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Determination of the Variations in the Circle of Willis by CT Angiography

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Abstract

We aimed to study the incidence and distribution spectrum of the variations in the circle of Willis, non-invasively by CT angiography, and also to see if these variations differ according to gender and age.

Material and Methods: *This study was carried out in 50 patients with various diagnoses such as intracranial tumour (IT), cerebrovascular ischemia (CVI), intracerebral hematoma (IH), ventricular hemorrhage (VH), subdural hematoma (SDH) and hydrocephalus (H). In all patients, CT angiography was done to investigate the variations in the circle of Willis.*

Results: *18 of the patients were admitted with CVI,15 with IT,7 with IH, and 4 with VH. subdural hematoma (SDH) in 4, and hydrocephalus (H) in 2. 17 patients had bilateral aplastic posterior communicating artery (PCoA),3 had bilateral PCoA hypoplasia, 2 had bilateral fetal type posterior cerebral artery (PCA),4 had left P1 aplasia, 7 had right P1 aplasia,4 had right P1 hypoplasia,5 had right A1 aplasia,6 had right A1 hypoplasia, 4 had left A1 aplasia,4 had left A1 hypoplasia, 9 had right and 6 had left PCoA aplasia, 3 had left PCoA hypoplasia, 6 had ACoA aplasia,1 had azygos A2 and 1 had fenestration at ACoA.2 patients were reported as normal. In this study, the percentage of the variations was determined according to age, gender, and diagnosis, but no statistical difference was obtained among the groups.*

Conclusssion: *The variations of the circle of Willis were seen in 96 % of the patients with various pathologies in our study. This means the variations of the circle of Willis is seen frequently and change the collateral flow in various pathologies which may influence the healing process differently, among the patients with the same pathologies.*

Keywords: CT Angiography, Variation, Circle of Willis

1. Introduction

The Circle of Willis was described by Thomas Willis in 1664. Some researchers have described its general morphological pattern and variations [1]. The key route for blood flow in ischemic conditions is collateral circulation within the Circle of Willis. For patients with severe carotid artery stenosis or obstruction, blood recirculation through cerebral collateral routes improves perfusion and may prevent ischemic events. Several collateral routes redistribute blood to under-supplied areas during internal carotid artery (ICA) obstruction. The main components of the Circle of Willis—the anterior communicating artery (ACoA) and bilateral posterior communicating arteries (PcoA)—act as primary collaterals. Secondary collaterals include reverse blood flow from the ophthalmic artery, anterior choroidal artery, and anastomoses among cortical branches of intracerebral arteries (leptomeningeal collaterals). These provide retrograde blood flow to areas in need. The collateral potential of the Circle of Willis in emergencies depends on the presence and size of the ACoA and PCoAs, which can differ among individuals. Recent studies using transcranial USG, DSA, and MRA have shown that the Circle of Willis plays a vital role in collateral blood flow when the ICA is obstructed. Given the clinical importance of variations and sizes of Circle of Willis components, recording the incidence of these variations in a normal population is valuable. This study aimed to define the detection rate of variations in the Circle of Willis using CT angiography, a non-invasive method. It also describes the spectrum of variations and differences across age groups and genders. The data from this study may serve as a reference for future CT angiography research on the Circle of Willis. The Circle of Willis is a polygon formed by connected arteries. It is located in the ventral surface of the diencephalon [2]. Bilateral ICAs, ACAs, ACoA, and its branches are called the anterior circulation and basilar bifurcation. PCAs and PCoA are called the posterior circulation. Arteries of the circle of Willis are.

