposed by Raymond-Roy et al. [31]:

Grade 1: Complete obliteration
Grade 2: Residual neck
Grade 3: Residual aneurysm

For statistical analysis we dichotomized into adequate occlusion (grade 1 and 2) and inadequate occlusion (grade3). At 6 month MRI follow-up, any increase in the Raymond-Roy-gradation was judged as regrowth of the aneurysm.

Clipping cases were controlled with DSA during initial hospitalization. Results were judged using the grading system by Sindou et al. [33]:

Grade 1: Less than 50% of neck size remnant
Grade 2: More than 50% of neck size remnant
Grade 3: Residual lobe of multilobulated aneurysm
Grade 4: Residual sack that is less than 75% of original aneurysm size
Grade 5: Residual sack that is more than 75% of original aneurysm size.

All cases with grade 4 or 5 remnant were scheduled with direct retreatment, whereas al cases with grade 1–3 remnant were further followed up with DSA or CT angiography. Subsequently we

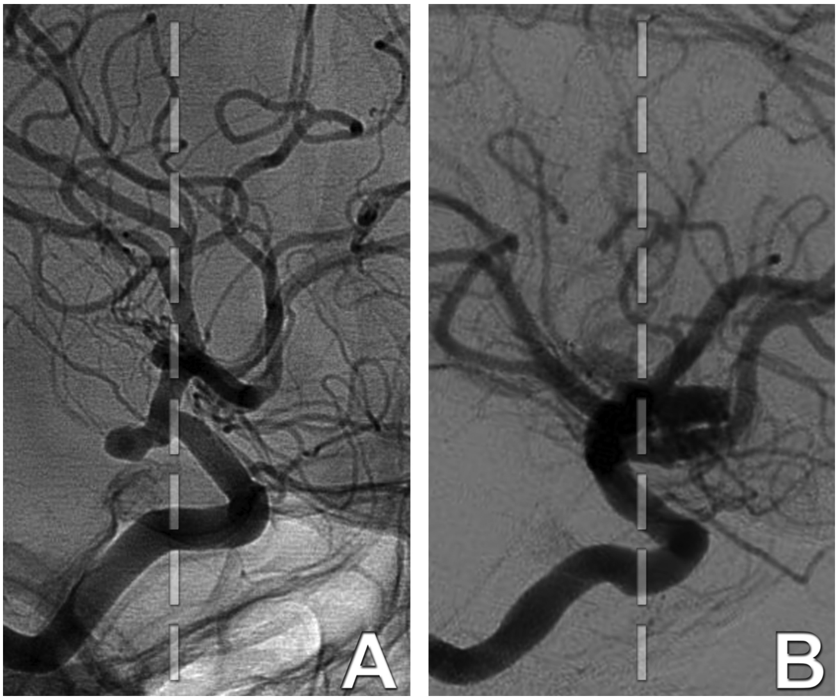

Fig. 2. Example of dome posterior (A) and anterior (B) projection of an AComAA in lateral view taken from DSA. For judgment of dome projection a line perpendicular to the anterior skull base was drawn through the aneurysm base (dashed line). Aneurysm dome projection anterior of this line were judged as 'anterior'. Subsequently, aneurysm dome projection posterior to this line was judged as 'posterior'.
Abbreviations: AComAA – Anterior communicating artery aneurysms; DSA – Digital substraction angiography

dichotomized into adequate occlusion (grade 1–3) and inadequate occlusion (grade 4–5).

Functional outcome was estimated using the modified Rankin scale [36] (mRs) at 6 month follow-up. mRS > 3 was defined as unfavorable outcome.

2.3. Statistical analysis

The impact of radiographic characteristics of AComAA on the treatment allocation was the ***primary endpoint*** of this study. In addition, the following ***secondary endpoints*** were also addressed: the association between the significant radiographic characteristics of AComAA with the completeness of aneurysm occlusion, aneurysm regrowth and functional outcome.

