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Anatomical Variations of the Arterial System of the Base of the Brain

TAKASHI OZAKI, HAJIME HANDA, KAZUHIKO TOMIMOTO*
and FUMITADA HAZAMA*

Department of Neurosurgery, Kyoto University Medical School
(Director : Prof. Dr. HAJIME HANDA)
*Department of Pathology, Kyoto University Medical School
(Director : Prof. Dr. YOSHIHIRO HAMASHIMA)
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Introduction

The arterial system in the base of the brain is one of the sites where we encounter many kinds of anatomical variation. The variations are considered to play an important role in the development of some cerebrovascular lesions, such as aneurysms, infarctions, etc. It is also important to keep in mind the variations of the basal arteries when we perform a ligation of the carotid artery or when we make a MATAS' test, in order to prevent accidents which may be caused by such variations. Thus precise knowledge about the anatomical configurations of the base of the brain are necessary to understand the developmental mechanisms of various cerebral lesions.

Though the variations of the arterial system involving the circle of WILLIS have been the subject of some reports in the literature, they are not satisfactory. To get wider and more detailed information about the variations, we studied the cerebral arterial system of the base of the brain anatomically in 153 autopsy cases in our department.

Materials and Methods

Materials for the present study were obtained from 153 autopsy cases, ranging in age from 13 hours after birth to 88 years old, in the Department of Pathology, Kyoto University Medical School between 1973 and 1975. One hundred cases were male and 53 female.

Arteries of the base of the brain were separated carefully from the brains well-fixed in 10% formalin. The following 10 parts of the cerebral arterial system (Fig. 1) were separately observed. They were the anterior communicating artery (A. com.), proximal part of the anterior cerebral artery (AC proximal), distal part of the anterior

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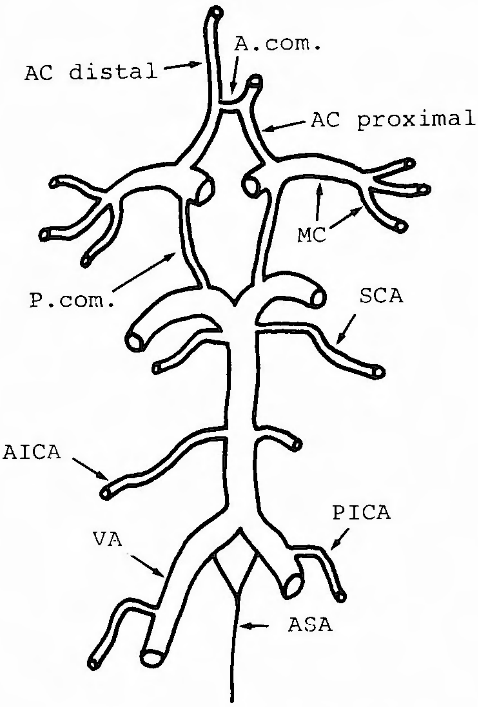
Present Address : Department of Neurosurgery, Kyoto University Medical School, Sakyo-ku, Kyoto, Japan. 〒 606
*Department of Pathology, Kyoto University Medical School, Sakyo-ku, Kyoto, Japan. 〒 606



