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ORIGINAL ARTICLE

Comparison of carotid and basilar bifurcation aneurysms versus non-T-angled bifurcations: the geometry is associated with the outcome

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Abstract

Patients with ruptured aneurysms of carotid bifurcation artery seem to suffer less often from cerebral vasospasm and early brain injury and have a better clinical outcome. Aim of our study was to identify differences in clinical course and outcome in aneurysms of terminus segments (carotid bifurcation artery and basilar tip) compared to aneurysms of other aneurysm locations except carotid bifurcation artery and basilar tip. Patients with SAH were entered into a prospectively collected database (1999 to June 2014). A total of 471 patients ('T-shaped' aneurysms $n = 63$, 'non-T-shaped' aneurysms $n = 408$) were selected. Outcome was assessed by modified Rankin Scale (mRS) 6 months after SAH. Mean age was 53.75 years. Statistically, analysis showed a significant better outcome in 'T-shaped' aneurysms ($p = 0.0001$) and a significant lower mortality rate ($p = 0.02$) despite higher rates of Fisher 3 bleeding pattern and CVS. In 'T-shaped' aneurysms, no prognostic factors for outcome could be detected. In 'non-T-shaped' aneurysms admission status ($p < 0.0001$), early hydrocephalus ($p < 0.0001$), shunt-dependence ($p = 0.001$), and the occurrence of severe CVS ($p = 0.01$) statistically were factors influencing patients' outcome. Multivariate analysis showed 'non-T-shaped' aneurysms itself as independent prognostic factor for patients' outcome. Despite same rate of poor admission status, early hydrocephalus and shunt dependence 'T-shaped' aneurysms have a highly significantly better. Pathophysiological mechanism actually is not understood. Further studies are necessary to identify, which factors lead to the decreased outcome in "non-T-shaped"- aneurysms.

Keywords Aneurysm location · Outcome · Prognostic factor · Subarachnoid hemorrhage · Geometry of carotid and basilar bifurcation aneurysms · 'T-shaped' aneurysms · 'non-T-shaped' aneurysms

Introduction

Already in 2014 Abla et al. [1] described that the location of a ruptured aneurysm minimally affects the maximum thickness of the subarachnoid hemorrhage (SAH) clot, but is predictive of symptomatic vasospasm or clinical deterioration from delayed cerebral ischemia like in pericallosal aneurysms. Ingebrigtsen et al. described in 2004 that the bifurcation geometry predicts the occurrence of a cerebral aneurysm, and identified different hemodynamic forces of the terminal segments of the basilar artery (BA), internal carotid artery (ICA) and middle cerebral artery (MCA) [2]. Furthermore, patients with so called 'T-shaped' ruptured aneurysms of carotid bifurcation artery seem to suffer less from cerebral vasospasm (CVS) and early brain injury (EBI) than other ('non-T-shaped') internal carotid artery aneurysms. Additionally, these patients had a better clinical outcome.

Also it is known, that smooth muscle cells are arranged helical, which will result not only in different hemodynamic forces [2], but also in different power transmission depending on the angle of enlarging vessels. Recently, Lilla et al. [3] presented that during an experimental SAH (endovascular filament model) an ultra-early contraction can be observed distinct later to the induced rupture and also distant to the

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ruptured vessels. This effect has direct and indirect effects to vessels and brain metabolism. Depending on helical structure and power transmission EBI, CVS and other, actually not known factors, could be different between 'T-shaped' and 'non-T-shaped' aneurysms depending on angle transmission differences.

Therefore, we compared ruptured aneurysms of 'non-T-shaped aneurysms' (aneurysms of middle cerebral artery, anterior cerebral artery, posterior communicating artery (PCom)), and 'T-shaped aneurysms' (aneurysms of carotid bifurcation artery and basilar tip) looking for differences, prognostic factors, and outcome in both patient groups.

Methods

Study population

The study was approved by the local ethics committee.

