Hiroshima J. Med. Sci.
Vol.39, No.3, 83~88, September, 1990
HIJM 39-14

An Investigation of Vascular Anatomy and Microvascular Architecture of the Brainstem in Cats

Toshinori NAKAHARA, Shuichi OKI, Zainal Muttaqin, Yoshio TOKUDA, Katsuya EMOTO, Satoshi KUWABARA and Tohru UOZUMI

Department of Neurosurgery, Hiroshima University School of Medicine, 1-2-3, kasumi, Minami-ku, Hiroshima 734, Japan

ABSTRACT

The vascular anatomy and microvascular architecture of the vertebrobasilar system, especially within the brainstem, was investigated in cats. The main branches of the basilar artery were observed and the inner diameters of these vessels were measured on vertebral angiograms. The three-dimensional microvascular architecture was constructed using molded vascular models. The arterial anastomoses between the arteries inside the brainstem were studied using contact microangiograms. The paramedian branch penetrated into the brainstem in a retrograde fashion from the cranial basilar artery, and in an anterograde fashion from the caudal basilar artery. Arterial anastomoses were noted between the circumferential arteries. The frequency of arterial anastomoses was higher and diameters of the anastomotic vessels were larger in the ventrolateral region of the brainstem than in the ventromedial region. Regarding the perforating arteries, the arterial anastomoses were present outside the brainstem. No arterial anastomoses were found inside the brainstem.

Key words: *Microvascular architecture, Vertebrobasilar circulation, Brainstem, Cat*

It is important to know the microvascular architecture of the animals used when studying cerebral ischemia experimentally. Little has been reported, however, concerning the microvascular architecture of the posterior cranial fossa in cats. The present study investigated the microvascular architecture of the posterior fossa in cats using vertebral angiograms, contact microangiograms, and molded vascular models.

MATERIALS AND METHODS

1. Materials

Forty five adult mongrel cats weighing 2 to 4 Kg were used : 33 for vertebral angiography, 7 for molded vascular models and 5 for contact microangiography. The animals were anesthetized by intraperitoneal injection of pentobarbital (30 mg/Kg) and immobilized with pancuronium bromide (0.08 mg/Kg). The animals were intubated and ventilated mechanically. Arterial blood gas was analyzed to maintain the PaO_2 and $PaCO_2$ within the physiological ranges from 80 to 120 and from 35 to 40 mmHg, respectively, during the experiment.

2. Vertebral angiography

An incision was made in the right anterior chest under supine position. The axillary and the subclavian arteries were then exposed to locate the vertebral artery. A 4 Fr. catheter was inserted into the vertebral artery via the subclavian artery, and 2 ml iopamidol or iohexol containing 300 mg/ml iodine was injected for vertebral angiography (Fig. 1). The X-ray apparatus was a TANKA portable X-ray unit model TP-20, and the X-ray film, Kodak XTL-2. The following vascular diameters were measured on the angiograms: the termination of the vertebral artery, the origin and termination of the basilar artery, the origins of the inferior and superior cerebellar arteries and the posterior cerebral artery, the trunk of the basilar artery, and the caudal ramus of the internal carotid artery.

3. Molded vascular models and contact microangiograms

The animals were sacrificed by intravenous injection of 10 ml saturated potassium chloride solution. Immediately after injection, a catheter was inserted into the descending aorta toward the cranial direction through a thoracotomy. The ascending aorta was ligated. The superior vena cava was then cannulated to allow the blood to flow out. The brain was perfused with 2000 ml heparinized physiological saline solution through the catheter in the descending aorta at a pressure of 150 mmHg. Molded vascular models and contact microangiograms were prepared using the following procedures (Fig. 2).

a) Molded vascular models

Methyl methacrylate resin (50 ml, Mercox®, Dainippon Ink And Chemicals Incorporated) was injected via the catheter which was inserted into the descending aorta at a pressure of 150 to 200