To address the primary endpoint, all demographic, clinical and radiographic parameters were analyzed in univariate manner, regarding their association with the treatment modality. For categorical variables, the chi-square test, or, if applicable, the Fisher exact test was used. For continuous variables, the Student's *t*-test was used for normally distributed and the Mann–Whitney U test for non-normally distributed data. Clinically relevant cutoffs were defined with receiver operating characteristic (ROC) curves. Significant parameters selected through univariate analysis were subsequently evaluated using multivariate regression analysis.

To address the secondary endpoints, a multivariate regression analysis adjusted for common outcome confounders (patients' age, clinical condition at admission and the severity of SAH) was also performed.

The data analysis was performed using Prism Version 7 for Windows (Graph Pad Inc., San Diego, California) and SPSS Version 22 for Windows (SPSS Inc., IBM, Armonk, New York). Continuous parameters are given in mean values ± standard deviation (SD). P-values < 0.05 were defined as significant. Missing data was managed using multiple imputation.

3. Results

Of 994 SAH patients in the database, 329 (33.1%) suffered from a ruptured AComAA. Twenty-nine cases were excluded because of no treatment (n = 13) or urgent microsurgical clipping and ICH evacuation upon CTA without further diagnostics with DSA (n = 16). Therefore, the remaining 300 SAH patients with AComAA represented the final cohort. The majority of the cases were allocated to treatment by coil embolization (221; 73.7%). Among these patients only 1 case (0.5%) was initial treated with stent associated coiling, no flow diverter were used in this series. The coiling rate during the first half of the observational period (January 2003 – September 2009) was 75.6% and in the second half (Oktober 2009 – June 2016) 71.3%. There was no significant difference regarding the coiling rate between these two observational periods (p = 0.431). 39.7% of the patients were in initial poor clinical condition and 84.5% had a high radiographic severity of SAH. Mean age of the cohort was 55 ± 13 years and more than half of the patients were female (55.7%). ICH was present in 29.3% of the cases and IVH in 51.3%. 74.3% of the patients underwent EVD placement due to acute hydrocephalus.

3.1. Univariate analysis of predictors of treatment allocation

Among all tested parameters (Table 1) the following variables could be identified as significant in univariate analysis: IAs selected for coil embolization were significantly larger (maximal sack size 6.47 ± 3.12 mm vs. 6.05 ± 3.79 mm; p = 0.034) and had a higher perpendicular height (6.66 ± 3.42 mm vs. 5.78 ± 3.49 mm p = 0.007). Furthermore, the values of aspect ratio (2.12 ± 0.91 vs. 1.68 ± 0.65; p < 0.001) and sack/neck-ratio (2.05 ± 0.85 vs. 1.73 ± 0.70; p = 0.001) were also higher in the coiling subgroup (Table 1). Accordingly, the following cutoffs for these variables were defined upon the ROC curves: 5 mm for sack size (AUC: 0.580), 6 mm for perpendicular height (AUC: 0.602), and 1.6 for both surrogate markers (AUC: 0.643 and 0.623 for aspect [supplements figure E1] and sack/neck-ratios respectively). There was no association between the demographic (age, sex, ethnicity), clinical (WFNS grade) and CT-based radiographic (Fisher grade, ICH presence and volume, IVH presence and severity) parameters of the patients and the selection of treatment modality.

Table 1
Univariate analysis of parameters influencing treatment allocation in case of ruptured AComAAs. Significant parameters are marked in bold.