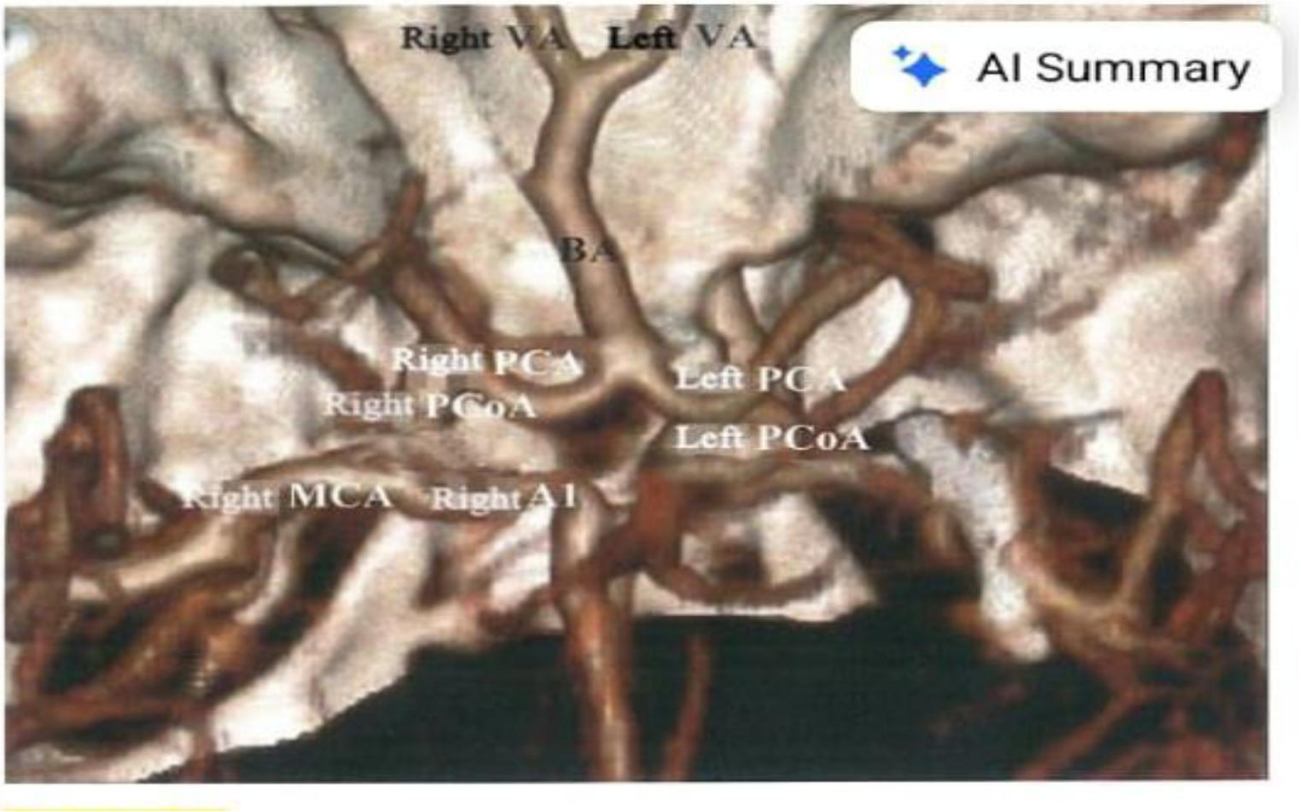

Figure 1: Azygos A2 Variation

- Bilateral ICAs
- Horizontal segments (A1) of both ACAs
- Anterior communicating artery (ACoA)
- Bilateral PCoAs
- Segments (P1) of bilateral PCAs
- Basilar artery

2. Materials and Methods

Firstly, we applied to our ethics committee. We have ethics board approval. Then we perform a study. This study included 50 patients who were admitted to N.E. University Meram Medical Faculty Neurosurgery Department with a diagnosed intracranial mass, hydrocephalus, ventricular hemorrhage, cerebrovascular event, intracerebral hematoma, subdural hemorrhage other than traumatic or spontaneous subarachnoid bleeding. Patient ages ranged from 11 to 87. 29 of the patients were female, and 21 were male. The patients underwent CT angiography, and the variations of the circle of Willis were investigated. The patients were informed before the imaging, and consents were obtained. Those with kidney function disorder (creatinine >1,5 mg/dl) and liver function disorder (SGOT>40 ıu/l, SGPT>40 ıu/l) were excluded.

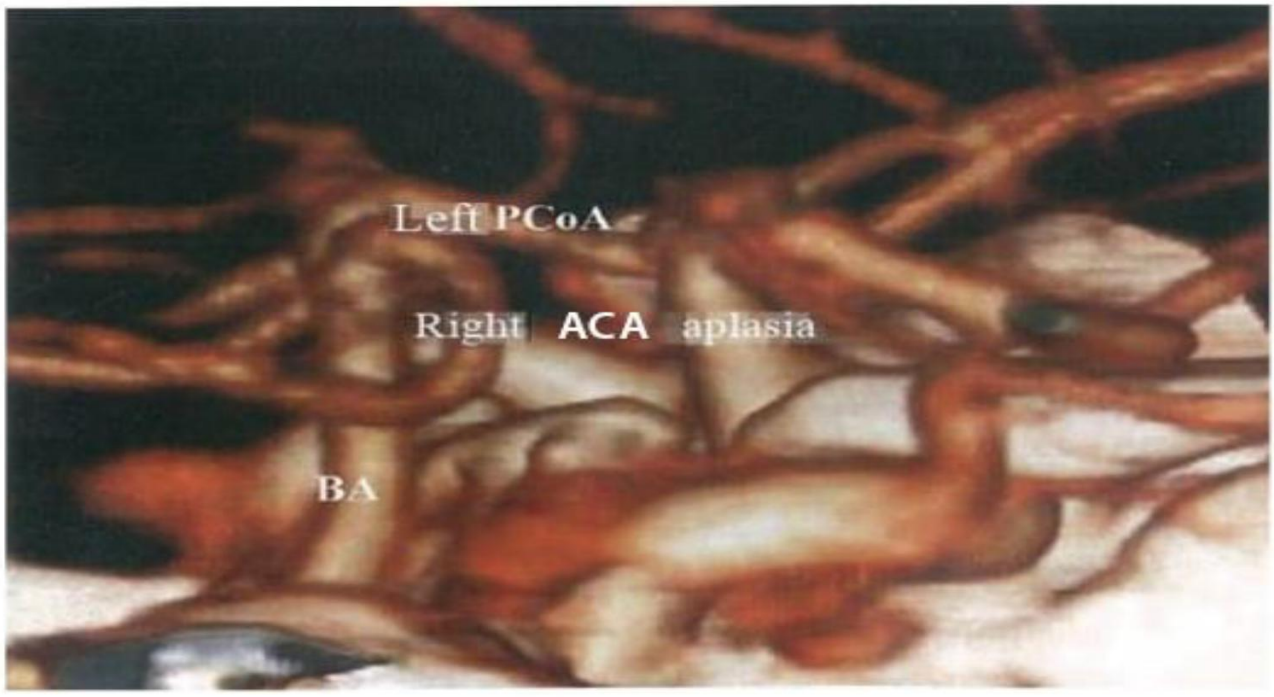

Figure 2: Right Anterior Cerebral Artery Aplasia

CT angiography was performed via Somatom Sensation 64 (Siemens, Forchheim, Germany). In the supine position, the head of the patient was placed into the craniocap and immobilized. 20 20-G cannula was placed into the median cubital vein. An automatic injector including 100 cc of non-ionic contrast agent and an IV cannula was connected via a connector. Once the cranial topography was obtained, an area of 3 cm was scanned, starting with the basis of the sella, parallel to the orbitomeatal plane, and an area with an anteroposterior diameter of approximately 15 cm was scanned with the sella in the midplane. The borders of the scanned area were determined angiographically based on vascular localization.

