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The Importance of Aneurysm Morphology and Perianeurysmal Environment in Aneurysmal Subdural Hematomas

Anevrizmal Subdural Hematomlarda Anevrizma Morfolojisi ve Perianevrizmal Ortamın Önemi

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ABSTRACT

Aim: Aneurysmal subdural hematoma (anSDH) is an uncommon condition associated with significant mortality risk. This study focused on the relationship between morphology and the perianeurysmal environment by comparing aneurysm location and clinical outcomes.
Material and Methods: A total of 486 patients with aneurysmal subarachnoid hemorrhage were retrospectively analyzed for accompanying subdural hematoma (SDH) cases. Demographic information, rebleeding, discharge, and 6 months of the modified Rankin scale scores (favorable and unfavorable) were recorded. The aneurysms were divided into 3 groups: internal carotid artery (ICA), anterior cerebral artery (ACA), and middle cerebral artery (MCA). Other parameters included aneurysm morphology, SDH width, intracerebral hematoma (ICH) volume, the presence of intraventricular hematoma, and distance to the subdural space.
Results: Concomitant SDH was detected in 19 (3.9%) patients. Aneurysms were located in the ICA, 10 (52.6%); MCA, 8 (42.1%); and ACA, one (5.3%). The mean size was 9.5±4.3 mm, and there was a significant difference in aneurysm size between the ICA and MCA (p=0.025). In six supraclinoid aneurysms (posterior communicating and anterior choroidal arteries), the aneurysm dome was in the inferior lateral projection. No significant differences were observed between patients with favorable and unfavorable modified Rankin scale in terms of clinical and aneurysm morphological characteristics, except for increased ICH volume (p=0.020) and shift effects (p=0.030).
Conclusion: The size and dome projection of ICA supraclinoid segment aneurysms may be important risk factors for SDH. We also believe that aneurysm localization may have a limited impact on clinical outcomes in the context of SDH.
Keywords: Subdural hematoma; aneurysm morphology; perianeurysmal environment.

ÖZ

Amaç: Nadir rastlanan anevrizmal subdural hematom (anSDH) oldukça yüksek mortaliteye sahiptir. Bu çalışma anevrizma yerleşimi ve klinik sonuçları karşılaştırılarak morfoloji ve perianevrizmal ortam arasındaki ilişkiye odaklanmıştır.
Gereç ve Yöntemler: Anevrizmal subaraknoid kanaması olan toplam 486 hasta, eşlik eden subdural hematom (SDH) olguları açısından retrospektif olarak analiz edildi. Demografik bilgiler, tekrar kanama, taburculuk ve 6 aylık modifiye Rankin skalası (olumlu ve olumsuz) kaydedildi. Anevrizmalar 3 gruba ayrıldı: internal karotid arter (internal carotid artery, ICA), anterior serebral arter (anterior cerebral artery, ACA), ve orta serebral arter (middle cerebral artery, MCA). Diğer parametreler arasında anevrizma morfolojisi, SDH genişliği, intraserebral hematom (intracerebral hematoma, ICH) hacmi, intraventriküler hematom varlığı ve subdural boşluğa olan mesafe yer aldı.
Bulgular: Eşlik eden SDH 19 (%3,9) hastada tespit edildi. Anevrizmaların 10'u (%52,6) ICA, 8'i (%42,1) MCA ve biri (%5,3) ACA'da yerleşmişti. Ortalama boyut 9,5±4,3 mm idi ve ICA ile MCA arasında anevrizma boyutu açısından anlamlı bir fark vardı (p=0,025). Altı supraklinoid anevrizmada (posterior komünikan ve anterior koroidal arterler) anevrizma kubbesi inferior lateral projeksiyonda idi. Modifiye Rankin skalasına göre olumlu ve olumsuz değerlendirilen hastalar arasında artmış ICH hacmi (p=0,020) ve orta hat kayma etkisi (p=0,030) dışında klinik ve anevrizma morfolojik özellikleri açısından anlamlı bir fark gözlenmedi.
Sonuç: ICA supraklinoid segment anevrizmalarının boyutu ve kubbe projeksiyonu SDH için önemli risk faktörleri olabilir. Ayrıca, anevrizma lokalizasyonunun SDH bağlamında klinik sonuçlar üzerinde sınırlı bir etkiye sahip olabileceğine inanıyoruz.
Anahtar kelimeler: Subdural hematom; anevrizma morfolojisi; perianevrizmal ortam.