Parameter	Microsurgical clipping	Endovascular treatment	p	OR	95% CI
	%/ mean ± SD	%/ mean ± SD			
Demographic parameters					
Age (years)	55 ± 13	56 ± 13	0.996	–	–
Gender female	53.2 %	56.6 %	0.601	0.87	0.52 - 1.46
Ethnicity Caucasian	92.5 %	94.1 %	0.597	0.77	0.28 - 2.09
SAH characteristics					
WFNS 4-5	38.0 %	40.3 %	0.789	0.91	0.54 - 1.54
Fisher 3-4 *	82.9 %	85.1 %	0.700	0.85	0.40 - 1.77
Acute Hydrocephalus	81.0%	71.9 %	0.134	1.66	0.88 - 3.14
IVH	58.9 %	48.6 %	0.147	1.52	0.90 - 2.56
Graeb score †	2.67 ± 3.43	2.63 ± 3.65	0.524	–	–
ICH	28.5 %	31.6 %	0.666	1.16	0.67 - 2.03
ICH volume (ml) ‡	11.80 ± 8.39	9.61 ± 11.11	0.098	–	–
IA morphology					
Sack size (mm)	6.05 ± 3.79	6.47 ± 3.12	**0.034**	–	–
Neck size (mm)	3.46 ± 1.49	3.27 ± 1.20	0.509	–	–
Perpendicular height (mm)	5.78 ± 3.49	6.66 ± 3.42	**0.007**	–	–
Sack-neck-ratio	1.73 ± 0.70	2.05 ± 0.85	**0.001**	–	–
Aspect ratio	1.68 ± 0.65	2.12 ± 0.91	< **0.001**	–	–
Anterior projection of IA dome	82.3 %	81.4 %	> 0.99	1.06	0.54 – 2.07
IA irregularity	54.4 %	57.0%	0.691	0.90	0.54 - 1.51
A1 characteristics					
A1-Assymetry	49.4 %	50.7 %	0.896	1.05	0.63 - 1.76
A1-Aplasie	13.9 %	11.3%	0.548	0.79	0.37 - 1.69
A1-Difference (mm)	0.97 ± 0.84	0.96 ± 0.90	0.828	–	–
A1-Ratio	1.95 ± 1.26	1.99 ± 1.31	0.636	–	–

*Data missing for 42 patients.
†Data missing for 20 patients.
‡Data missing for 8 patients.

3.2. Multivariate analysis of predictors of treatment allocation

Among the IA-related characteristics, an aspect ratio of ≥1.6 ($p = 0.005$; adjusted odds ratio [aOR] = 2.57; 95% confidence interval [95% CI] 1.33–4.96) was the only independent predictor of treatment allocation in favor of coiling. Sack size ≥ 5 mm ($p = 0.235$; aOR = 1.58; 95% CI 0.74–3.34), perpendicular height ≥6 mm ($p = 0.250$; aOR = 1.47; 95% CI 0.76–2.86) and sack-neck- ratio ≥1.6 ($p = 0.444$; aOR = 1.33; 95% CI 0.64–2.74) had no independent predictive value.

The strong association between the aspect -ratio and treatment allocation remained significant after adjusting for possible clinical and demographic confounders (patients´ age, WFNS and Fisher grades and ICH volume). In particular, the aspect ratio ≥1.6 was the sole independent predictor of treatment allocation in this enhanced multivariate analysis ($p = 0.003$; aOR = 2.77; 95% CI 1.41–5.45, Table 2).

3.3. Coiling and clipping rates in different aspect ratio subgroups

There were 108 (36%) AComAA with an aspect ratio < 1.6. Of them, 66 individuals were selected for endovascular treatment (61.1%, compared with 80.7% coiling rate among AComAA with the aspect ratio ≥1.6). For higher and lower values of the aspect ratio, the differences in the coiling-to-clipping rates were even stronger. So, only 48.8% (21/43) of the AComAAs with the aspect ratio ≤1.2 underwent endovascular treatment, while the cases with the aspect ratio ≥3.2 were mostly coiled (26/28, 92.8%; example aneurysm in supplements figure E2).

Table 2
Multivariate analysis of radiographic/clinical/demographic parameters regarding the influence on treatment allocation.