In our department between 1999 and June 2014, a total of 1588 were admitted with aneurysmal subarachnoid hemorrhage (SAH). All these patients were entered into a prospectively conducted database (IBM SPSS ®, Armonk, NY). Due to almost exclusively coiling in basilar tip aneurysms, only endovascular-treated patients were selected to avoid a treatment bias. Based on AP (anterior-posterior) and lateral views of the DSA (digital subtraction angiography), an experienced neuroradiologist (ST) retrospectively selected all patients suffering from SAH out of a 'T-shaped' (aneurysm of carotid bifurcation artery and basilar tip) and 'non-T-shaped' aneurysms (aneurysms of middle cerebral artery, anterior cerebral artery). Aneurysms, which are projecting medially (some cases with P1- deficiency) or laterally (A1- deficiency) were excluded from analysis. From these patients, we retrospectively selected all patients suffering from SAH out of a 'T-shaped' (aneurysm of carotid bifurcation artery and basilar tip) and 'non-T-shaped' aneurysms (other aneurysm locations except carotid bifurcation artery and basilar tip (e.g., aneurysms of middle cerebral artery, anterior cerebral artery, posterior communicating artery)). All patients were admitted to intensive care unit (ICU). All patients initially received a DSA and after interdisciplinary consensus aneurysm treatment [4, 5]. Cerebral vasospasms (CVS) were identified by clinical observation and in conscious patients with transcranial duplex (TCD), followed by further diagnostic imaging via computed tomographic angiography (CTA) and magnetic resonance angiography (MRA). CVS was treated until a reversal of CVS was confirmed by imaging. All patients received nimodipine from the beginning of admission (60 mg 6×/24 h). Furthermore, in case of an early hydrocephalus, insertion of an extern ventricular drainage (EVD) followed. Outcome was assessed by modified Rankin Scale (mRS) 6 months after SAH.

Statistical analysis

Statistically, analyses were performed with commercially available software (IBM SPSS ®Inc. 22, Armonk, NY). Categorical variables were analyzed using the Fisher exact test and the unpaired *t* test for parametric values. Multivariate analysis and binary regression analysis were performed. Factors included were patient age, WFNS grade, Fisher grade at time of admission, modified Rankin Scale (mRS) 6 months after SAH, the occurrence of an early hydrocephalus and aneurysm location. Probability values < 0.05 were considered statistically significant.

Results

Patients' characteristics

A total of 471 patients were included to this study with a mean age of 53.7 ± 13.7 years. Sixty-three patients suffered from SAH out of a ruptured 'T-shaped' aneurysm. In 408 patients, cause of SAH was the rupture of a 'non-T-shaped' aneurysm. Detailed patient characteristics are shown in Table 1.

Two hundred ninety-nine patients (63.5%) showed a good admission status, quantified by initial WFNS-grades I–III (World Federation of Neurological Surgeons). In 279 patients (59.2%), the application of an external ventricular drainage (EVD) was necessary because of an existing early hydrocephalus. Ninety-seven patients (20.6%) received a ventricular peritoneal shunt (VP shunt) (see Table 1).

Outcome characteristics

Overall, 318 patients (67.5%) achieved favorable outcome 6 months after aneurysmal SAH (mRS 0–2) (details see Table 2). Significant prognostic factors for a favorable outcome were the admission status, early hydrocephalus, the occurrence of severe CVS, delayed neurological deficit (DND), Fisher 3-bleeding pattern, and a later shunt dependence. Furthermore, intracerebral hemorrhage (ICH) statistically showed an influence on patients' outcome. Patients' sex had no influence on outcome (details see Table 2).

Subgroup analysis of 'T-shaped' aneurysms

In this actual study, 56 patients (88.9%) with 'T-shaped' aneurysms showed favorable clinical outcome six months after subarachnoid hemorrhage. Only seven patients (11.1%) achieved an unfavorable outcome. Only two patients (3.2%) of this subgroup died. In statistical analysis, due to the low number of events, no prognostic factors for an unfavorable outcome could be detected. Details are shown in Table 3.