Feg. 1. 10 parts of the circle of Willis

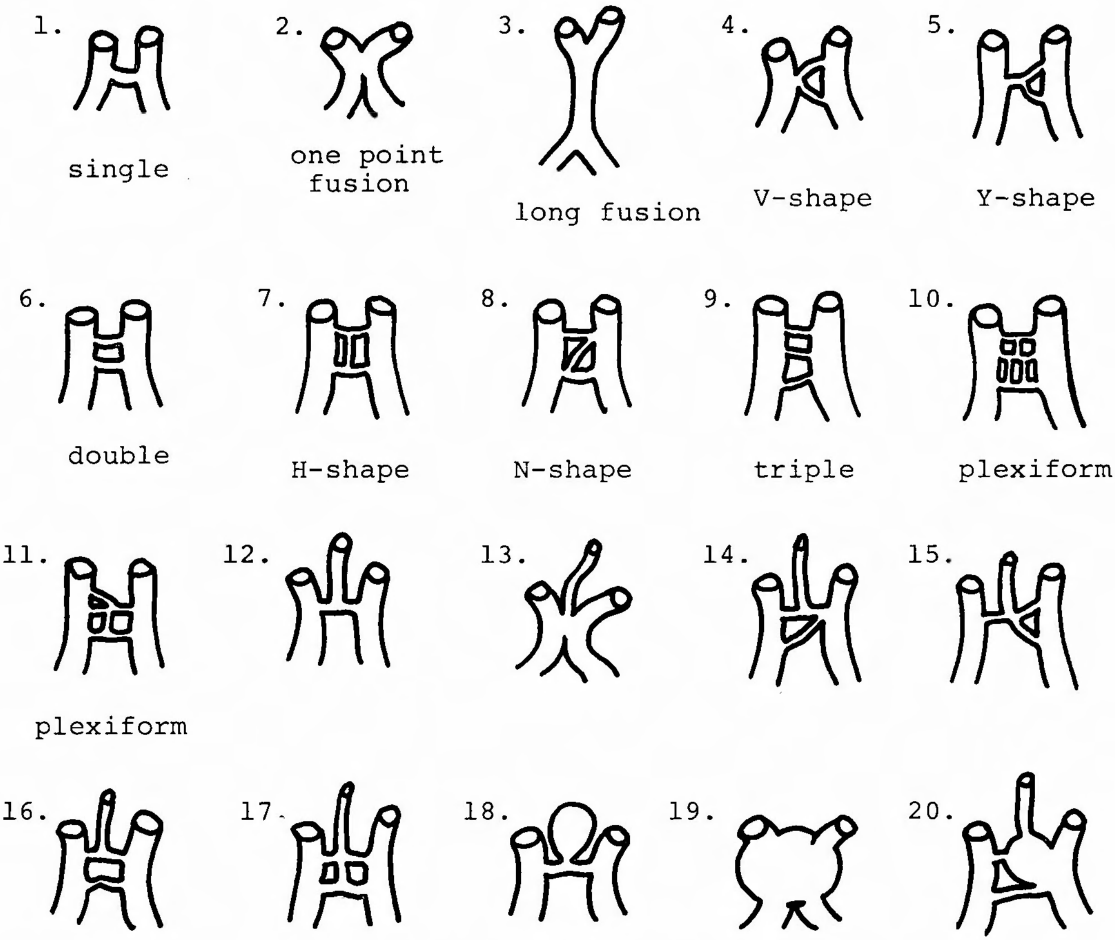
cerebral artery (AC distal), middle cerebral artery (MC), posterior communicating artery (P. com.), superior cerebellar artery (SCA), anterior inferior cerebellar artery (AICA), posterior inferior cerebellar artery (PICA), anterior spinal artery (ASA) and vertebral artery (VA). The total number of cerebral arteries which completely preserved all components was 62 in 153 cases, because of the artefacts at the time of autopsy or cerebral lesions such as tumor or hematoma of the base. Numbers of the separately observed 10 components were 148 cases of A. com., 146 cases of AC proximal, 146 cases of AC distal, 126 cases of MC, 136 cases of P. com., 133 casses of SCA, 113 cases of AICA, 98 cases of PICA, 101 cases of ASA, and 122 cases of VA.

A. com., P. com. and ASA were classified by their form of the vessel. MC and SCA were classified by number of branches of vessels and SCA further by their origin. AC proximal, AC distal, AICA, PICA and VA were classified by difference in thickness between the right and left sides, and additionally AICA and PICA by origin and formation. Concerning the circle of WILLIS, the completely preserved ones were classified according to RIGGS and RUPP[26)]

Result

A. com. showed 8 types of variation as shown in Fig. 2 (1-8) and additional 3 combined types (Fig. 2, 9-11). However, the frequently observed variations were 4 groups, one point communication with each AC (single, one point fusion and long fusion), three points communication (V-shape and Y-shape), four points communication (H-shape, N-shape and double) and complicated communication (triple and plexiform). Furthermore, the median anterior cerebral artery and aneurysm were recognized on A. com. component associated with these variations (Fig. 2, 12-20). The numbers and incidences of A. com. variations of the present study and other authors were shown in Table 1.

Among the variations of AC proximal, the accessory middle cerebral artery was found in 8 cases, and fenestration was observed in 3 cases. Both the accessory middle cerebral artery and fenestration was in 1 case. Except for these cases, the numbers and incidences of the variations of AC proximal were shown in Table 2 and classified by the difference in thickness between both sides of the vessel.



Feg. 2. Variations of A. com.

AC distal usually consists of two vessels, the right and left, but occasionally 3 vessels, associating a median anterior cerebral artery, and only one vessel, that is an azygos anterior cerebral artery. In our study, there was one rare case which showed 4 vessels as AC distal component, having two vessels in each side. This case was associated with absent A. com. The remaining 124 cases had two vessels as AC distal component, and the thickness of both sides of the vessels was similar as shown in Table 3.