Parameter	p	aOR	95% CI
Sack size ≥ 5 mm	0.196	1.65	0.77 - 3.53
Sack-neck-ratio ≥ 1.6	0.472	1.31	0.63 - 2.70
Perpendicular height ≥ 6mm	0.184	0.63	0.32 - 1.25
Aspect ratio ≥ 1.6	**0.003**	2.77	1.41 - 5.45
Age (years)	0.634	0.99	0.98 - 1.02
WFNS 4-5	0.516	0.82	0.46 - 1.49
Fisher 3-4	0.931	0.97	0.44 - 2.12
ICH volume (ml)	0.252	1.02	0.98 - 1.06

3.4. Influence of aspect ratio < 1.6 on outcome and treatment success

In the coiling subgroup, the aspect ratio < 1.6 showed no impact on unfavorable outcome at 6 month follow-up could ($p = 0.285$), after correction for age ($p = 0.138$) poor initial clinical condition ($p < 0.001$; aOR = 9.00; 95% CI 4.26–19.03) and high Fisher grades ($p = 0.150$). This also accounted for adequate aneurysm occlusion ($p = 0.903$) and regrowth at 6 month follow-up ($p = 0.209$) after correction for aneurysm sack size (mm; $p = 0.10$; aOR = 0.84; 95% CI 0.74 – 0.96 and $p = 0.344$ respectively).

In the microsurgical clipping subgroup, there was also no influence of the aspect ratio < 1.6 on unfavorable outcome ($p = 0.502$), after correction for age ($p = 0.008$; aOR = 1.064; 95% CI 1.02–1.11), poor initial clinical condition ($p = 0.081$) and high Fisher grade ($p = 0.227$). Furthermore, there was no impact on adequate aneurysm occlusion ($p = 0.923$) after correction for aneurysm sack size (mm; $p = 0.540$) and intraoperative aneurysm rupture ($p = 0.720$) as well. No regrowth of aneurysm remnant occurred in this subgroup.

4. Discussion

The aim of this study was to identify the parameters that influence treatment allocation of ruptured AComAAs in a large institutional SAH cohort. Among the IA related radiographic parameters, only an aspect ratio of 1.6 showed an independent impact on treatment allocation. This was also the case after correction for potential clinical/radiographic/demographic confounders.

4.1. AComAA radiographic characteristics and their clinical value

Radiographic parameters of ruptured AComAA including sack and neck size, sack/neck ratio, perpendicular height, aspect ratio, IA irregularity as well as radiographic features of associated vessels as A1 diameter, asymmetry (or aplasia) have been extensively evaluated for their impact on AComAA growth and rupture [3,23,7,8,32,18,6]. Only a small portion of these anatomic IA characteristics have been addressed as potential confounders of treatment decision of ruptured AComAA.

4.2. Treatment allocation in case of ruptured AComAA

Since publication of the ISAT [25], there has been a major paradigm shift towards endovascular treatment of ruptured IA. This also accounts for AComAA, whereas the portion of endovascular treated AComAAs has further increased over time, most likely due to improvement of endovascular techniques [27]. At the same time, wide necked [26] or very small IA [17] were recognized as less suitable for endovascular approach, especially in the earlier post-ISAT time. Also in our cohort, AComAA with a small sack size and low sack/neck ratio were more likely to be treated using microsurgical clipping. However, our multivariate analysis identified aspect ratio as the sole predictor of treatment allocation (superior to other radiographic IA characteristics and SAH features). Additionally, dome projection has been proposed to be a factor that should be taken into consideration during treatment decision of AComAA [29]. Our data showed no influence of anterior projection of the IA dome on treatment allocation. Also, sub-analysis of the data regarding AComAAs in the BRAT and the subsequent post BRAT cases failed to prove the influence of this parameter on treatment decision [27]. In the BRAT study, further reasons for crossover from the endovascular treatment arm to the microsurgical treatment arm regarding AComAAs included large aneurysms in young patients and ICH that urged subsequent evacuation [26]. Our analysis failed to draw an independent association between treatment allocation and patients' age or ICH volume. Perhaps partly due to our study design. SAH cases with space-occupying ICH requiring urgent treatment due to clinical signs of brain-herniation were referred directly to clipping without preceding DSA and consideration for coiling.