Table 1 Patient characteristics

Patient characteristics	All patients	'non-T-shaped' (other than basilar tip and carotid bifurcation)	'T-shaped' (basilar tip and carotid bifurcation)	p value	OR (95% Cl)
Number of patients	471	408 (86.6)	63 (13.4)		
Mean age (years)	53.7 ± 13.7	54.1 ± 13.8	51.3 ± 12.9		
Female sex	323 (68.6)	277 (67.9)	46 (73)	NS (0.5)	
Good admission status (WFNS grades I–III)	299 (63.5)	258 (63.2)	41 (65.1)	NS (0.8)	
Early hydrocephalus	279 (59.2)	241 (59.1)	38 (60.3)	NS (0.9)	
Shunt dependence	97 (20.6)	84 (20.6)	13 (20.6)	NS (1)	
Fisher grade 3	340 (72.2)	293 (71.8)	47 (74.6)	NS (0.7)	
Severe CVS	88 (18.7)	72 (17.6)	16 (25.4)	NS (0.5)	
Favorable outcome (mRS 0–2)	318 (67.5)	262 (64.2)	56 (88.9)	0.0001	0.22 (0.11–0.48)
Death	57 (12.1)	55 (13.5)	2 (3.2)	0.02	4.75 (1.28–17.61)

Subgroup analysis of 'non-T-shaped' aneurysms

64.2% of all included patients with 'non-T-shaped' aneurysms showed a favorable outcome and 13.5% of affected patients in this subgroup died. Significant prognostic factors for patients with 'non-T-shaped' aneurysms were poor admission status early hydrocephalus, shunt dependence, severe CVS, and Fisher 3 bleeding pattern. Details are shown in Table 4.

Comparison of 'T-shaped' and 'non-T-shaped' aneurysms

Admission status in both groups showed no significant difference (NS 0.8), just as rate of early hydrocephalus and shunt dependence in comparison of both patient groups. In 'T-shaped' aneurysms, we identified a tendency (but not significant) to a higher rate of Fisher grade 3 bleeding (74.6% vs. 71.8%) and CVS (17.6% vs. 25.4%) (details are listed in Table 1). However, despite these known negative prognostic factors (higher rate of Fisher 3 bleeding pattern and CVS), the outcome was significantly better in the 'T-shaped' group compared to the 'non-T-shaped' group. So, in 'T-shaped' aneurysms, 88.9% of included patients showed a favorable outcome compared to 64.2% in patients with 'non-T-shaped' aneurysms ($p = 0.0001$). Furthermore, 'non-T-shaped' aneurysms showed a significant higher mortality rate compared to 'T-shaped' aneurysms ($p = 0.02$) (details s. Table 1). Both 'T-shaped' groups showed better outcome in subgroup analysis than 'non-T-shaped' aneurysms. Furthermore, carotid-T and basilar tip aneurysms showed similar favorable outcome (see suppl.Table 1).

Multivariate analysis

Multivariate analysis showed as independent prognostic factors for an unfavorable outcome a poor admission status ($p < 0.0001$), early hydrocephalus ($p = 0.02$), and severe CVS ($p = 0.04$). Additionally, 'non-T-shaped' aneurysms

Table 2 Outcome and prognostic factors for all included patient

				Univariate analysis		Multivariate analysis	
Patient characteristics	Total number	Favorable outcome	Unfavorable outcome	p value	OR (95% Cl)	p value	OR (95% Cl)
Number of patients	471	318 (67.5)	153 (32.5)				
Mean age (years)	53.7 ± 13.7	51.6 ± 12.6	58.2 ± 14.8				
Female sex	323 (68.6)	217 (68.2)	106 (69.3)	NS (0.8)			
Poor admission status (WFNS grades IV–V)	172 (36.5)	70 (22)	102 (66.7)	< 0.0001	7.08 (4.71–10.65)	< 0.0001	5.34 (3.26–8.75)
Early hydrocephalus	279 (59.2)	155 (48.7)	124 (81)	< 0.0001	4.49 (2.84–7.12)	0.02	1.89 (1.09–3.25)
Shunt dependence	97 (20.6)	52 (16.4)	45 (19.4)	0.001	2.13 (1.35–3.37)	NS (0.5)	
Fisher grade 3	340 (72.2)	217 (68.2)	123 (80.4)	0.006	1.91 (1.20–3.04	NS (0.7)	
ICH	61 (12.9)	24 (7.5)	37 (24)	< 0.0001	3.71 (2.24–6.82)	NS (0.7)	
Severe CVS	88 (16.6)	43 (13.5)	45 (29.4)	< 0.001	2.66 (1.66–4.28)	0.04	2.29 (1.31–4.03)
'non-T-shaped' aneurysms	408 (86.6)	262 (64.2)	146 (35.8)	0.0001	4.46 (1.98–10.03)	< 0.0001	6.03 (2.46–14.75)