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INTRODUCTION

While intracranial aneurysm rupture is associated with subarachnoid hemorrhage (SAH), subdural hematoma (SDH) usually occurs because of trauma and anticoagulant use. Aneurysmal subdural hematoma (anSDH) is a rare condition that usually occurs due to the rupture of a posterior communicating artery (PComA) aneurysm (35-41%) (1-3). These cases are associated with poor clinical outcomes, with a mortality rate of 70% (4).

Aneurysms develop in the subarachnoid spaces bounded by the arachnoid space, bones, brain parenchyma, and dura. The subarachnoid space forms the center of the perianeurysmal environment (PAE) and is associated with aneurysm growth and rupture (5-7). It is logical to associate PAE with additional bleeding such as intracerebral hematoma (ICH), intraventricular hematoma (IVH), and SDH after rupture.

Neurovascular imaging is necessary to determine the source of bleeding and treatment plans for SDH (8). Computed tomography (CT) angiography is a minimally invasive method that provides clinicians with rapid and precise morphological information for easy access. This is the first study to determine the diagnosis and treatment of aneurysms in most patients (9).

Studies of anSDH have mostly focused on the mechanisms of its formation, management, and prognosis. Studies on aneurysm morphology and PAE are rare. In this article, we present a series of patients with SDH components in addition to SAH after aneurysm rupture. We focused on aneurysm morphology and its relationship with PAE by comparing aneurysm locations and clinical outcomes. In doing so, we aimed to highlight the critical features that may pose a risk of anSDH and affect the clinical outcomes of patients with unruptured aneurysms.

MATERIAL AND METHODS

Medical records, surgical videos, and reports of 486 patients with aneurysmal SAH treated at our institution were retrospectively analyzed to detect and assess the development of any accompanying SDH. The inclusion criterion was an age of >18 years. The exclusion criteria were isolated falcine or tentorial SDH, poor image quality, the presence of bleeding diathesis, and a history of anticoagulant use. Medical records were reviewed, and the following data were collected: demographic information, World Federation of Neurosurgical Societies (WFNS) grade, rebleeding, treatment methods, discharge, and modified Rankin Scale (mRS) score at the sixth month.

We evaluated SDH size, midline shift (MLS), the presence of ICH and IVH, and aneurysm features (morphological and PAE) on CT and CT angiography, which are frequently used to determine the diagnosis and treatment. ICH was diagnosed based on CT scans at admission, and the ICH volume was calculated using the formula, A×B×C/2 (10). All intraparenchymal hemorrhages ≥10 ml were defined as ICH (11). Aneurysms were categorized into three groups based on their location: internal carotid artery (ICA) including ophthalmic artery, anterior choroidal artery (AChoA), and PComA, middle cerebral artery (MCA), and anterior cerebral artery (ACA). The cross-sectional width of the aneurysmal sac at its widest point was measured as aneurysm size. Aneurysms were classified into three morphological types: irregular, bleb, and lobulated. The other morphological parameters assessed were multiplicity and thrombosis. Measurements were obtained using DCOM format with 2D and 3D software (version V4.4EU; Synapse 3D Fujifilm Medical Systems, USA), which can be used on a personal computer.

The PAE was visualized using 3D CT angiography. Based on the aneurysm shape and projection, the relationships (distance to the subdural space and overlap) with the brain parenchyma, dura, and bone structures were examined.