MC was classified referring to TEAL[33]. We observed 5 cases of early bifurcation (4.0 %) and 2 cases of duplication (1.6%). All cases of these variations were unilateral, and there were no associated cases of these two variations. The accessory middle cerebral artery was observed in 9 cases as has been described in the part concerning AC proximal. One hundred nineteen cases except for these 7 cases were classified by the number of distal branches from the main branching (so-called trifurcation). Cases with an equal number of branches in both sides were counted as 38.9% (49 cases), cases with a larger number of branches in the right than the left as 34.9% (44 cases) and cases with more branches

Table 1. Incidence of variations of A. com.

variations of A. com.	Ozaki 1976	Hasebe 1928	Windle 1888	Fawcett & Blachford 1906	Blackburn 1907	Kleiss 1941
single	59 (39.7%)	33 (39.8%)	170 (85.0%)	645 (92.2%)	197 (90.0%)	120 (36.9%)
one point fusion	25 (16.9%)	0	…	…	…	…
long fusion	1 (0.7%)	1 (1.2%)	1 (0.5%)	…	7 (3.2%)	…
V-shape, Y-shape	18 (12.2%)	20 (24.1%)	20 (10.0%)	53 (7.6%)	14 (6.4%)	44 (13.6%)
double, H-shape, N-shape	10 (6.8%)					26 (8.0%)
triple, plexiform	9 (6.1%)	29 (34.9%)	3 (1.5%)	1 (0.1%)	…	20 (6.2%)
median ant. cerebr. art.	21 (14.2%)	15 (18.1%)	9 (4.5%)	23 (3.2%)	2 (0.9%)	…
single	9					
one point fusion	6					
V-shape, Y-shape	3					
double, H-shape	3					
aneurysm formation	4 (2.7%)	0	…	…	…	…
single	2					
one point fusion	1					
double & median ant. cerebr. art.	1					
absent	1 (0.7%)	0	6 (3.0%)	1 (0.1%)	2 (0.9%)	…
total	148 (100.0%)	83	200	700	220	325

Table 2. Incidence of variations of AC proximal

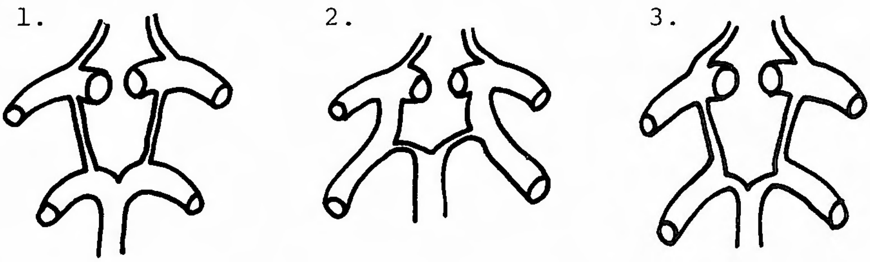
variations of AC proximal	Ozaki 1976	Hasebe 1928	Blackburn 1907	Kleiss 1941
equal thickness	118 (80.7%)	44 (53.0%)	…	…
rt thicker than lt	8 (5.5%)	17 (20.5%)	…	12 (3.6%)
rt thinner than lt	8 (5.5%)	22 (26.5%)	…	15 (4.6%)
accessory mid. cerebr. art. unilat.	7 (4.8%)	0	5 (2.3%)	…
bilat.	1 (0.7%)			
accessory mid. cerebr. art. (rt) & fenestration (lt)	1 (0.7%)	0	…	…
fenestration (unilat.)	3 (2.1%)	6 (7.2%)	…	2 (0.6%)
total	146 (100.0%)	83	220	325

Table 3. Incidence of variations of AC distal

variations of AC distal	Ozaki 1976	Hasebe 1928	Baptista 1963
equal thickness	124 (84.9%)	67 (80.7%)	…
azygos ant. cerebr. art.	0	1 (1.2%)	1
median ant. cerebr. art.	21 (14.4%)	15 (18.1%)	50 (13%)
4 vessels (combined with A. com. absence)	1 (0.7%)	0	…
total	146 (100.0%)	83	381

in the left than right as 20.6% (26 cases). There was no hypoplasia nor aneurysm in MC.

P. com. was divided into 3 types : average type, primitive type and transitional type according to the classification of STEHBENS[30]. We classified by combining both sides as in Fig. 3. Table 4 indicates the results of P. com. The observed 3 cases of aneurysm



bilateral average types　　bilateral primitive types　　bilateral transitional types

Feg. 3. Variations of P. com.

were all IC-PC ones, and the type of side with aneurysm is shown in Table 4. The contralateral side of vessels is all of average type. Absence of P. com. was observed in 25 cases, in which 5 cases showed bilateral absence.

The results of SCA, which was classified by number and the origin of the vessels, are shown in Table 5.