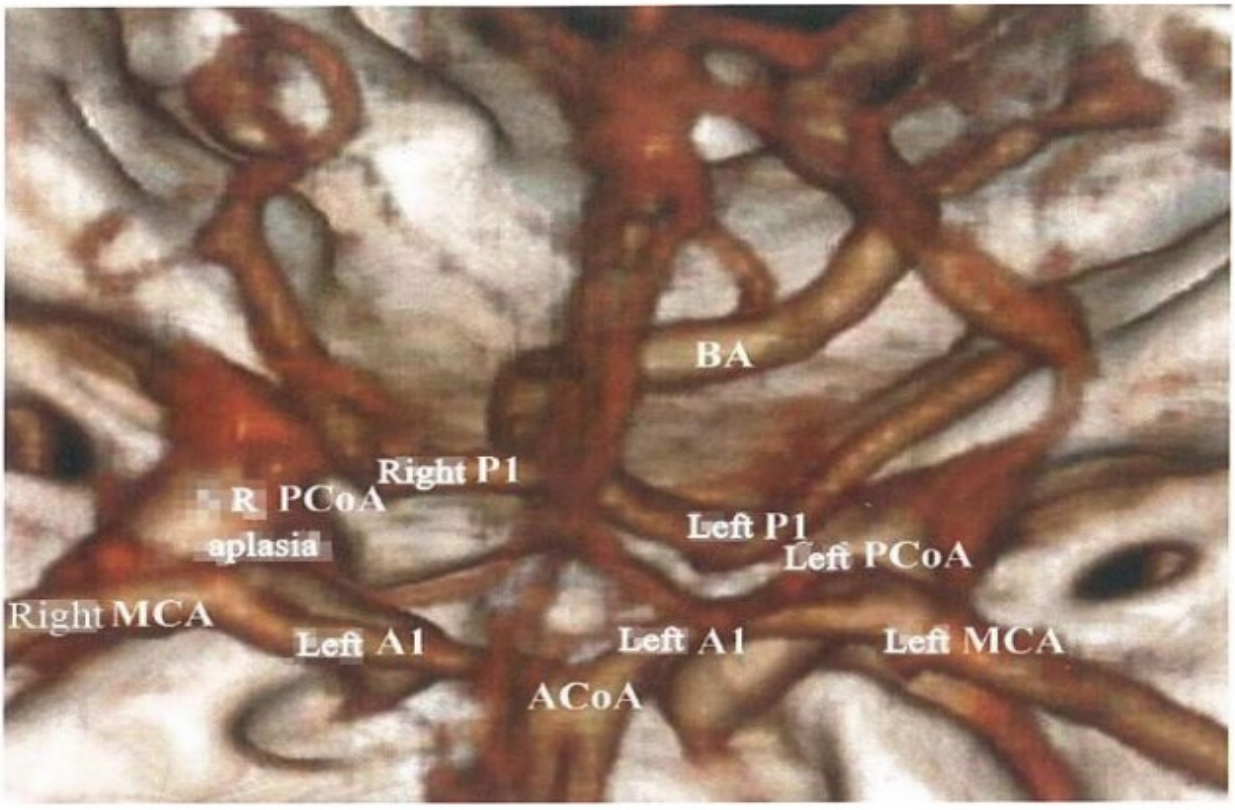

Figure 3: Right Posterior Communicating Artery Aplasia

The contrast agent release rate of the automatic injector was set to 3cc/sec in the first phase and to 1 cc/sec in the second phase. A reference image was obtained before the contrast agent was released to determine if the primary level was proper or not. Right or left shifts of patient dispositions were corrected. 25 seconds after the contrast agent was released, the imaging was started with a section thickness and interval of 1 mm and table speed of 1 mm/sec. The duration of the imaging varied according to the width of the scanned area, ranging from 20 to 30 seconds.

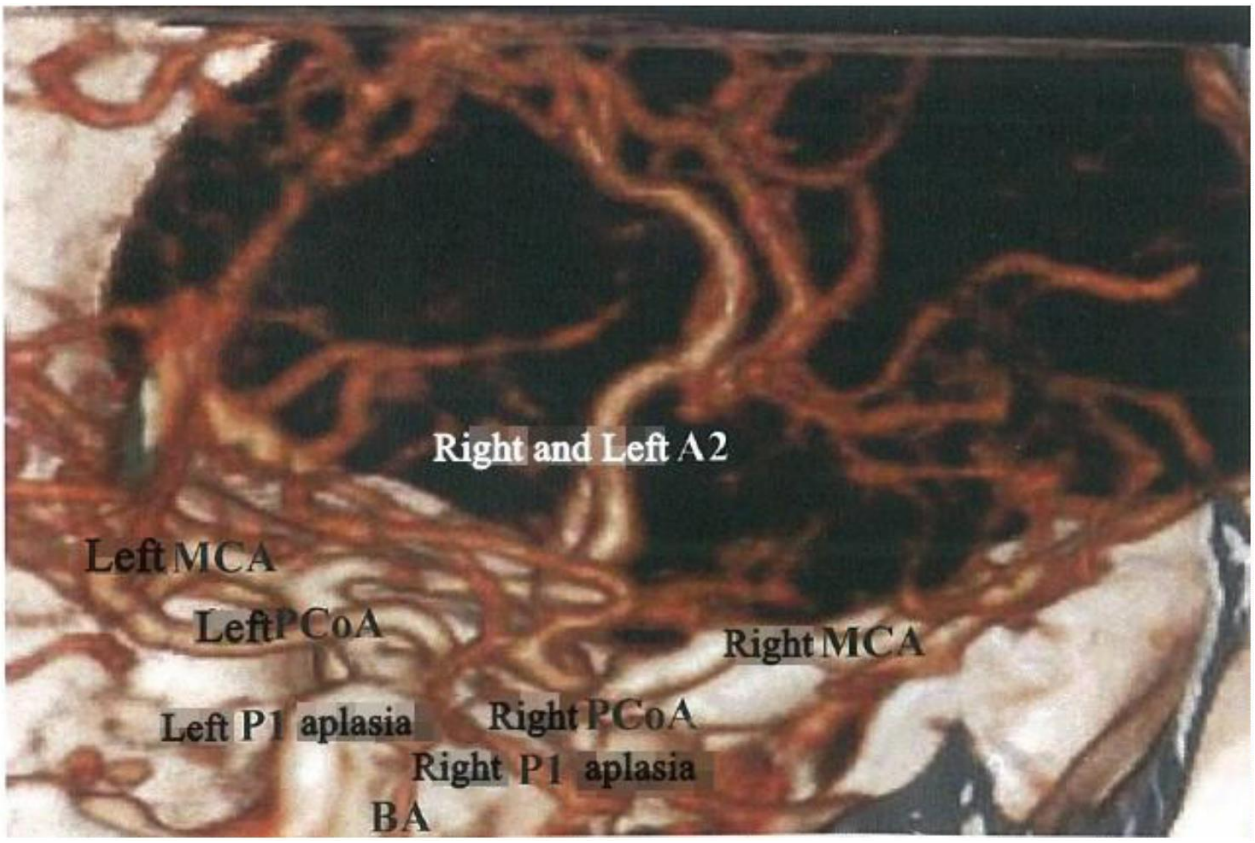

Figure 4: Bilateral Fetal Type Posterior Cerebral Artery (Bilateral P1 Aplasia)

The axial sections obtained were prepared as images to be reconstructed in 3 dimensions by taking the vascular structures into the visualized area and excluding bony structuresviaVRT.Theywerethenpreparedas3-dimensional images by using the MIP and surface shaded display (SSD) algorithms present in the software of the spiral CT. The threshold value used for 3-dimensional reconstructions varied between 150 and 165 hU. This value was optimized for each patient. Furthermore, 3-dimensional reconstructions that present the bony and vascular structures at the same time were prepared for each patient. The time needed for reconstruction varied between 15 and 20 minutes.