To the best of our knowledge, the aspect ratio has not been analyzed regarding treatment allocation of ruptured AComAA. For unruptured IA, an aspect ratio > 1.6 has been identified as the only independent predictor of treatment decision in favor of coiling without additional endovascular techniques (implantable devices). In case of an aspect ratio < 1.2, additional techniques were almost ultimately necessary [4]. A low aspect ratio reflects two classic features of an aneurysm that makes it more difficult to coil. A larger neck, which increases the risk of coil protrusion and therefore thromboembolic complications as well as a smaller aneurysm height with less space to contain the coil mass. Utilization of additional techniques like flow diversion and stent assisted coiling have gained acceptance in the case of SAH [1]. These techniques come along some inconvenient, because of the need for dual antiplatelet therapy preceding and following the implantation of the device [14,37]. Especially in case of patients that need further surgical treatment like decompressive craniectomy or placement/revision of EVD, this could be connected with a higher bleeding risk and related morbidity [12,20,22,11]. A recent meta analysis of utilization of flow diversion in case of SAH showed that this treatment modality might achieve a good occlusion rate but still comes with a relevant complication rate [5]. Therefore, a treatment using microsurgical clipping might be considered as more suitable in cases with an aspect ratio < 1.6 if applicable. Flow diversion might be an option in cases where whether microsurgical clipping, nor endovascular coiling seem to be an adequate option. An even newer endovascular device is the Woven EndoBridge (WEB) [13]. Which was mainly designed to make more wide necked aneurysms suitable for endovascular treatment. One of the main advantages is that in case of sole use of the WEB there is no need for antiplatelet therapy. However, the available data so far mostly consists of mixed (ruptured and unruptured) series without controls. Most of these series do not report initial occlusion rates but only midterm occlusion rates [2]. This is an important point as especially in case of SAH the direct adequate aneurysm occlusion is one of the main goals to prevent rebleeding after therapy.

5. Limitations

The crucial issue of this retrospective analysis is the lower quality/completeness of data compared with prospective data storage. Furthermore, radiographic ratios have not been calculated in the setting of treatment allocation discussion but retrospectively. Even though, the imaging parameters even if not directly calculated before treatment seem to influence treatment decision. We think that this study presents a large dataset with so far unevaluated parameters regarding treatment allocation in case of ruptured AComAA.

6. Conclusion

Although not routinely assessed during initial allocation of treatment, our retrospective analysis confirmed aspect ratio as a reliable predictor of treatment allocation in favor of coiling of ruptured AComAAs. Except for large space-occupying ICH commonly obligating the microsurgical treatment, other clinical and radiographic characteristics of SAH and the ruptured AComAA do not seem to be of clinical relevance for the selection of treatment modality.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Declaration of Competing Interest

None.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.clineuro.2019.105506.

References

[1] P.S. Amenta, R.T. Dalyai, D. Kung, A. Toporowski, S. Chandela, D. Hasan, L.F. Gonzalez, A.S. Dumont, S.I. Tjoumakaris, R.H. Rosenwasser, M.G. Maltenfort, P.M. Jabbour, Stent-assisted coiling of wide-necked aneurysms in the setting of acute subarachnoid hemorrhage: experience in 65 patients, Neurosurgery 70 (2012) 1415–1429, https://doi.org/10.1227/NEU.0b013e318246a4b1 discussion 1429.

[2] S. Asnafi, A. Rouchaud, L. Pierot, W. Brinjikji, M.H. Murad, D.F. Kallmes, Efficacy and safety of the woven EndoBridge (WEB) device for the treatment of intracranial aneurysms: a systematic review and meta-analysis, AJNR Am. J. Neuroradiol. 37 (2016) 2287–2292, https://doi.org/10.3174/ajnr.A4900.

[3] P. Summers, P. Bijlenga, C. Ebeling, M. Jaegersberg, A. Rogers, A. Waterworth, J. Iavindrasana, J. Macho, V.M. Pereira, P. Bukovics, E. Vivas, M.C. Sturkenboom, J. Wright, C.M. Friedrich, A. Frangi, J. Byrne, K. Schaller, D. Rufenacht, Risk of rupture of small anterior communicating artery aneurysms is similar to posterior circulation aneurysms, Stroke 44 (2013) 3018–3026, https://doi.org/10.1161/strokeaha.113.001667.