The results of AICA, classified by formation, thickness and origin, are shown in the Table 6-1, 6-2. Bilateral absence of AICA was observed in 1 case (0.9%), while unilateral in 19 cases (16.8%).

PICA was classified by thickness, origin as well as existence of the vessel as in the case of AICA. The results are indicated in the Table 6-1, 6-3. Bilateral absence was recognized in 3 cases (3.1%), and unilateral in 27 cases (27.5%). In the bilateral existent cases, the right and left vessels showed almost the same thickness as in the cases of AICA. PICA originated from AICA was observed in 15 cases (15.3%). In contrast AICA originated from PICA was observed in 3 cases (3.2%). Forty seven cases which had both bilateral AICAs and bilateral PICAs were further classified according to TAKAHASHI[32] and shown in Fig. 4.

Table 4. Incidence of variations of P. com.

variations of P. com.	Ozaki 1976	Hasebe 1928	Windle 1888	Blackburn 1907	Fawcett & Blachford 1906	Kleiss 1941
bilat. average types	80 (58.8%)	54 (65.1%)	…	…	…	…
bilat. transitional types	1 (0.7%)	1 (1.2%)	…	…	…	16 (5.0%)
bilat. primitive types	7 (5.2%)	5 (6.0%)	…	23 (10.5%)	…	6 (1.8%)
unilat. primitive type	11 (8.1%)	14 (16.9%)	…	…	10 (1.4%)	49 (15.0%)
average type & transitional type	9 (6.6%)	6 (7.2%)	…	…	…	…
aneurysm formation —	3 (2.2%)					
average type	2	0	…	…	…	…
transitional type	0					
primitive type	1					
absence —	25 (18.4%)	3 (3.6%)	25 (12.5%)		26 (3.6%)	
bilat.	5	0	3		3	
unilat. & average type	15	2		2 (0.9%)		…
〃 transitinal	1	0	22		23	
〃 primitive	4	1				
total	136(100.0%)	83	200	220	700	325

Table 5. Incidence of variations of SCA

variations classified by number of vessel		Ozaki 1976	Hasebe 1928	Blackburn 1907	Mani et al 1968
equal vessels —	each 1 vessel	103 (77.5%)	51 (61.5%)	…	…
	each 2 vessels	2 (1.5%)	7 (8.4%)	2 (9.1%)	8 (8%)
rt more than lt—	rt : 3 vessels & lt : 2	1 (0.8%)	0	…	…
	rt : 2 vessels & lt : 1	17 (12.7%)	15 (18.1%)	4 (18.2%)	20 (20%)
rt fewer than lt —	rt : 1 & lt : 2 (all cases)	10 (7.5%)	10 (7.5%)	2 (9.1%)	
total		133 (100.0%)	83	220	100

by origin	Ozaki 1976	Hasebe 1928
basilar art. bilat.	124 (93.1%)	82 (98.9%)
basilar art. & contralat. basilar art. and post. cerebr. art.	5 (3.8%)	0
basilar art. & post. cerebr. art.	3 (2.3%)	0
bilat. post. cerebr. art.	1 (0.8%)	1 (1.1%)
total	133 (100.0%)	83

Table 6-1. AICA and PICA classification by existence

existence or absence of AICA		Ozaki 1976		Hasebe 1928	Blackburn 1907
bilat. existence	— equal thickness	88	93 (82.3%)	77 (92.8%)	…
	rt thicker than lt	3			
	rt thinner than lt	2			
existent rt and absent lt		13 (11.5%)		1 (1.2%)	…
absent rt and existent lt		6 (5.3%)		4 (4.8%)	…
bilat. absence		1 (0.9%)		1 (1.2%)	7 (3.2%)
AICA total		113 (100.0%)		83	220
existence or absence of PICA		Ozaki 1976		Hasebe 1928	Blackburn 1907
bilat. existence	— equal thickness	64	68 (69.4%)	48 (64.9%)	…
	rt thicker than lt	3			
	rt thinner than lt	1			
existent rt and absent lt		14 (14.3%)		6 (8.1%)	6 (2.7%)
absent rt and existent lt		13 (13.2%)		15 (20.2%)	10 (4.5%)
bilat. absence		3 (3.1%)		5 (6.8%)	…
PICA total		98 (100.0%)		74	220

Teble 6-2. Incidence of AICA classified by origin

AICA classified by origin	Ozaki 1976
basilar art. bilat.	87 (93.6%)
basilar art. and PICA	3 (3.2%)
basilar art. and vertebral art.	3 (3.2%)
total	93 (100.0%)
basilar art. unilat.	18
unilat. vertebral art.	1
unilat. PICA	0
total	19

Variations of ASA are shown in Fig. 5 and summarized in Table 7. Most cases had their origins from the bilateral vertebral arteries (56.4%) and 23.8% of the cases from the unilateral vertebral artery. The remaining 19.8% showed various types.