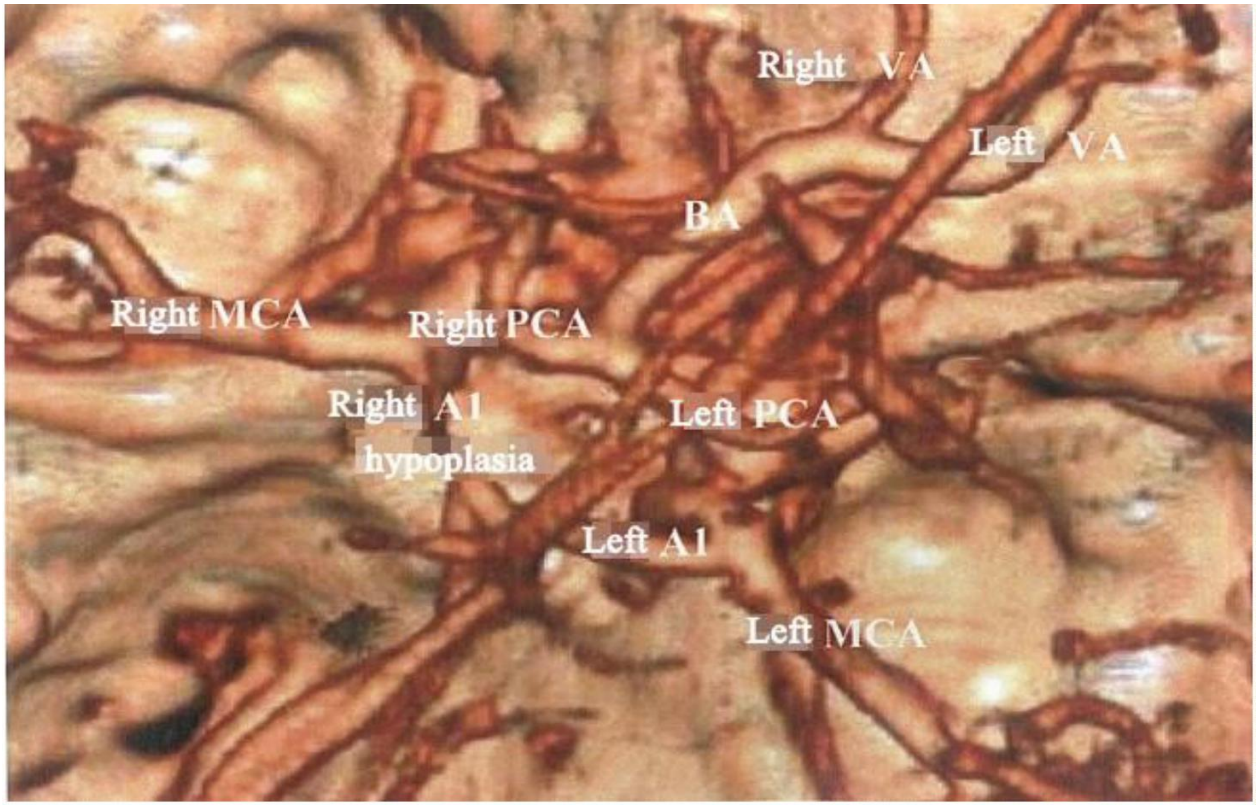

Figure 5: Right A1 Hypoplasia

The variations of the arteries in the circle of Willis were assessed through both axial sections and 3D reconstructions. Aplasia was defined as the absence of the segment, while hypoplasia was characterized by a very thin form of the segment.