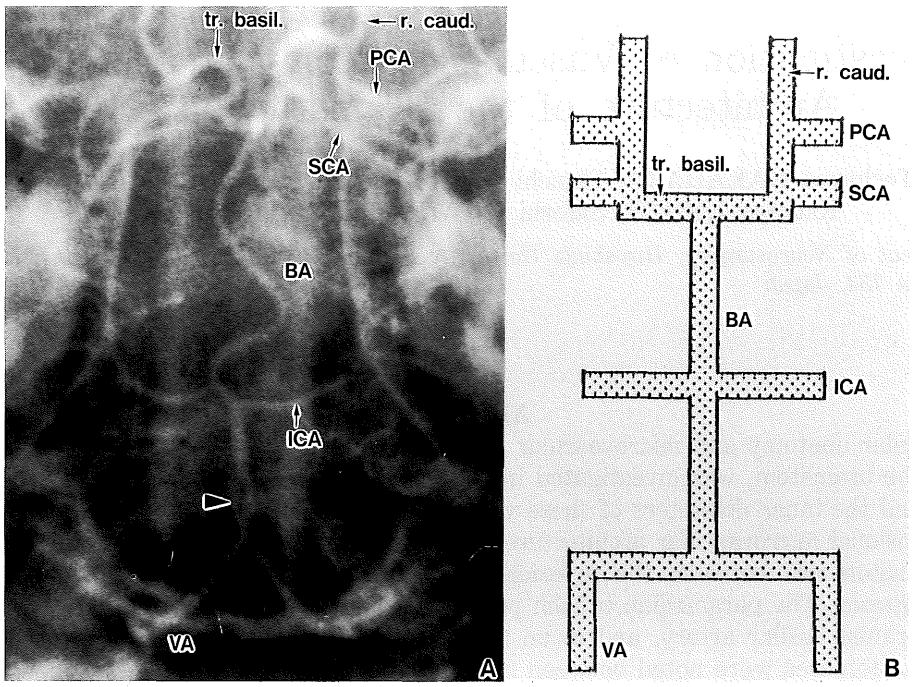


Fig. 1. Vertebral angiogram (A) and schematic diagram (B) of the vertebrobasilar system in cats Fenestration (arrowhead) of the basilar artery was revealed.
r. caud. : Caudal ramus of the internal carotid artery
PCA : Posterior cerebral artery
tr. basil. : Basilar trunk
SCA : Superior cerebellar artery
BA : Basilar artery
ICA : Inferior cerebellar artery
VA : Vertebral artery

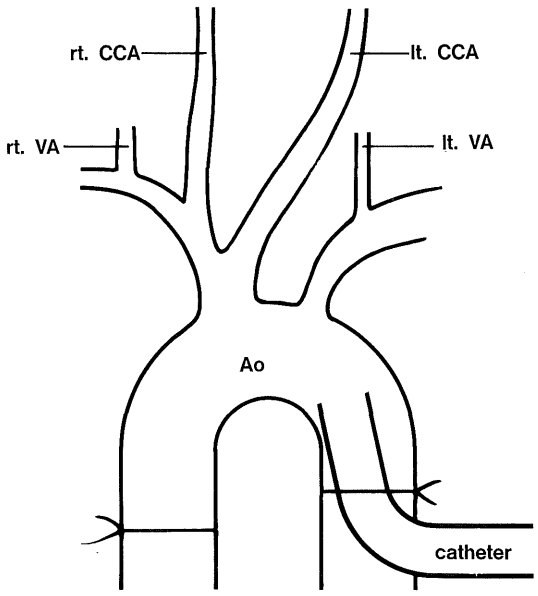


Fig. 2. Schematic diagram of cerebral perfusion for Mercox® or microbarium injection
Ao : aorta
rt CCA : right common carotid artery
lt CCA : left common carotid artery
rt VA : right vertebral artery
lt VA : left vertebral artery

mmHg. A craniotomy was performed immediately after the resin injection and the brain was carefully isolated. After photography (Fig. 3 A), the brain was immersed in 20% NaOH solution for 2 weeks at room temperature. During this period, the dissolved tissues were removed by repeated washing with running water. Molded vascular models were obtained and the microvascular architecture of the brainstem was observed with the operating microscope (WILD model 308795) (Fig. 4).

b) Contact microangiograms

300 ml of 50% microbarium containing 5% gelatin was injected through a catheter inserted into the descending aorta at a pressure of 150 mmHg. After injection the animals were kept at 4°C for 24 hrs, and the brain carefully isolated (Fig. 3 B). It was then cut into 3 mm-thick coronal sections from the level of the mamillary body to the spinal cord. Contact microangiograms were obtained and the microvascular architecture in the cerebral parenchyma was observed (Fig. 5). The X-ray apparatus used was a SHIMAZU circlex U14VN-25 ; the film was Kodak X-Omat TL.