[4] W. Brinjikji, H.J. Cloft, D.F. Kallmes, Difficult aneurysms for endovascular treatment: overwide or undertall? AJNR Am. J. Neuroradiol. 30 (2009) 1513–1517, https://doi.org/10.3174/ajnr.A1633.

[5] F. Cagnazzo, D.T. di Carlo, M. Cappucci, P.H. Lefevre, V. Costalat, P. Perrini, Acutely ruptured intracranial aneurysms treated with flow-diverter stents: a systematic review and meta-analysis, AJNR Am. J. Neuroradiol. 39 (2018) 1669–1675, https://doi.org/10.3174/ajnr.A5730.

[6] W. Cai, C. Hu, J. Gong, Q. Lan, Anterior communicating artery aneurysm morphology and the risk of rupture, World Neurosurg. 109 (2018) 119–126, https://doi.org/10.1016/j.wneu.2017.09.118.

[7] W. Cai, D. Shi, J. Gong, G. Chen, F. Qiao, X. Dou, H. Li, K. Lu, S. Yuan, C. Sun, Q. Lan, Are morphologic parameters actually correlated with the rupture status of

anterior communicating artery aneurysms? World Neurosurg. 84 (2015) 1278–1283, https://doi.org/10.1016/j.wneu.2015.05.060.
[8] J.H. Choi, K.I. Jo, K.H. Kim, P. Jeon, J.Y. Yeon, J.S. Kim, S.C. Hong, Morphological risk factors for the rupture of anterior communicating artery aneurysms: the significance of fenestration, Neuroradiology 58 (2016) 155–160, https://doi.org/10.1007/s00234-015-1610-9.
[9] J.H. Choi, M.J. Kang, J.T. Huh, Influence of clinical and anatomic features on treatment decisions for anterior communicating artery aneurysms, J. Korean Neurosurg. Soc. 50 (2011) 81–88, https://doi.org/10.3340/jkns.2011.50.2.81.
[10] E.S. Connolly Jr., A.A. Rabinstein, J.R. Carhuapoma, C.P. Derdeyn, J. Dion, R.T. Higashida, B.L. Hoh, C.J. Kirkness, A.M. Naidech, C.S. Ogilvy, A.B. Patel, B.G. Thompson, P. Vespa, Guidelines for the management of aneurysmal subarachnoid hemorrhage: a guideline for healthcare professionals from the American Heart Association/american Stroke Association, Stroke 43 (2012) 1711–1737, https://doi.org/10.1161/STR.0b013e3182587839.
[11] M. Darkwah Oppong, K. Buffen, D. Pierscianek, A. Herten, Y. Ahmadipour, P. Dammann, L. Rauschenbach, M. Forsting, U. Sure, R. Jabbarli, Secondary hemorrhagic complications in aneurysmal subarachnoid hemorrhage: when the impact hits hard, J. Neurosurg. (2019) 1–8, https://doi.org/10.3171/2018.9.jns182105.
[12] M. Kohrmann, M. Darkwah Oppong, O. Gembruch, D. Pierscianek, C. Kleinschnitz, C. Deuschl, C. Monninghoff, K. Kaier, M. Forsting, U. Sure, R. Jabbarli, Post-treatment antiplatelet therapy reduces risk for delayed cerebral ischemia due to aneurysmal subarachnoid hemorrhage, Neurosurgery (2018), https://doi.org/10.1093/neuros/nyy550.
[13] Y.H. Ding, D.A. Lewis, R. Kadirvel, D. Dai, D.F. Kallmes, The Woven EndoBridge: a new aneurysm occlusion device, AJNR Am. J. Neuroradiol. 32 (2011) 607–611, https://doi.org/10.3174/ajnr.A2399.
[14] S. Fischer, Z. Vajda, M. Aguilar Perez, E. Schmid, N. Hopf, H. Bazner, H. Henkes, Pipeline embolization device (PED) for neurovascular reconstruction: initial experience in the treatment of 101 intracranial aneurysms and dissections, Neuroradiology 54 (2012) 369–382, https://doi.org/10.1007/s00234-011-0948-x.