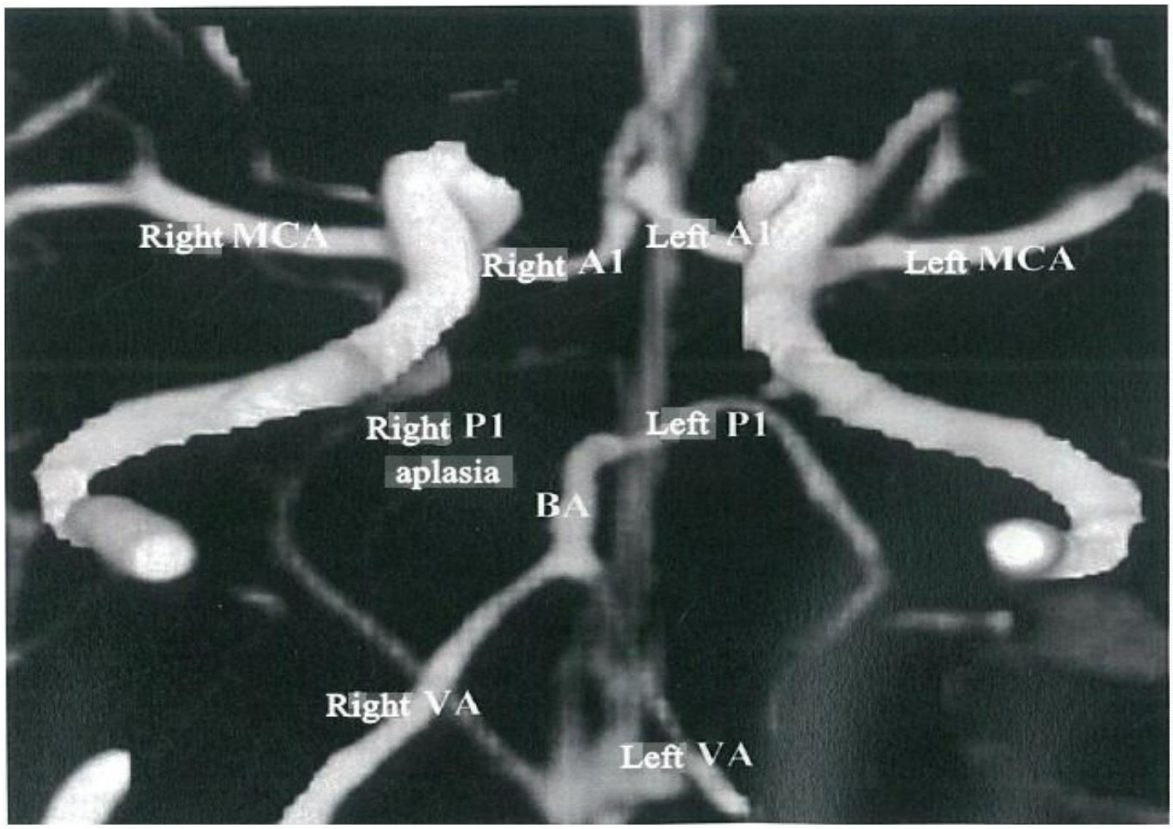

Figure 6: Aplasia of the P1 Segment of the Right Posterior Cerebral Artery

The data obtained in this study were entered into the SPSS 13.0 program package, and the t-test and chi-square test were used for statistical analyses. A p-value <0.05 was accepted as statistically significant.

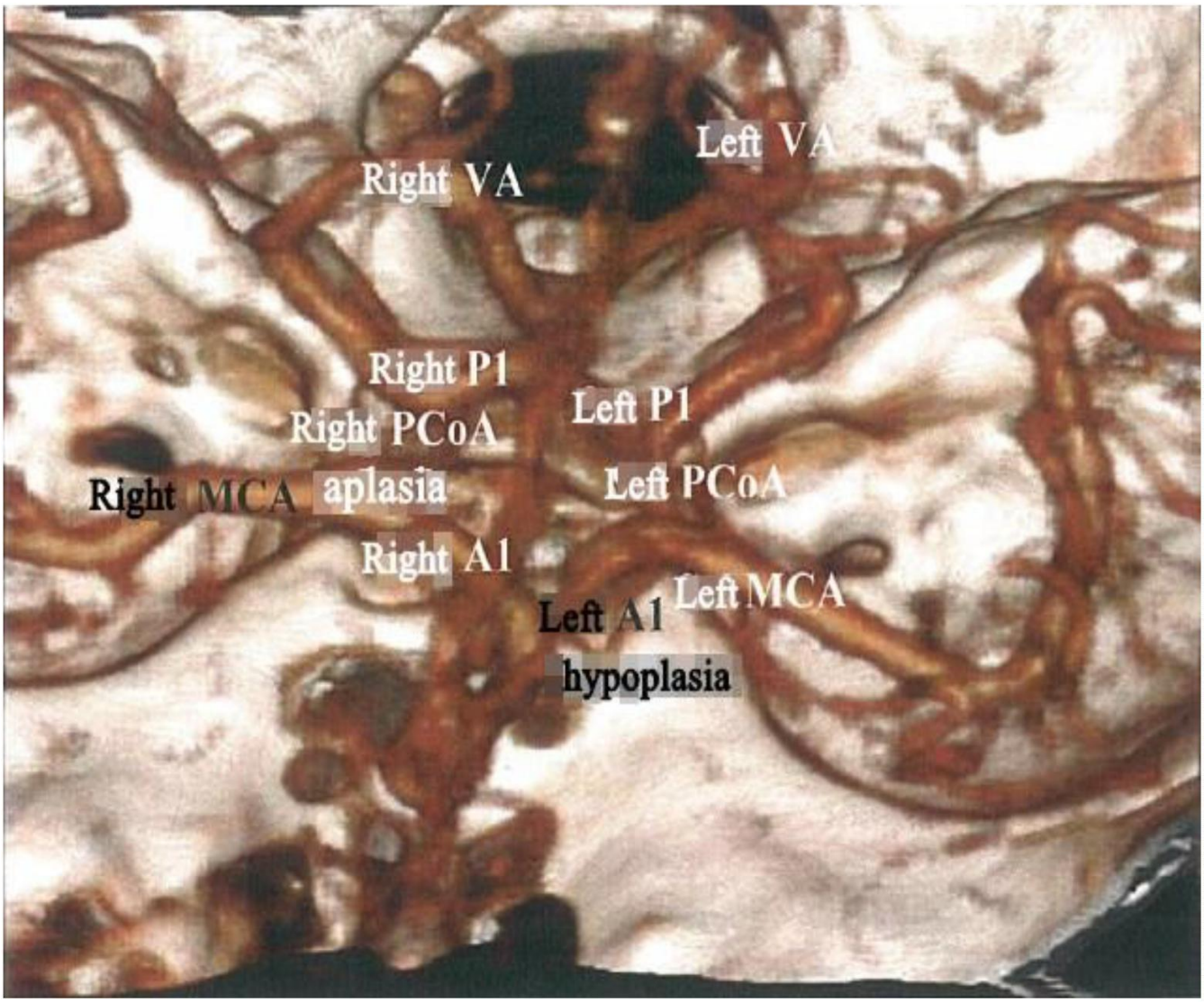

Figure 7: Hypoplasia of the A1 Segment of the Left Anterior Cerebral Artery and Aplasia of the Right Posterior Communicating Artery

3. Results

Diagnosed abnormalities were cerebrovascular ischemia-(event) (CVE) in 18 patients, intracranial mass (ICM) in 15, intracerebral hematoma (ICH) in 7, subdural hematoma (SDH) in 4, ventricular hemorrhage (VH) in 4, and hydrocephalus (H) in 2. The demographic characteristics of the patients are presented in Table 1.