The choice of treatment (surgery or endovascular) was determined after a multidisciplinary evaluation, considering the general medical and neurological status, the presence of a mass effect due to SDH or ICH, and aneurysm morphology. Clinical status at discharge and at 6 months was categorized as favorable (mRS 0-3) or unfavorable (mRS 4-6) outcomes. Patients were divided into two groups based on aneurysm location (MCA and ICA) and clinical outcomes (favorable and unfavorable). ACA aneurysms were excluded from the comparative statistical evaluation because there was only one. MCA and ICA groups were compared for clinical and morphological parameters to assess the risk of AnSDH. The study was conducted following the guidelines and was approved by the ethics committee of Bursa Yüksek İhtisas Training and Research Hospital (11.08.2021, 2021/08-17).

Statistical Analysis

For statistical analysis, JASP (0.16.1) and Jamovi (2.2.5.0, The JAMOVI Project, Sydney, Australia, 2022) were used. Continuous data with normal distribution were presented with mean and standard deviation, while continuous variables without normal distribution were reported with median, minimum, and maximum values for descriptive statistics Categorical variables were displayed as numbers and percentages. For normality, Shapiro-Wilk, Kolmogorov-Smirnov, and Anderson-Darling tests were used. Pearson's chi-square and Fisher's exact tests were used to compare the two category components, while RxC tables were analyzed with the Fisher-Freeman-Halton test. To compare two groups with normally distributed numerical variables, an independent sample t-test was employed. The Mann-Whitney U test was used to compare the two groups with non-normally distributed variables. The statistical significance level was set at $p<0.05$.

RESULTS

AnSDH was detected in 19 (3.9%) patients. The mean age of the patients was 64.2±11.4 years, and 14 (73.7%) were >60 years old. Ten (52.6%) of the patients were female. The mean WFNS score at presentation was 3.7±0.9, the same at the time of intervention. Ten (52.6%) aneurysms were located in the ICA (seven PComA, two ophthalmic, and one AChoA), eight (42.1%) in the MCA, and one (5.3%) in the ACA. The initial mean maximal SDH thickness was 9.7±5.9 mm, and the mean MLS was 8.4±5.9 mm. The mean MLS due to an MCA aneurysm was 12.8±2.9 mm, significantly different from an ICA aneurysm (p=0.012). SDH occurred on the right side in ten (52.6%) patients, on the left side in eight (42.1%), and bilaterally in one (5.3%). All patients presented with Fisher grade 4 SAH, of them 17 (89.5%) had ICH. All patients with MCA aneurysm rupture-induced SDH had ICH, with a median volume of

46.1 (range, 36-84) ml, the median volume of the ICA aneurysms was 18 (range, 8-44) ml. ICH volumes due to MCA aneurysm rupture were significantly higher (p=0.020). IVH was observed in four (21.1%) patients (Table 1).

While the shortest distance between the MCA aneurysm and subdural space was <10 mm, the mean distance between the ICA aneurysm and subdural space was 2.6±2.9 mm. Six (75%) aneurysms, except for two MCA aneurysms, were found to be directed towards the brain parenchyma. Four (50%) projections of MCA aneurysms were temporal, two (25%) were frontal, and two (25%) were sylvians. While eight (80%) ICA aneurysms overlapped with the brain parenchyma, both ophthalmic artery aneurysms were associated with both the parenchyma and the subdural space. It was observed that the projections of six (60%) ICA aneurysms were lateral, two (20%) were anterosuperior, and two (20%) were posterolateral. It was observed that the projection of 75% of supraclinoid aneurysms (PComA and AChoA) was in an inf-lateral direction. Rebleeding was observed in two patients (10.5%).

The mean aneurysm size was 9.5±4.3 mm, and there was a statistically significant difference in the sizes of the ICA and MCA aneurysms (p=0.025). Eight (42.1%) aneurysms were ≥10 mm in size and mostly ICA aneurysms. While seven (36.8%) aneurysms had an irregular shape, six (31.6%) had blebs, and six (31.6%) were lobulated. Multiplicity and thrombosed aneurysms were present in three (15.8%). Sixteen (84.2%) patients underwent aneurysm clipping, and three (15.8%) underwent endovascular coiling.