[15] C.M. Fisher, J.P. Kistler, J.M. Davis, Relation of cerebral vasospasm to subarachnoid hemorrhage visualized by computerized tomographic scanning, Neurosurgery 6 (1980) 1–9.
[16] D.A. Graeb, W.D. Robertson, J.S. Lapointe, R.A. Nugent, P.B. Harrison, Computed tomographic diagnosis of intraventricular hemorrhage, Etiol. Progn. Radiol. 143 (1982) 91–96, https://doi.org/10.1148/radiology.143.1.6977795.
[17] V. Gupta, M. Chugh, A.N. Jha, B.S. Walia, S. Vaishya, Coil embolization of very small (2 mm or smaller) berry aneurysms: feasibility and technical issues, AJNR Am. J. Neuroradiol. 30 (2009) 308–314, https://doi.org/10.3174/ajnr.A1374.
[18] M.C. Kim, S.K. Hwang, The rupture risk of aneurysm in the anterior communicating artery: a single center study, J. Cerebrovasc. Endovasc. Neurosurg. 19 (2017) 36–43, https://doi.org/10.7461/jcen.2017.19.1.36.
[19] R.U. Kothari, T. Brott, J.P. Broderick, W.G. Barsan, L.R. Sauerbeck, M. Zuccarello, J. Khoury, The ABCs of measuring intracerebral hemorrhage volumes, Stroke 27 (1996) 1304–1305.
[20] D.K. Kung, B.A. Policeni, A.W. Capuano, J.D. Rossen, P.M. Jabbour, J.C. Torner, M.A. Howard, D. Hasan, Risk of ventriculostomy-related hemorrhage in patients with acutely ruptured aneurysms treated using stent-assisted coiling, J. Neurosurg. 114 (2011) 1021–1027, https://doi.org/10.3171/2010.9.jns10445.
[21] N. Lin, K.S. Cahill, K.U. Frerichs, R.M. Friedlander, E.B. Claus, Treatment of ruptured and unruptured cerebral aneurysms in the USA: a paradigm shift, J. Neurointerv. Surg. 4 (2012) 182–189, https://doi.org/10.1136/jnis.2011.004978.
[22] K.B. Mahaney, N. Chalouhi, S. Viljoen, J. Smietana, D.K. Kung, P. Jabbour, K.R. Bulsara, M. Howard, D.M. Hasan, Risk of hemorrhagic complication associated with ventriculoperitoneal shunt placement in aneurysmal subarachnoid hemorrhage patients on dual antiplatelet therapy, J. Neurosurg. 119 (2013) 937–942, https://doi.org/10.3171/2013.5.jns122494.
[23] H. Matsukawa, A. Uemura, M. Fujii, M. Kamo, O. Takahashi, S. Sumiyoshi, Morphological and clinical risk factors for the rupture of anterior communicating artery aneurysms, J. Neurosurg. 118 (2013) 978–983, https://doi.org/10.3171/2012.11.jns121210.
[24] C.G. McDougall, R.F. Spetzler, J.M. Zabramski, S. Partovi, N.K. Hills, P. Nakaji, F.C. Albuquerque, The barrow ruptured aneurysm trial, J. Neurosurg. 116 (2012) 135–144, https://doi.org/10.3171/2011.8.jns101767.
[25] A. Molyneux, R. Kerr, I. Stratton, P. Sandercock, M. Clarke, J. Shrimpton, R. Holman, International Subarachnoid Aneurysm Trial (ISAT) of neurosurgical clipping versus endovascular coiling in 2143 patients with ruptured intracranial aneurysms: a randomised trial, Lancet 360 (2002) 1267–1274.
[26] K. Moon, M.R. Levitt, R.O. Almefty, P. Nakaji, F.C. Albuquerque, J.M. Zabramski, C.G. McDougall, R.F. Spetzler, Treatment of ruptured anterior communicating artery aneurysms: equipoise in the endovascular era? Neurosurgery 77 (2015) 566–571, https://doi.org/10.1227/neu.0000000000000878 discussion 571.