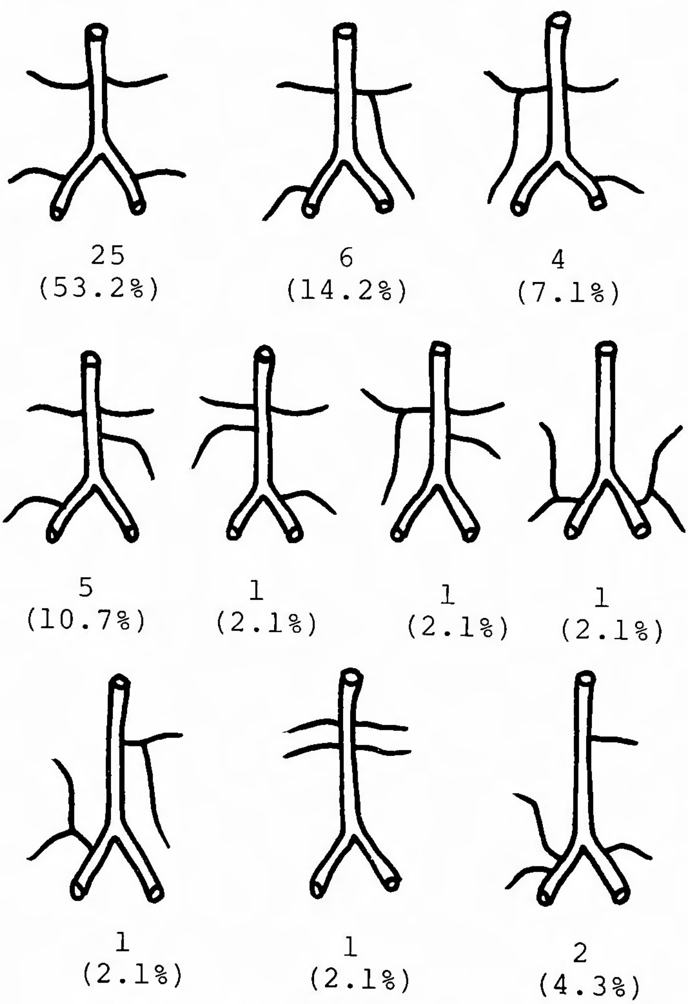
VAs were classified by the difference of both sides of the vessels in thickness. Table 8 indicates the results. Fenestration was observed in 3 cases (2.5%), all of which were unilateral. An aneurysm of fusiform type was seen in 2 cases (1.6%), one of which showed also the existence of the same type of aneurysm on the unilateral internal carotid artery.

As the anterior choroidal artery showed many artefacts, the artery was omitted from the present study. In the basilar artery there were no changes, such as aneurysm, fenestration, carotid-basilar anastomosis and so on.

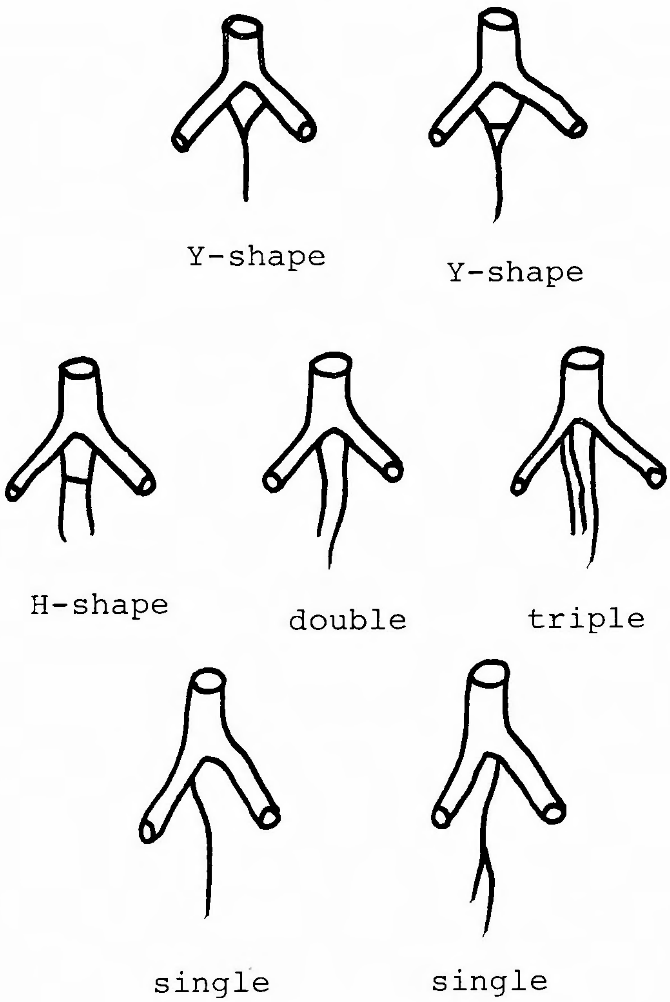
Teble 6-3. Incidence of PICA classified by origin