The mRS values at discharge and 6 months were the same, and nine (47.4%) patients had favorable outcomes. The mortality rate was 42.1% (n=8). The factors affecting the clinical outcomes were ICH volume (p=0.020) and shift effects (p=0.030). No other clinical or aneurysm morphological features showed a statistically significant difference between the patients with favorable and unfavorable outcomes. The most important factor affecting clinical outcomes was the WFNS score (p=0.010).

DISCUSSION

Risk factors for anSDH include old age, sentinel headache before SAH, PComA aneurysm, and ICH on the initial CT (4,12). SDH occurs in approximately 0.5-7.9% of anSAHs (13). This was similar to the rate observed in the present study (approximately 3.8%). In our study, 73.7% of the patients were aged 60 years and older. 36.8% of the study participants had a PComA aneurysm and the rate of ICH on the initial CT scan was 89.5%. Our findings support those of previous studies on the possible risk factors. However, most previous investigations did not include additional data regarding the relationship between specific aneurysm morphology and PAE.

Bleeding into the subdural space, either directly or via the subarachnoid space, is the most frequently discussed theory on the mechanism of SDH development (14). Therefore, PAE

Table 1. Patient characteristics

No	Age	Gender	WFNS	Location	Subdural Size (mm)	Shift (mm)	IVH	ICH	mRS	mRS (6 months)	Aneurysm Size (mm)	Death	Morphology	Multiplicity	Thrombosed	Re-bleed	Treatment	Subdural Dis. (mm)	Projection
1	55	M	5	MCA	6	14	N	Y	UF	UF	9	Y	Irregular	N	N	N	Clips	≥10	Frontal
2	89	F	5	ICA-OphtA	19	10	N	Y	UF	UF	16	Y	Lobulated	N	Y	Y	Clips	0	Inf-lateral
3	61	F	4	MCA	9	16	Y	Y	UF	UF	15	N	Irregular	N	N	N	Clips	≥10	Temporal
4	75	F	2	ICA-PComA	4	0	N	N	F	F	5	N	Blep	N	N	N	Coil	2.7	Inf-lateral
5	62	M	2	ACA-PComA	5	3	N	Y	F	F	6	N	Irregular	Y	N	N	Clips	3.7	Anterior
6	41	F	3	MCA	8	10	Y	Y	F	F	7	N	Lobulated	N	N	N	Clips	≥10	Temporal
7	67	M	4	MCA-ETB	4	14	N	Y	F	F	6	N	Irregular	N	N	N	Clips	≥10	Frontal
8	59	M	4	MCA	3	16	Y	Y	UF	UF	4	Y	Blep	N	N	N	Clips	≥10	Temporal
9	70	M	3	ICA-OphtA	11	6	N	Y	F	F	13	N	Lobulated	N	N	N	Clips	0	Anterior
10	60	M	5	ICA-PComA	13	0	N	Y	UF	UF	12	Y	Irregular	N	Y	N	Clips	1.8	Inf-lateral
11	48	M	3	ICA-PComA	7	0	N	Y	F	UF	10	N	Irregular	Y	N	N	Clips	3.8	Inf-lateral
12	55	F	4	ICA-PComA	16	11	Y	Y	UF	UF	7	N	Blep	N	N	N	Clips	4	Inf-posteric
13	60	M	4	MCA	20	14	N	Y	UF	UF	5	Y	Lobulated	N	N	N	Clips	≥10	Sylviyan
14	65	F	3	ICA-PComA	3	0	N	Y	F	F	4	N	Lobulated	N	N	N	Coil	3	Inf-lateral
15	68	F	5	MCA	12	11	N	N	UF	UF	5	Y	Blep	N	N	Y	Clips	≥10	Temporal
16	63	F	4	ICA-AChoA	11	6	N	N	F	F	14	N	Blep	N	N	N	Clips	2	Inf-lateral
17	74	M	3	ICA-PComA	10	4	N	N	F	F	13	N	Blep	N	N	N	Coil	4.8	Inf-posteric
18	63	F	4	MCA	5	8	N	Y	UF	UF	9	Y	Lobulated	Y	N	N	Clips	≥10	Frontal
19	85	F	4	ICA-PComA	22	17	N	N	UF	UF	17	Y	Irregular	N	Y	N	Clips	1.5	Inf-lateral