[27] K. Moon, M.S. Park, F.C. Albuquerque, M.R. Levitt, C.B. Mulholland, C.G. McDougall, Changing paradigms in the endovascular management of ruptured anterior communicating artery aneurysms, Neurosurgery 81 (2017) 581–584, https://doi.org/10.1093/neuros/nyw051.
[28] A. Morita, T. Kirino, K. Hashi, N. Aoki, S. Fukuhara, N. Hashimoto, T. Nakayama, M. Sakai, A. Teramoto, S. Tominari, T. Yoshimoto, The natural course of unruptured cerebral aneurysms in a Japanese cohort, N. Engl. J. Med. 366 (2012) 2474–2482, https://doi.org/10.1056/NEJMoa1113260.
[29] E. Nossek, A. Setton, R. Karimi, A.R. Dehdashti, D.J. Langer, D.J. Chalif, Analysis of superiorly projecting anterior communicating artery aneurysms: anatomy, techniques, and outcome. A proposed classification system, Neurosurg. Rev. 39 (2016) 225–235, https://doi.org/10.1007/s10143-015-0677-4 discussion 235.
[30] F. Proust, B. Debono, D. Hannequin, E. Gerardin, E. Clavier, O. Langlois, P. Freger, Treatment of anterior communicating artery aneurysms: complementary aspects of microsurgical and endovascular procedures, J. Neurosurg. 99 (2003) 3–14, https://doi.org/10.3171/jns.2003.99.1.0003.
[31] D. Roy, G. Milot, J. Raymond, Endovascular treatment of unruptured aneurysms, Stroke 32 (2001) 1998–2004, https://doi.org/10.1161/hs0901.095600.
[32] X. Shao, H. Wang, Y. Wang, T. Xu, Y. Huang, J. Wang, W. Chen, Y. Yang, B. Zhao, The effect of anterior projection of aneurysm dome on the rupture of anterior communicating artery aneurysms compared with posterior projection, Clin. Neurol. Neurosurg. 143 (2016) 99–103, https://doi.org/10.1016/j.clineuro.2016.02.023.
[33] M. Sindou, J.C. Acevedo, F. Turjman, Aneurysmal remnants after microsurgical clipping: classification and results from a prospective angiographic study (in a consecutive series of 305 operated intracranial aneurysms), Acta Neurochir. 140 (1998) 1153–1159.
[34] T. Steiner, S. Juvela, A. Unterberg, C. Jung, M. Forsting, G. Rinkel, European Stroke Organization guidelines for the management of intracranial aneurysms and subarachnoid haemorrhage, Cerebrovasc. Dis. 35 (2013) 93–112, https://doi.org/10.1159/000346087.
[35] G.M. Teasdale, C.G. Drake, W. Hunt, N. Kassell, K. Sano, B. Pertuiset, J.C. De Villiers, A universal subarachnoid hemorrhage scale: report of a committee of the World Federation of Neurosurgical Societies, J. Neurol. Neurosurg. Psychiatr. 51 (1457) (1988).
[36] J.C. van Swieten, P.J. Koudstaal, M.C. Visser, H.J. Schouten, J. van Gijn, Interobserver agreement for the assessment of handicap in stroke patients, Stroke 19 (1988) 604–607.
[37] C. Wang, X. Xie, C. You, C. Zhang, M. Cheng, M. He, H. Sun, B. Mao, Placement of covered stents for the treatment of direct carotid cavernous fistulas, AJNR Am. J. Neuroradiol. 30 (2009) 1342–1346, https://doi.org/10.3174/ajnr.A1583.