Age	Gender	Diagnosis	Detected vascular abnormality
36	M	ICM	Bilateral aplastic PCoA
17	F	ICM	Bilateral fetal type PSA (bilateral aplastic P1)
65	F	ICH	Bilateral hypoplastic PCoA, right hypoplastic P1
60	F	VH	Bilateral aplastic PCoA, right hypoplastic A1
58	F	CVE	Bilateral aplastic PCoA and ACoA
48	M	CVE	Complete circle
71	M	ICM	Complete circle
79	F	ICM	Left hypoplastic A1, right aplastic PCoA
25	M	ICM	Left aplastic PCoA, right fetal type PSA (right aplastic P1)
87	F	ICM	Right fetal type PSA (right aplastic P1), left aplastic PCoA
69	F	CVE	Right aplastic PCoA
76	M	CVE	Aplastic ACoA
53	F	CVE	Azygos A2
40	F	ICM	Bilateral aplastic PCoA, right aplastic A1
73	F	CVE	Left aplastic PCoA, right hypoplastic P1
71	F	CVE	Bilateral plastic PCoA and right A1, ACoA fenestra
55	M	SDH	Right aplastic A1
75	F	CVE	Bilateral aplastic PCoA, right hypoplastic A1
42	M	CVE	Left hypoplastic PCoA, right aplastic PCoA
50	F	ICM	Right hypoplastic A1 and P1, left PCoA originates from the proximal part of M1
77	F	VH	Right aplastic PCoA and left aplastic A1, left PCoA is short
33	M	CVE	Right occluded P1, right P2 fills with PCoA, left aplastic PCoA
62	M	ICH	Bilateral aplastic PCoA
62	M	VH	Bilateral aplastic PCoA
71	M	ICH	Aplastic ACoA, right PCOA and left P1
78	M	SDH	Left hypoplastic A1, right fetal type PSA (right aplastic P1)
74	M	ICH	Bilateral fetal type PSA (bilateral aplastic P1)
62	F	ICM	Bilateral aplastic PCoA
51	F	CVE	Right fetal type PSA (right aplastic P1)
56	F	CVE	Right aplastic PCoA, left hypoplastic PCoA
72	F	ICH	Aplastic ACoA and left PCoA, right fetal type PSA (right aplastic P1)
72	F	SDH	Aplastic left A1 and right PCoA, left fetal type PSA (left aplastic P1)
81	M	CVE	Right hypoplastic A1, right aplastic PCoA, left fetal type PSA (left aplastic P1)
68	F	CVE	Right hypoplastic A1, right aplastic PCoA
78	F	ICM	Right plastic A1, left hypoplastic PCOa
46	F	VH	Bilateral aplastic PCoA
11	M	H	Aplastic left A1 and bilateral PCoA
54	F	ICM	Aplastic ACoA and bilateral PCoA

57	F	H	Left hypoplastic PCoA, right fetal type PSA (right aplastic P1)
54	F	CVE	Right hypoplastic A1, bilateral aplastic PCoA
57	M	SDH	Right aplastic A1, right hypoplastic PCoA
14	F	ICM	Bilateral hypoplastic PCoA
67	M	ICM	Aplastic left A1 and bilateral PCoA
61	M	CVE	Left hypoplastic A1, bilateral aplastic PCoA
54	F	UCM	Left hypoplastic A1, bilateral aplastic PCoA
49	M	CVE	Left hypoplastic PCoA
70	F	CVE	Left aplastic A1, left aplastic PCoA, left fetal type PSA (left aplastic P1)
63	F	ICM	Left aplastic PCoA, aplastic ACoA
36	M	ICH	Bilateral aplastic PCoA
62	M	ICH	Right hypoplastic P1, bilateral hypoplastic PCoA

Table 1: The Demographic Characteristics of the Patients.

The abnormalities observed in patients and their distributions are presented in Table 2. The total number of abnormalities is 84 since one patient could have more than one abnormality.

Abnormality	Count
Bilateral aplastic PCoA	17
Bilateral hypoplastic PCoA	3
Bilateral fetal type PSA (bilateral aplastic P1)	2
Left aplastic P1	4
Right aplastic P1	7
Right hypoplastic P1	4
Right aplastic A1	5
Right hypoplastic A1	6
Left aplastic A1	4
Left hypoplastic A1	4
Right aplastic PCoA	9
Left aplastic PCoA	6
Left hypoplastic PCoA	3
Aplastic ACoA	6
Azygos A2	1
ACoA fenestration	1
Complete circle	2

Table 2: Abnormalities Observed in Patients.

Single and multiple abnormalities were detected in 30% and 60% of the patients, respectively, and no abnormality was observed in 4 patients. Patient percentages according to the number of abnormalities are presented in Table 3.

		Incidence	Percentage
Abnormality	Single	15	30.0
	Multiple	33	66.0
	Complete circle	2	4.0
	Total	50	100.0

Table 3: Patient Distribution According to the Number of Abnormalities.

Diagnosis on admission was CVE for 36% of the patients, ICM for 30%, ICH for 14%, SDH for 8%, VH for 8% and H for 4%. Patient percentages according to the diagnosis are presented in Table 4.

		Incidence	Percentage
Diagnosis	CVE	18	36.0
	ICM	15	30.0
	ICH	7	14.0
	SDH	4	8.0
	VH	4	8.0
	H	2	4.0
	Total	50	100.0

Table 4: Patient Distribution According to the Diagnosis.

The percentage of single abnormality was 46.7% among women and 53.3% among men, whereas the percentage of multiple abnormality was 66.7% among women and 33.3% among men. The Circle of Willis was complete in 2 men; no woman was observed without variation. The number of abnormalities according to gender is presented in Table 5.

	Single abnormality	Multiple abnormality	Complete circle	Total
Women Number	7	22	0	29
Percentage	46.7%	66.7%	0%	58.0%
Men Number	8	11	2	21
Percentage	53.3%	33.3%	100.0%	42.0%
Total Number	15	33	2	50
Percentage	100.0%	100.0%	100.0%	100 %

Table 5: Abnormality Distribution According to the Gender.

The percentage of single abnormality was 13.3% under 35 years of age, 46.7% between 35 and 59, and 40% over 60 years of age. The percentage of multiple abnormalities was 9.1% under 35 years of age, 30.0% between 35 and 59, and 60.0% over 60 years of age. No patient without variation was observed under 35, one patient with variation was observed between 35 and 59, and one patient was observed over 60. The number of abnormalities according to age is presented in Table 6.