WFNS: World Federation of Neurosurgical Societies, IVH: intraventricular hematoma, ICH: intracerebral hematoma, mRS: modified Rankin Scale, Dis: distance, M: male, F: female, MCA: middle cerebral artery, ICA: internal carotid artery, ACA: anterior cerebral artery, OphtA: ophthalmic artery, PComA: posterior communicating artery, AChoA: anterior choroidal artery, ETB: early temporal branch, Y: yes, N: no, F: favorable, UF: unfavorable can be considered the primary factor in the development of anSDH. As the aneurysm dome grows, dense adhesions develop with the arachnoid membrane, causing the basal cistern to fuse almost completely with the wall of the aneurysm. Especially in ICA aneurysms, when this adherent dome protrudes towards the skull base dura (bleb or lobule), the PAE-subdural space distance decreases (Figure 1). To date, aneurysm size has not been reported as a risk factor for anSDH (4,12,14,15). Our findings showed that ICA aneurysms were significantly larger than MCA aneurysms. Additionally, 70% of ICA aneurysms were 10 mm or larger in size. Another striking finding was that the projection of six (75%) of the eight ICA-supraclinoid aneurysms was inferolateral (Figure 2). The distance of these aneurysms to the nearest dural anatomical structures (anterior clinoid process) was 2.6 (range, 0-4.8) mm. In our study, the distance between all MCA aneurysms and the subdural space was greater than 10 mm. The mean length of the ICA-supraclinoid segment was 14.8±3.0 mm (16). In fact, it was reported that this length was shorter in the presence of a PComA aneurysm (17). If these segment aneurysms tend towards the petroclinoid area in the subdural space, where the ICA passes, and reach large sizes, this naturally increases the risk of acute SDH. Considering these close anatomical connections at the skull base, our findings suggest that medium-large (10 mm and above) and inferior lateral projection ICA-supraclinoid segment aneurysms are potential risk factors for the development of anSDH.

Another hypothesis on the etiology of anSDH is the leakage of a large amount of blood from the parenchyma into the subdural space through tears in the parenchyma and arachnoid membrane (14). Aneurysms surrounded by brain tissue, such as MCA aneurysms (Figure 3), are associated with a high risk of ICH (12). Spontaneous ICH is defined as bleeding with a volume of 25-30 mL (18). No specific volume has been defined for SAH with ICH as it is associated with widespread subarachnoid clots and edema that can affect cerebral circulation. The presence of an accompanying SDH complicates the situation. In our study, ICH was observed in 89.5% of the patients with SDH. In previous studies, the association between anSDH and ICH has ranged from 27% to 63% (4,19). The high rate observed in our study may be attributable to the inclusion of all hematomas measuring ≥10 ml as ICH. However, we believe that ICH is frequently observed after aggressive aneurysmal rupture, extending into the subdural space.

Another remarkable finding was that, although ICH volumes and MLS were significantly higher in the MCA group than in the ICA group, there was no significant difference in the clinical results. We believe that the fact that the accompanying hematoma in SDH cases did not have a significant effect on clinical outcomes despite increasing volumes may be due to altered vascular circulation and impaired cerebral perfusion after SAH. Consistent with previous studies (4,12,19), the most important factor affecting clinical outcomes in our study