RESULTS

1. Vertebral angiograms (Fig. 1)

The vessels observed by the vertebral angiogram

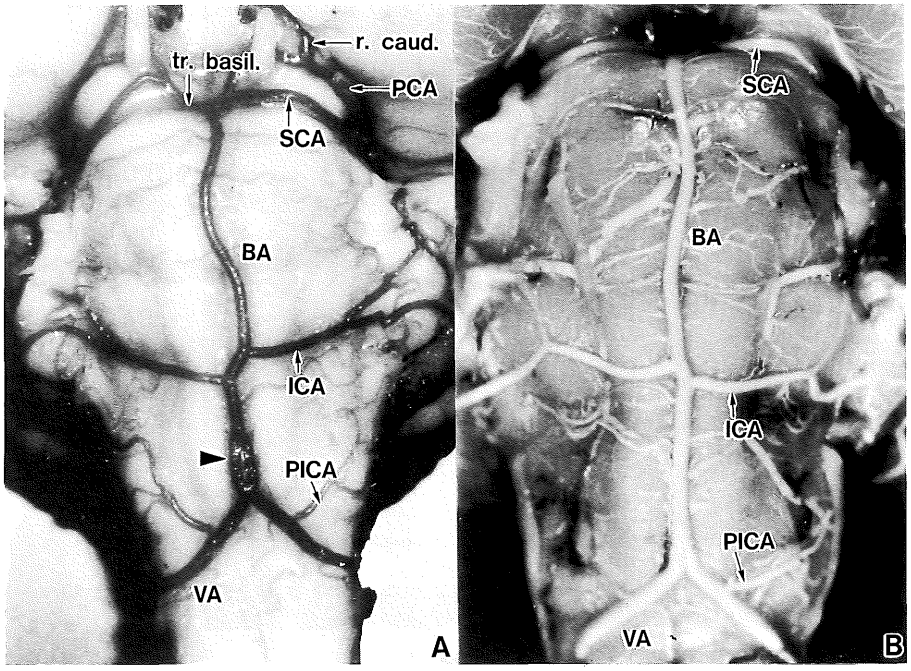


Fig. 3. Ventral view of brainstem after Mercox® injection and barium injection
A : Mercox® injection
B : 50% microbarium containing 5% gelatin injection. Fenestration (arrowhead) of the basilar artery was revealed.
r. caud. : Caudal ramus of internal carotid artery
PCA : Posterior cerebral artery
tr. basil. : Basilar trunk
SCA : Superior cerebellar artery
BA : Basilar artery
ICA : Inferior cerebellar artery
PICA : Posterior inferior cerebellar artery
VA : Vertebral artery

were : the vertebral artery (VA), basilar artery (BA), inferior cerebellar artery (ICA), superior cerebellar artery (SCA), posterior cerebral artery (PCA), basilar trunk (tr. basil.), and caudal ramus of the internal carotid artery (r. caud.). Fenestration of the basilar artery was observed at its origin in 4 of the 33 cats. Duplication of the basilar artery was not noted. Only the main branches of the vertebral and basilar arteries could be identified by vertebral angiograms. A caudal ramus of the internal carotid artery (r. caud.) was noted in all animals. This caudal ramus was a communicating branch between the internal carotid artery and the posterior cerebral artery. Since there were no differences in the inner diameters of vessels between the right and left sides (Student's t test, $p<0.05$), the vessel diameters of both sides are shown together in the table (Table 1). The vessel diameter was smallest at the termination of the basilar artery in its course from the terminal segment of the vertebral artery to the terminal segment of the basilar artery. The diameters of the branches of the basilar artery were smaller than the diameter of the basilar artery itself.