Age	Single abnormality	Multiple abnormality	Complete circle	Total
Below 35 Number	2	3	0	5
Percentage	13.3%	9.1%	0%	10.0%
35-59 Number	7	10	1	18
Percentage	46.7%	30.3%	50.0%	36.0%
Over 65 Number	6	20	1	27
Percentage	60.0%	60.6%	50.0%	54.0%
Total Number	15	33	2	50
Percentage	100.0%	100.0%	100.0%	100.0%

Table 6: Distribution of Abnormality According to Age.

The single abnormality rate was 60% below 60 years of age and 40% over 60. The multiple abnormality rate was 39.4% below 60 years of age and 60.0% over 60. No variation was detected in one patient below and over 60 years of age. Abnormalities observed below and over 60 are presented in Table 7.

Number of abnormalities	Single abnormality	Multiple abnormality	Complete circle	Total
Below 60 Number	9	13	1	23
Percentage	60.0%	39.4%	50.0%	46.0%
Over 60 Number	6	20	1	27
Percentage	40.0%	60.6%	50.0%	54.0%
Total Number	15	33	2	50
Percentage	100.0%	100.0%	100.0%	100.0%

Table 7: Abnormality Distribution Below and Over 60.

Percentages of single abnormality were 33.3%, 26.7%, 20%, 6.7% and 13.3% in SVE, ICM, ICH, SDH, and VH, respectively. Percentages of multiple abnormalities were 36.4%, 30.0%, 12.1%, 9.1%, 6.1% and 6.1% for SVE, ICM, ICH, SDH, VH, and H, respectively. No variation was detected in one patient with SVE and ICM. The number of abnormalities according to the diagnosis is presented in Table 8.

Diagnosis-number of abnormalities	Single abnormality	Multiple abnormality	Complete circle	Total
CVE Number	5	12	1	18
Percentage	33.3%	36.4%	50.0%	36.0%
ICM Number	4	10	1	15
Percentage	26.7%	30.3%	50.0%	30.0%
ICH Number	3	4	0	7
Percentage	20.0%	12.1%	0%	14.0%
SDH Number	1	3	0	4
Percentage	6.7%	9.1%	0%	8.1%
VH Number	2	2	0	4
Percentage	13.3%	6.1%	0%	8.1%
H Number	0	2	0	2
Percentage	0%	6.1%	0%	4.0%
Total Number	15	33	2	50
Percentage	100.0%	100.0%	100.0%	100.0%

Table 8: Abnormality Distribution According to Diagnosis.

SVE was detected in 64.7% of the women and 35.3% of the men. ICM was detected in 78.6% of the women and 21.4% of the men. ICH was detected in 28.6 of the women and 71.4 of the men. SDH was detected in 25% of the women and 75% of the men. VH was detected in 75% of the women and 25% of the men. H was equal among women and men. Diagnoses according to gender are presented in Table 9.

Gender	CVE	ICM	ICH	SDH	VH	H	Total
Women Number	11	11	2	1	3	1	29
Percentage	64.7%	78.6%	28.6%	25.0%	75.0%	50.0%	60.4%
Men Number	6	3	5	3	1	1	19
Percentage	35.3%	21.4%	71.4%	75.0%	25.0%	50.0%	39.6%
Total Number	17	14	7	4	4	2	48
Percentage	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table 9: Distribution of the Diagnoses According to Gender.

SVE was observed at rates of 47.1% and 52.9%, ICM was 57.1% and 42.9%, ICH was 14.3% and 85.7%, SDH was both 50%, and VH was 25% and 75% below and over 60 years of age, respectively. All H cases were below 60 years of age. Distribution of the diagnoses according to age is presented in Table 10.

Age		CVE	ICM	ICH	SDH	VH	H	Total
Below 60	Number	8	8	1	2	1	2	22
	Percentage	47.1%	57.1%	14.3%	50.0%	25.0%	100.0%	45.8%
Over 60	Number	9	6	6	2	3	0	26
	Percentage	52.9%	42.9%	86.7%	50.0%	75.0%	0%	54.2%
Total	Number	17	14	7	4	4	2	48
	Percentage	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table 10: Distribution of the Diagnoses According to Age.

One patient had an Azygos A2 variation, which was the A2 segment of ACA and was in the form of a single and thick artery (Image 3.1).