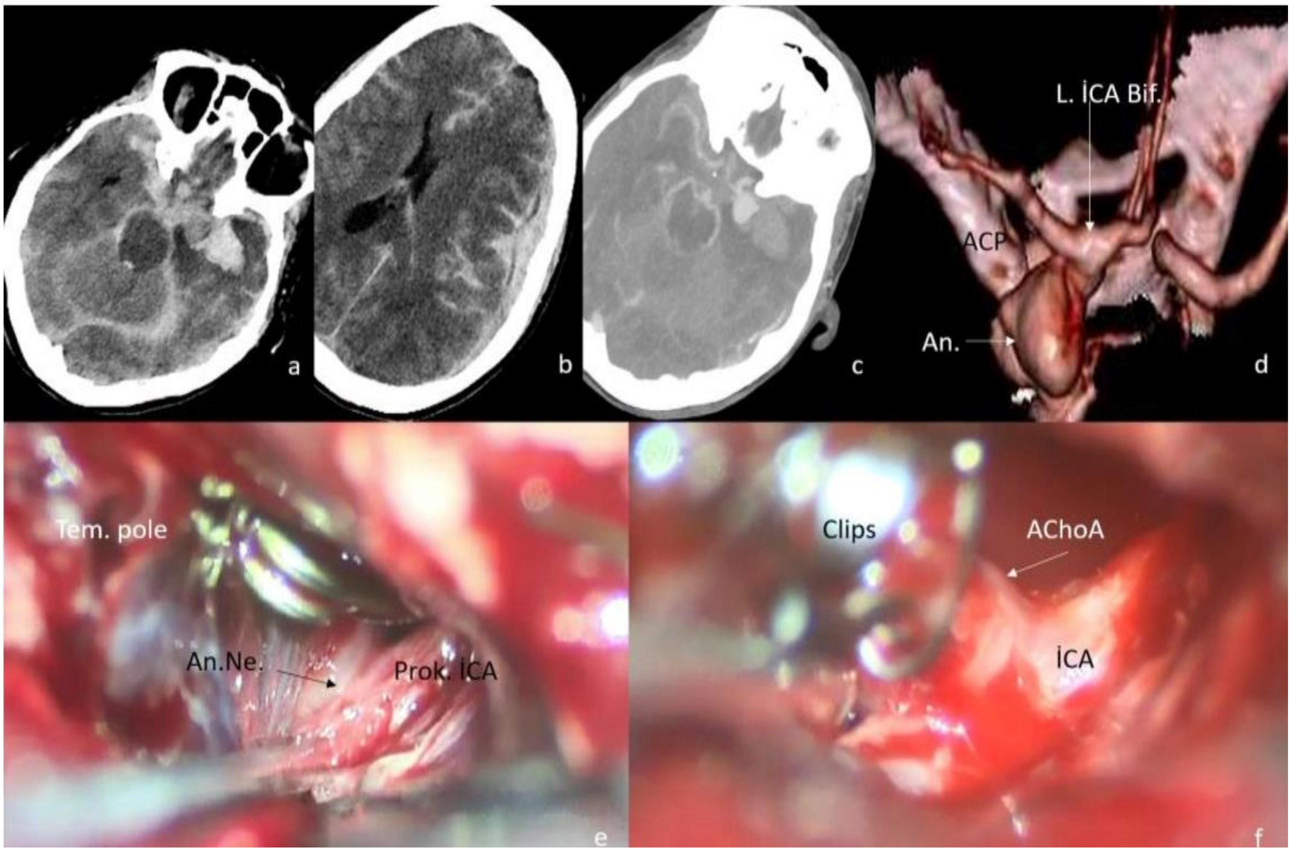

Figure 1. a,b) Initial computed tomography (CT) scan showing diffuse subarachnoid hemorrhage, left temporal intracerebral hematoma, and subdural hematoma in the convexity, **c,d)** On CT angiography, a 14-mm saccular aneurysm was observed in the anterior choroidal artery(AChoA) extending to the anterior fossa dura, **e,f)** After emergency surgery, drainage of the hematoma and subdural hematoma, and temporary clipping, the AChoA aneurysm is clipped (patient number, 16)

L. ICA Bif: left internal carotid artery bifurcation, ACP: anterior clinoid process, An: aneurysm, An.Ne: Aneurysm neck, Tem: temporal, Pro: proximal