PICA classified by origin	Ozaki 1976
bilat. vertebral art.	45 (66.2%)
vertebral art. and AICA	14 (20.6%)
vertebral art. and basilar art.	8 (11.8%)
basilar art. bilat.	1 (1.4%)
total	68 (100.0%)
unilat. vertebral art.	26
unilat. AICA	1
basilar art. unilat.	0
total	27

Variations of the circle of WILLIS was classified into 15 types as shown in Fig. 6, referring to the study of RIGGS and RUPP[26]. In classifying the variations, A. com. component was treated as a typical single type in all cases except for one case without A. com. Table 9 shows the results. Those P. com.s under 1 mm in diameter were defined as "string-like" as ALPERS and BERRY[1]. Spontaneous occlusion



Feg. 4. Cases of various combinations AICA with PICA

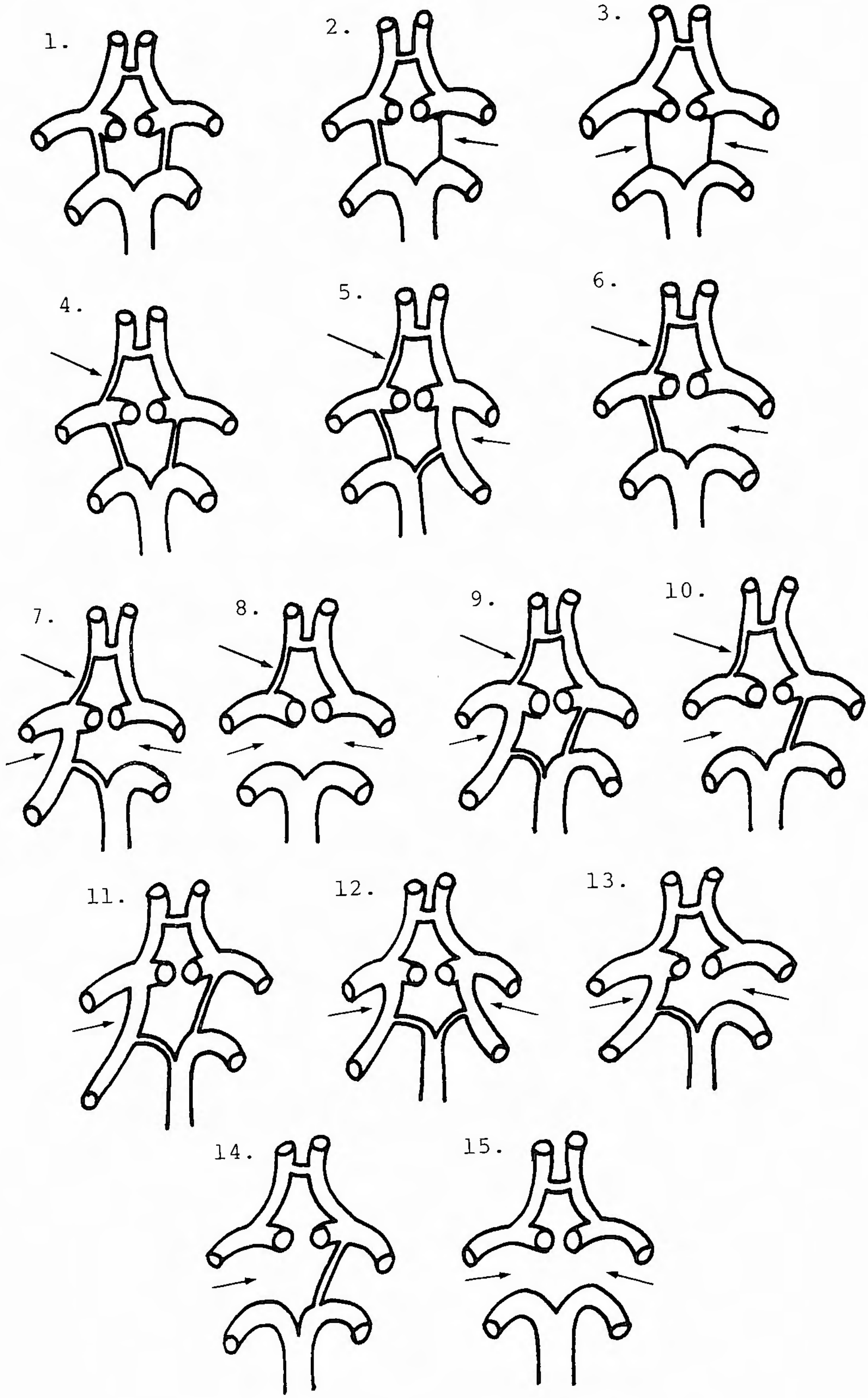


Feg. 5. Variations of ASA

Table 7. Incidence of variations of ASA

variations of ASA	Ozaki 1976	Stopford 1916
Y-shape	26 (25.7%)	
H-shape	17 (16.8%)	85%
double	14 (13.9%)	
single	24 (23.8%)	15%
triple	6 (5.9%)	…
plexiform or combined	14 (13.9%)	…
total	101 (100.0%)	150

of the circle of WILLIS was not recognized in the present study. Aneurysm was identified in 9 cases : they were 4 cases of A. com., 3 cases of IC-PC, 1 case of VA and 1 case of association of IC and VA. The former 7 aneurysms of 7 cases were of the saccular type and the latter 3 in 2 cases of the fusiform type.



Feg. 6. Variations of the circle of Willis

Table 8. Incidence of variations of VA

variations of VA	Ozaki 1976	Hasebe 1928	Godinov 1929	Mizukami et al 1968	Kowada et al 1972	Gerald et al 1973
equal thickness	90 (73.8%)	29 (35.8%)	93 (93%)	…	…	71 (71%)