2. Molded vascular models (Fig. 3)

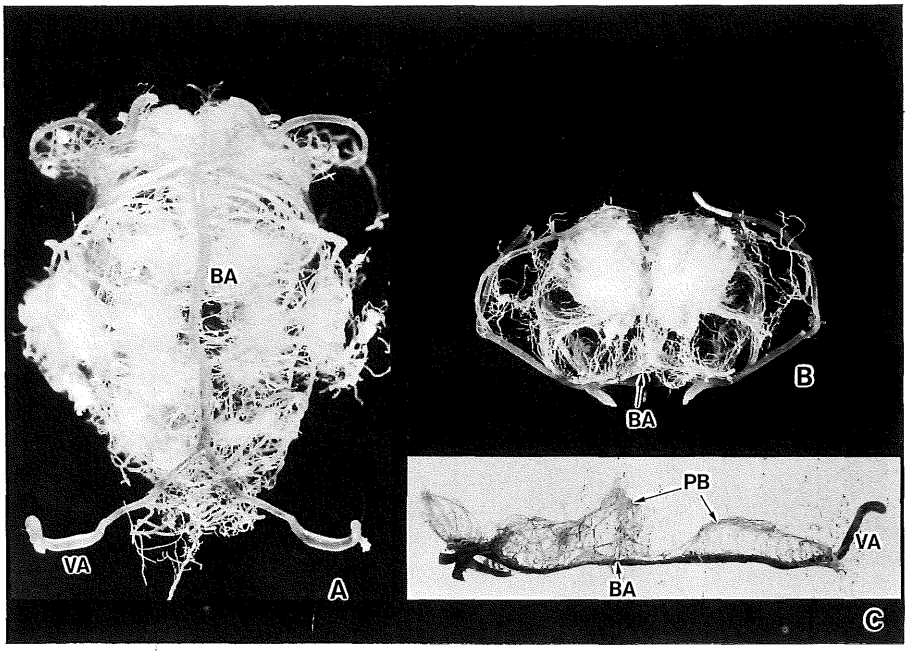
The arteries of the brainstem consisted of branches from the vertebral and basilar arteries. The branches of the basilar artery consisted of the paramedian branches (PBs) perforating dorsally into the median groove of the brainstem and the long circumferential branches (LCBs) and the short circumferential branches (SCBs) running laterally on the brainstem. In this study the basilar artery was divided into two parts at the level of the inferior cerebellar artery (ICA). The cranial portion to this point was designated the cranial basilar artery, and the caudal portion was designated the caudal basilar artery.

a) Length of the basilar artery

The full length of the basilar artery was 17 to 20 mm. The length of the cranial basilar artery was 12 to 14 mm, the caudal basilar artery 5 to 7 mm.

b) Paramedian branches (PBs)

There were about 10 paramedian branches (PBs) from the cranial basilar artery on each side. The site of branching was the dorsolateral portion of the basilar artery. The diameters of these branches at their origins were 20 to 30 μm. The vessels branched in a retrograde manner slightly outside the medulla, and ran at right angles to the basilar



r. caud. : Caudal ramus of internal carotid artery
PCA : Posterior cerebral artery
tr. basil. : Basilar trunk
SCA : Superior cerebellar artery
BA : Basilar artery
ICA : Inferior cerebellar artery
PICA : Posterior inferior cerebellar artery
VA : Vertebral artery
PB : Paramedian branch