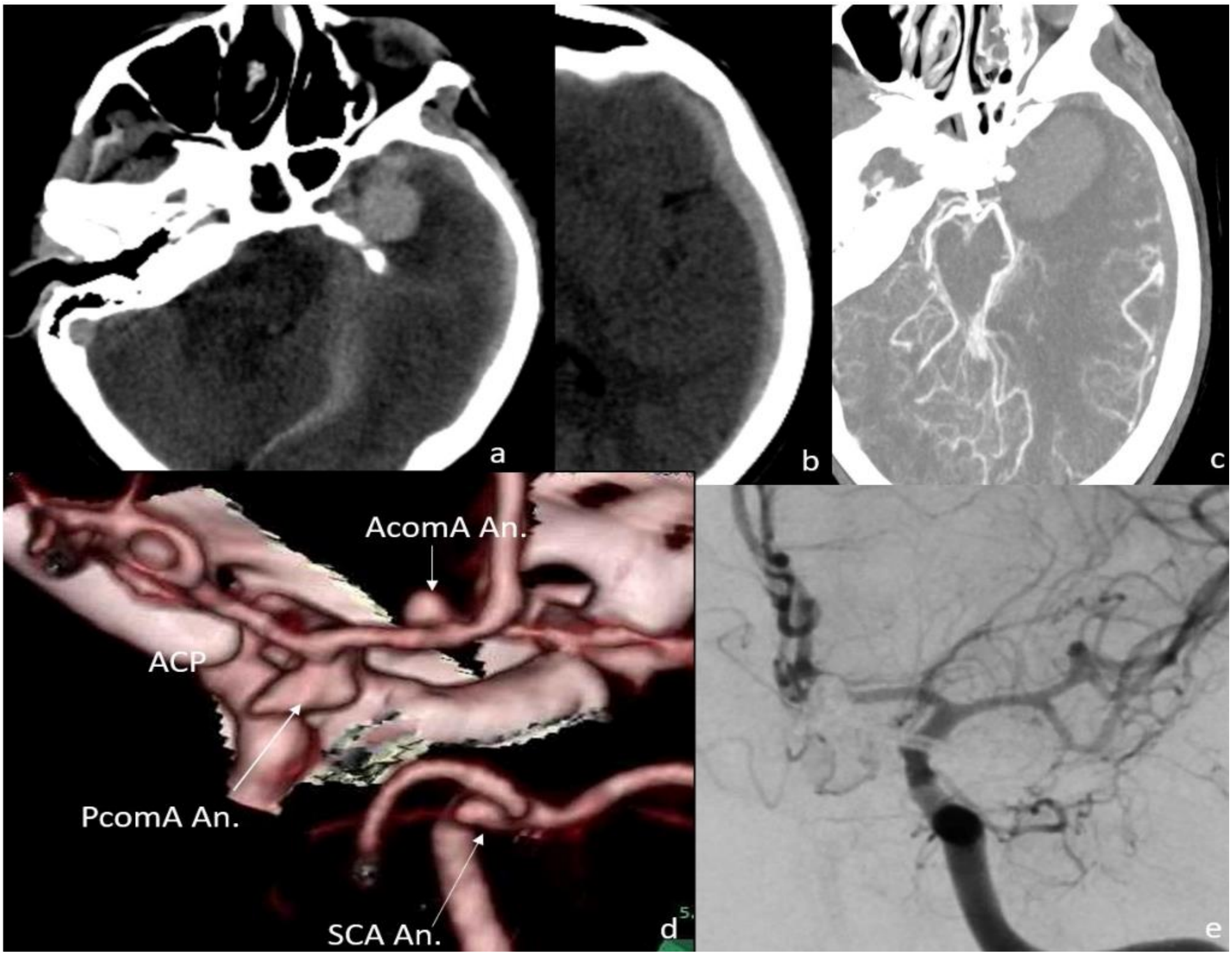

Figure 2. a,b) Computed tomography (CT) showing diffuse subarachnoid hemorrhage, intracerebral hematoma starting from the left temporal pole and extending to the convexity, and subdural hematoma, **c,d)** CT angiography revealed saccular aneurysms in the inferior laterally oriented posterior communicating artery (PComA), superior cerebellar artery (SCA), and anterior communicating artery (AComA), considering that the PComA aneurysm was bleeding, consistent with a hematoma, emergency surgery was performed, clip ligation of PComA and AComA aneurysms was performed in the same session, **e)** postoperative digital subtraction angiography image (patient number, 11)
ACP: anterior clinoid process, An: aneurysm