Table 3 Outcome and prognostic factors in 'T-shaped' aneurysms

Patient characteristics	Total number	Favorable outcome	Unfavorable outcome	*p* value	OR (95% Cl)
Number of patients	63 (13.4)	56 (88.9)	7 (11.1)		
Mean age (years)	51.3 ± 12.9	50.2 ± 12.2	59.9 ± 15.7		
Female sex	46 (73)	40 (71.4)	6 (85.7)	NS (0.7)	
Poor admission status (WFNS grades IV–V)	22 (34.9)	18 (32.1)	4 (57.1)	NS (0.2)	
Early hydrocephalus	38 (60.3)	33 (58.9)	5 (71.4)	NS (0.7)	
Shunt dependence	13 (20.6)	11 (19.6)	2 (28.6)	NS (0.6)	
Fisher grade 3	47 (74.6)	40 (71.4)	7 (100)	NS (0.2)	
Severe CVS	16 (25.4)	14 (25)	2 (28.6)	NS (1)	

itself were an independent negative prognostic factor for patients' outcome ($p < 0.0001$). Details are shown in Table 2.

Discussion

A recently presented study showed a better outcome in patients with ruptured aneurysms of carotid bifurcation artery in contrast to other carotid artery aneurysms. Pathophysiological mechanisms explaining these results are still unknown. Furthermore, one result of the above mentioned study described a lower incidence of an early hydrocephalus as a possible indicator for an early brain injury (EBI).

Outcome characteristics in all included patients

We identified worse admission status (WFNS grade), high Fisher grade bleeding pattern, occurrence of severe CVS, and an existing early hydrocephalus as significant prognostic factors for poor outcome. Abla et al. [1] identified an aneurysm site specific risk developing severe CVS and DND. Despite a higher risk of CVS in our analysis, the aneurysm configuration ('T-shaped') showed a better outcome. Until now, the pathophysiology is not clearly understood. Westermaier et al. [6] described in 2009 in an experimental study on early vessel constriction even after minor SAH, which can lead to focal or global perfusion deficits. This fact can be reinforced by additional factors like hydrocephalus, hypoventilation, or hypotension. Recently, Lilla et al. [3] presented that during an experimental SAH (endovascular filament model), an ultra-early contraction can be observed distinct later to the induced rupture and distant to the ruptured vessels. This vasoconstriction has direct and indirect effects to the vessels and brain metabolism and can also lead to a so called 'memory' for later CVS. Depending on helical structure and angle power, the transmission is different. EBI, and other actually not known factors, could be different between 'T-shaped' and 'non-T-shaped' (less than 90° angle) aneurysms. Additionally, an concomitant early hydrocephalus still is said to be an indicator for EBI [7].

The admission status is highly associated with patients' outcome, as well as Fisher 3 bleeding pattern, an early hydrocephalus, and shunt dependence. Comparing data in our patient groups, still, there had been no significant difference concerning the rate of patients with a good admission status ('T-shaped' aneurysms 65.1% vs. 'non-T-shaped' aneurysms 63.2%) but outcome in 'T-shaped' aneurysms was significant better. Also, in our examined and compared patient groups, there had been no significant difference concerning the occurrence of an early hydrocephalus and shunt dependence, but still outcome in 'T-shaped' aneurysms is better. Moreover, patients with 'T-shaped' aneurysms showed a higher rate (but not significant, but still a tendency) of CVS and Fisher 3 bleeding pattern, but outcome in this patient group is still better.