rt thicker than lt	8 (6.5%)	12 (14.8%)	3 (3%)	…	…	2 (6%)
rt thinner than lt	19 (15.6%)	40 (49.4%)	4 (4%)	…	…	7 (23%)
aneurysms formation—bilat. (fusiform type)	1 (0.8%)	0	…	…	…	…
aneurysms formation (fusiform type)—unilat.	1 (0.8%)					
fenestration (unilat.)	3 (2.5%)	0	…	10 (0.9%)	8 (2.2%)	…
total	122(100.0%)	81	100	1107 (angio.)	362 (angio.)	30 (angio.)

Table 9. Incidence of variations of the circle of Willis

variations of Willician circle	Fig.6	Ozaki 1976	Fawcett et al 1906	Wilson et al 1954	Alpers et al 1959	Riggs et al 1963	Fisher 1965
typical	1	62 (46.3%)	72.8%	10 (8.8%)	183 (52.3%)	192 (19.6%)	19 (4.6%)
unilateral string-like P. com.	2	8 (6.0%)	…	…	28 (8.0%)	214 (21.6%)	23 (5.6%)
bilateral string-like P. com.s	3	8 (6.0%)	…	…	21 (6.0%)		126 (30.4%)
unilateral AC proximal anomaly (thinner, fenestration)	4	13 (9.8%)	…	47 (41.3%)	…	119 (12.0%)	…
unilateral AC proximal anomaly & contralateral P. com. anomaly (absent, primitive)	5, 6	2 (1.4%)	…	6 (5.3%)	…	5 (0.5%)	…
unilateral AC proximal anomaly & homolateral P. com. anomaly	9, 10	2 (1.4%)	…	15 (13.1%)	…	30 (3.0%)	…
unilateral AC proximal anomaly & bilateral P. com. anomalies	7, 8	2 (1.4%)	…	5 (4.4%)	…	5 (0.5%)	…
unilateral primitive P. com.	11	10 (7.5%)	1.42%	20 (17.5%)	…	73 (7.3%)	35 (8.4%)
unilateral primitive P. com. & contralateral P. com. absence	13	3 (2.2%)	…	…	…	…	…
bilateral primitive P. com.s	12	7 (5.2%)	0.14%	11 (9.6%)	…	33 (3.3%)	13 (3.1%)
unilat. P. com. absence	14	13 (9.8%)	3.2%	…	…	0	…
bilat. P. com. absence	15	4 (3.0%)	0.4%	…	…	0	…
total	/	134(100.0%)	700	114 (aneurysms)	350	994	414