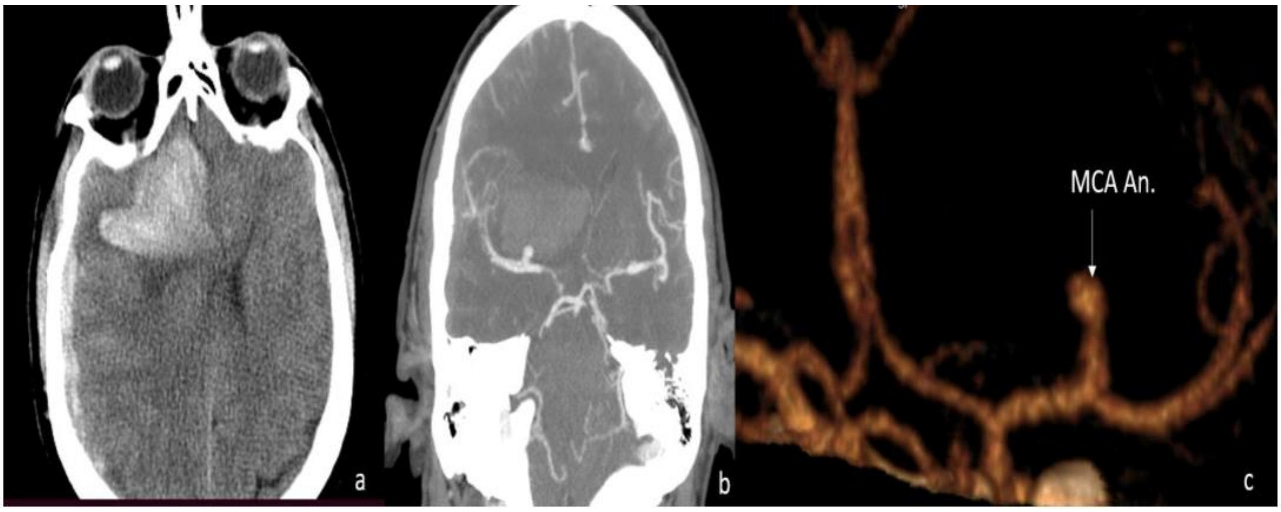

Figure 3. a) right temporal intracerebral hematoma (ICH) and subdural hematoma (SDH) were observed on computed tomography (CT), **b,c)** a right middle cerebral artery early branch aneurysm is detected on CT angiography, emergency surgery was performed by clip ligation and SDH-ICH drainage, (patient number, 7)
MCA: middle cerebral artery, An: aneurysm

was the WFNS score. In addition, aneurysm morphology and localization did not significantly affect clinical results. Although the results of our study are important, additional research with a larger sample size is required.

This study has several limitations. The small sample size limited subgroup analysis, hence, some therapeutically relevant findings may not have been statistically significant. 3D neuroimaging provided extensive information on aneurysm morphology, but a high-resolution MRI is needed to determine the link between aneurysms and their surroundings. Future studies should evaluate the relationship between aneurysm morphology and arachnoid membrane and dura, especially in patients with and without supraclinoid anSDHs.

CONCLUSION

The relationship between aneurysm morphology and PAE in the etiology of anSDH is clear, and the size and dome projection of ICA aneurysms, particularly supraclinoid ICA aneurysms, may be an additional risk factor. The findings of our study may also help determine the prognosis of unruptured supraclinoid aneurysms. Furthermore, our study showed that the specific localization of aneurysms and concomitant bleeding (IVH and ICH) did not significantly affect the clinical outcomes of anSDH.

Ethics Committee Approval: The study was approved by the Ethics Committee of Bursa Yüksek İhtisas Training and Research Hospital (11.08.2021, 2021/08-17).

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