4. Discussion

Circle of Willis variations have been seldom studied via CT angiography in the literature so far. The relations of age, gender, and diagnoses with the variations of the circle of Willis were investigated in our study. CT angiography is a non-invasive imaging technique. Images are obtained after administration of a contrast agent. The images are independent of the flow rate and reflect the amount of contrastagentwithinthevascularstructures.CTangiography is performed safely in patients with metallic implants or materials such as cardiac pacemakers, cochlear implants, or aneurysm clips that cannot undergo MRI or MRA [25]. The relation and orientation of the vascular structures with the bone structures, which are critically important in the surgical approach, may be detected via CT angiography using source images and three-dimensional images. Angiography is the most reliable method in the evaluation of the intracranial structures; however, it is an invasive method and causes many complications [3,18]. These complications may be related to the surgery; an increase in the intracranial pressure during intubation, hypotension, or hypertension are the reactions caused by anesthetic drugs. Complications related to the angiography technique are hematoma, spasms, thrombus formation, arteriovenous fistula, dissection, and infections, which are local; and allergic reactions, embolism, ischemic symptoms, and vasospasms, which are systemic [2,18]. Due to the complications of cerebral angiography described above, the use of non-invasive imaging techniques such as MRA and CT angiography has been studied extensively. MRA imaging does not necessitate contrast agent administration, the patient is not exposed to radiation, and examinations in different plans and 3D reconstructions are possible. However, it cannot be used in intubated patients or those carrying a ferromagnetic foreign substance. MRA takes a long time, MRI takes a short time. This study indicates that CT angiography may be used as an alternative to or complementary to cerebral angiography in the detection of circle of Willis variations. In the autopsy study of Alpers and Berry[4]onnormalindividualsandthosewithneurovascular findings, a complete ring was detected in 33% of the patients with cerebral ischemia and 37% of those with aneurysms; the rate reported for those with no neurovascular disease was 5'%. Riggs and Rupp [31] have detected a 21% complete ring in their study conducted on patients with neurological dysfunction. [26] have detected an anterior complete circle in 60% and a posterior complete circle in 74% of the patients with carotid occlusion in their DSA study. Has reported 15% asymmetry in the pre-communicating part of the anterior cerebral artery; among those, 7% was wider on the right side, and 8% was wider on the left side [38]. He has detected A1 hypoplasia at a rate of 4%. Have detected 30.65% asymmetry and 9.16% hypoplasia [25]. Duplication of the post communicating segment of the anterior cerebral artery was reported at a rate of 1% in the study of and at a rate of 3.3% in the study of [25,38]. have reported 6.66% fenestration and 1.66% aplasia [25]. has reported 7% triple arteries and 4% V-shaped arteries [38]. have detected 1% anterior communicating artery aplasia [12]. Have reported 7.8% P1 hypoplasia [25]. Posterior communicating artery asymmetry was reported by Seydel [38] at a rate of 32% and by at a rate of 29% [25]. The latter group has also reported 15% hypoplasia. Seydel [38] has reported 3% unilateral aplasia, have reported 3.6% unilateral aplasia and 0.4% bilateral aplasia [19]. 16% right PCoA hypoplasia, 11% left PCoA hypoplasia, and 33% bilateral PCoA hypoplasia were reported in the study of [12]. 14% ACoA hypoplasia, 11.5% unilateral PCoA hypoplasia, 7% unilateral PCoA hypoplasia and ACoA concomitance, 23% bilateral PCoA hypoplasia, and bilateral PCOA hypoplasia and ACoA concomitance were reported in the study of [10]. A complete circle of Willis was observed in 126 of 160 Chinese patients (79%) in the study of and among those, 122 were normal and 4 had 2 AcoAs [20]. 34 patients had an incomplete circle of Willis, and among those, 19 had A1 hypoplasia and aplasia. 17 had (11%) fetal type posterior part of the circle of Willis, and among those, 15 were partial, and 2 were complete fetal type. 73% of the partial fetal type was unilateral, and 27% was bilateral. In our study, 15% of the patients had a fetal type of the posterior part of the circle of Willis, and among those, 85% were unilateral, and 15% were bilateral. In

another study, asymmetry between vertebral arteries was found to be 75%, and serious hypoplasia in one vertebral artery was found to be 10% [17]. In another study, the vertebral artery terminated at PICA at a rate of 1% and did not communicate to the basilar artery [41]. In our study, 30% of the patients had a single abnormality, 66% had multiple abnormalities, and 4% had no abnormalities. When the effect of gender on the abnormality was investigated, more women had multiple abnormalities than men, and more men had a single abnormality than women. The number of normal cases was 2, but statistically, no difference was observed between genders in the abnormality rate. When the effect of age on abnormality was investigated, the single abnormality rate was higher in the 35-39 age group, and the multiple abnormality rate was higher in the >60 age group; below 35, both single and multiple abnormality rates were lower compared to the 35-39 and >60 age groups. One of the normal patients belonged to the 35-39 age group, and the other belonged to the >0 age group. However, statistically, no difference was observed between groups about abnormality. When the age groups were considered as below and over 60 years of age, patients with a single abnormality were more in the <60 age group compared to the>0 age group, whereas patients with multiple abnormalities were more in the >60 age group. One of the normal patients belonged to the <60 age group, and the other belonged to the>60 age group. However, statistically, no difference was observed between groups about abnormality. When the diagnosis and abnormality count were compared, patients with both single and multiple abnormalities were more among the SVE group compared to other diagnosis groups. No single abnormality was detected in patients with hydrocephalus, whereas the multiple abnormality count was 2. One of the normal patients belonged to the SVE group, and the other belonged to the ICM group. However, statistically, no difference was observed between groups in the abnormality rate. When gender was compared with the diagnosis, SVE was observed 64.7% in women and 35.3% of men. ICM was observed 78.6% in women and 21.4% of men. ICH was observed 28.6% in women and 71.4% of men. SDH was observed 25% in women and 75% of men. VH was observed 75% in women and 25% of men. H was observed 50% in women and 50% of men. As mentioned above, no statistical correlation was detected in the gender, age, diagnosis, and abnormality count parameters in our study. The reason for that may be the insufficient sample size since 50 patients were classified into 6 groups with different diagnoses. If they were investigated in a single diagnosis group, statistically significant outcomes might be observed; however, another aim of this study was to investigate the incidence of variation in patients with neurosurgical diagnoses. It was observed in our study that the relation between the circle of Willis variations and cranial disorders is important. Hypoplastic segments are highly related to the aneurysms of the circle [15,16,25,29,32,39]. Congenitally unformed circle of Willis, which is common in the general population, is quite common in patients with stroke [15]. In another ongoing study of ours, we have been investigating the circle of Willis variations of patients with aneurysms via CT angiography, and we hope to see more significant outcomes since we are studying a single group.

Conclusion

The most important limitation of CT angiography is low resolution, which makes the visualization of the small but functional collaterals difficult. The threshold vessel diameter necessary for a collateral flow is 0.4- 0.6 mm [14]. This means that some functional collaterals may not be visualized via CT angiography. Although CT angiography has a high sensitivity in determining the vessels of the circle of Willis, it has some limitations, like being unable to show small vessels with slow or turbulent flow. Since the increase in flow rate increases the signal intensity, the sensitivity of CT angiography to determine small communicant arteries increases as the flow rate within them increases. Non-appearance of a vessel in CT angiography may either mean the real absence of that vessel or a low flow rate within it. In healthy individuals, the bilateral flow rate of equal pressure may reduce the flow rate and lead to non-imaging of that vessel. We believe that complete circle prevalence, therefore, seems lower than the autopsy series. As seen, the circle of Willis variations may be detected via CT angiography. Although these variations have been imaged via other imaging techniques, CT angiography in neurological disorders is first used in our study. However, the study of on Chinese patients with no neurological disorders was published recently [20]. The variations of the circle of Willis were seen in 96 % of the patients with various pathologies in our study. This means the variations of the circle of Willis is seen frequently and change the collateral flow in various pathologies which may influence the healing process differently, among the patients with the same pathologies.

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