Discussion

According to PADGET'S study[25] on the embryological development of the cranial arteries, the basilar artery is formed from the bilateral longitudinal neural arteries at the stage of 29 ± 1 days embryo. At the stage of 32 ± 1 days embryo, the vertebral artery is being formed and at the stage of 40 ± 1 days embryo formation of the artery is completed. This process of formation begins in the ductus arteriosus. At this same stage the anterior and middle cerebral arteries begin to advance and at A. com. region there is a plexus between the bilateral anterior cerebral anteries. Then at the stage of 44 ± 1 days embryo the anterior and middle cerebral arteries extend along the cerebral hemispheres and A. com. is formed from the bilateral arterial plexus to complete the circle of WILLIS. At the stage of 52 ± 1 days embryo the formation of both posterior cerebral and both inferior cerebellar arteries is completed. As the present data and other reports indicate, the variation of A. com. exists very frequently (60.3% in this study) and in a multiplicity of forms. These facts represent retention of the most primitive embryonic structure, as A. com. is formed from the plexus between the bilateral anterior cerebral arteries as PADGET has already reported.

The circle of WILLIS is considered to play a very important role in cerebral hemodynamics as a buffer mechanism, and the anomalous formation of the circle may become a cause for the development of various cerebral lesions. However, since there are a very few cases of absent and hypoplastic A. com. and most variations of A. com. do not relate to the continuity of the circle of WILLIS, the variations of the artery are considered not to give serious effects on the buffer mechanism of the circle.

On the other hand, a discontinuous change of the circle of WILLIS caused by hypoplasia or aplasia of P. com. was most frequently seen. Theoretically the absence of the artery can not be considered, because P. com. originates from the bilateral longitudinal neural arteries according to PADGET. Though, in fact, many vestigial, reticular small channels were often encountered at the portion of the artery, they can be practically regarded as aplasia. In the present study only string-like small arteries were classified into hypoplasia. The hypoplasia and aplasia of P. com. cause important effects on the buffer mechanism of the circle. Clinically, the existence of connection between the internal carotid artery and vertebral artery, in other words the existence of functioning blood flow in P. com. is a very important problem in cases of temporary clipping or ligation of the carotid artery. In the present study unilateral or bilateral hypoplasia and aplasia were found to exist in 29.8% (Fig. 6-2, 3, 6, 7, 8, 10, 13, 14, 15). This fact is noticeable and must be kept in mind at surgical operations.

As in the case of hypoplasia or aplasia of P. com., the existence of the accessory middle cerebral artery, median anterior cerebral artery and primitive P. com. presumably give effects on the hemodynamics of the circle of WILLIS, and may play some roles in the development of aneurysm and other cerebrovascular changes. Further studies are underway to elucidate the interrelationship between variations and the development of cerebrovascular disease.

Summary

Variations of the cerebral arteries taken from 153 autopsied cases in the Department of Pathology, Kyoto University were macroscopically studied.

1) The median anterior cerebral artery was found to exist in 14.4% of all cases, the accessory middle cerebral artery in 5.9%, the fenestration of the anterior cerebral arteries in 2.6%, and the fenestration of vertebral artery in 2.0%. There was one combined case of an accessory middle cerebral artery and contralateral AC proximal fenestration, and one case of both AC proximal and VA fenestrations.

2) Aneurysm was found in 5.9% (9 cases) of all cases. There were combined cases of aneurysm and variations of the cerebral arteries such as one case of A. com. aneurysm and median anterior cerebral artery, and one case of P. com. aneurysm and both AC proximal and VA fenestrations.

3) Absence was observed in A. com., P. com., AICA and PICA, and the percentages were 0.7, 16.3, 13.1 and 19.6% respectively.

4) The development of variations of A. com. as well as P. com. was discussed. A new classification was made of the variations of the circle of WILLIS.

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和文抄録

脳底部動脈系の Variation について

京都大学医学部脳神経外科学教室（主任：半田　肇教授）

尾崎高志，半田　肇

京都大学医学部病理学教室（主任：浜島義博教授）

冨元一彦，挾間章忠

京都大学医学部病理学教室における 153 剖検例について，脳底部動脈系を解剖学的に検索した．脳底部動脈を十個所に区分し，それぞれについて，その variation を，形態，分枝数，origin 等によって分類した．

前交通動脈部には，多様な variation が認められた．ウイリス輪の連続性を断つ variation として，前交通動脈の欠除，後交通動脈の無形成又は，形成不全があったが，それぞれの頻度は，0.7%，29.8%であった．稀な variation として，median anterior cerebral artery（全例中14.4%），accessory middle cerebral artery（5.9%），前大脳動脈近位部の窓形成（2.6%），椎骨動脈の窓形成（2.0%）が認められた．脳動脈瘤は，全例の 5.9%に見られ，variation と合併するものも見られた．その他ウイリス輪の分類を行った．

前交通動脈及び後交通動脈の variation について，発生学的に考察を加え，その多様性を検討した．