Table 4 Outcome and prognostic factors in 'non-T-shaped' aneurysms

Patient characteristics	Total number	Favorable outcome	Unfavorable outcome	*p* value	OR (95% Cl)
Number of patients	408 (86.6)	262 (64.2)	146 (35.8)		
Mean age (years)	54.1 ± 13.8	51.9 ± 12.7	58.1 ± 14.8		
Female sex	277 (67.9)	177 (67.6)	100 (68.5)	NS (0.9)	
Poor admission status (WFNS grades IV–V)	150 (36.8)	52 (19.9)	98 (67.1)	< 0.0001	8.24 (5.3–12.7)
Early hydrocephalus	241 (59.1)	122 (46.6)	119 (81.5)	< 0.0001	5.06 (3.1–8.2)
Shunt dependence	84 (20.6)	41 (15.6)	43 (29.5)	0.001	2.25 (1.4–3.7)
Fisher grade 3	293 (71.8)	177 (67.6)	116 (79.5)	0.01	1.86 (1.1–2.9)
Severe CVS	72 (17.6)	29 (11.1)	43 (29.4)	0.01	3.35 (1.9–5.7

Comparison of 'T-shaped' and 'non-T-shaped' aneurysms

In 'non-T-shaped' aneurysms, the 'typical' prognostic factors were identified: admission status, occurrence of an early hydrocephalus and later shunt dependence, Fisher grade 3 bleeding in CCT, and at least occurrence of severe CVS. However, statistical analysis showed no significant prognostic factors in ruptured 'T-shaped' aneurysms, maybe due to the small number of patients and a high rate of favorable outcome. Cause for the significant better outcome in this special patient group is still unclear, but is consistent with further studies. Maybe, these results have a correlation to EBI or other pathophysiological mechanisms like perfusion deficits at ictus [3], but these mechanisms are still not completely known and are contents of several experimental researches. Ingebrigtsen et al. [2] indicated in a study published in 2004 that depending on branch angles, different hemodynamic forces can be measured. So, different hemodynamic changes may be a possible cause for better outcome in 'T-shaped' aneurysms.

Also, it is known that smooth muscle cells are arranged helical, which will result in different power transmission depending on the angle of enlarging vessels [8, 9]. Earlier, Walmsley et al. [8, 9] described that smooth muscle orientation differ in different locations of Circulus arteriosus of Willis, which may play a role in hemodynamic forces or occurrence of CVS- but this is unknown actually.

In conclusion, despite higher rates of Fisher 3 bleeding pattern and CVS 'T-shaped' aneurysms statistically have a better clinical outcome. There may be several possible theories explaining the actual and previously shown results [1], but actual only assumptions can be made. However, further studies are necessary to identify possible pathophysiological mechanisms after SAH influencing the outcome as a basis for a better understanding of pathophysiological changes.

Limitations and generalizability

The study has several limitations. It is a retrospective, single center statistical analysis, but data were collected prospectively. Because of the retrospective design, there are the typical restrictions, such as the lack of data not documented initially in the medical records. To avoid a treatment bias (due the low number of clipped basilar aneurysms) a 'positive' selection bias was used. Another limitation of this study is, despite the high number of treated patients with SAH (n = 1588), the only small number of 'T-shaped' aneurysms (n = 63). So, further studies are necessary to re-evaluate these results.

Conclusion

Despite same rate of poor admission status, early hydrocephalus and shunt dependence 'T-shaped' aneurysms have a highly significantly better outcome. Additionally, 'non-T-shaped' aneurysms itself seems to be an independent risk factor for an unfavorable outcome. However, the pathophysiological mechanism is actually not understood and needs further (experimental/translational) evaluation.

Contributorship statement NB, ST, WS collected and analyzed the data. NB, MB and JK performed statistically analysis. NB drafted the manuscript. JK, ST, JB, CS, and VS contributed to critical revision of the manuscript for important intellectual content. VS critically supervised the manuscript. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest JB: Consulting fee or honorarium: proctor for WEB, Sequent Medical and member of the scientific advisory board of Acandis. There is a permanent scientific cooperation between Siemens Healthcare AG and the Institute of Neuroradiology and travel expenses for presentation of projects are covered by the company. The other authors have no personal, financial, or institutional interest. All other authors declare that they have no competing interests.

Ethical approval Approval for the retrospective study was obtained from the local ethic committee.

Informed consent For this type of study (retrospective study) formal consent is not required.

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