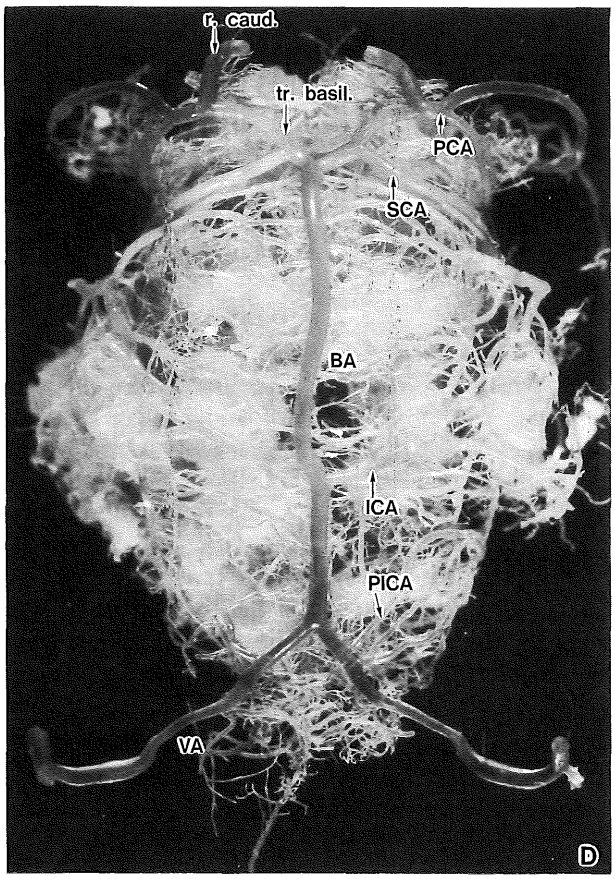


Fig. 4. Microvascular molded model
Both the long and short circumferential branches perfuse the ventromedial side of the brainstem, but the ventrolateral or dorsal side of the brainstem is perfused by the long circumferential branches only.
A : ventral view
B : coronal section
C : sagittal section
D : higher magnification of ventral view

artery within the medulla.

There were about 10 to 15 PBs from the caudal basilar artery on each side. The site of branching was also the dorsolateral portion of the basilar artery. There were 2 to 4 additional branches from the caudal basilar artery which ran 2 to 6 mm cranially parallel to the basilar artery. Another 3 to 5 PBs diverged from these additional branches.

c) Long circumferential branches (LCBs)

The longest LCBs were the inferior cerebellar artery (ICA) and the superior cerebellar artery (SCA). The ICA and SCA ran transversely on the brainstem and the perforating arteries branched at right angles from them.

The ICA often divided into 2 branches in the ventrolateral region of the brainstem, and supplied the cerebellum. In addition to the ICA and SCA, there were 3 to 7 LCBs from the cranial basilar artery on each side. Their diameters at their origins were 90 to 200 μm.

In the ventromedial region of the brainstem, arterial anastomoses (about 15 to 20 μm in diameter) between the LCB and the SCB were noted in their extramedullary parts. Furthermore, arterial anastomoses (about 40 to 50 μm in diameter) between the ICA, the SCA, and the LCB were often observed in the ventrolateral region. The caudal basilar artery had 0 to 3 LCBs of about 100 μm in diameter. Like the LCBs of the cranial basilar artery, arterial anastomoses were observed between the LCB and the SCB. The posterior inferior cerebellar artery (PICA) ran in a cranio-lateral direction and branched perforating arteries to the medulla oblongata. In the ventromedial region, PICA had anastomoses with SCBs and LCBs, while in the ventrolateral region it had anastomoses with the ICA and LCBs.

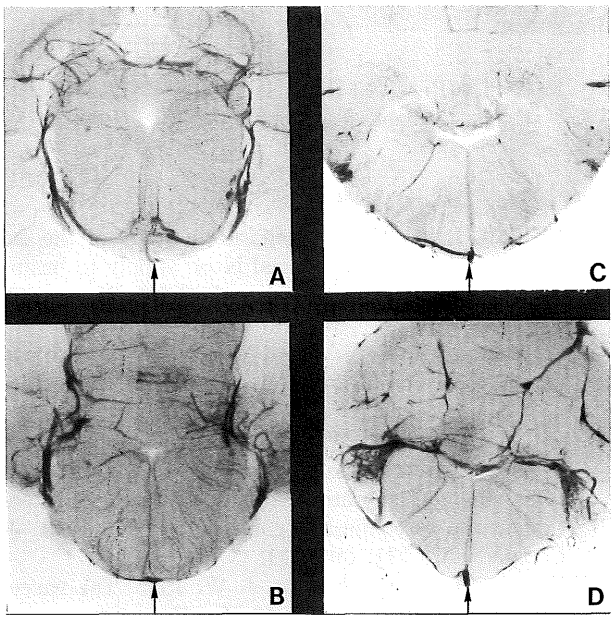


Fig. 5. Contact microangiogram
The perforating arteries are well visualized to their ends. There are more perforating arteries in the ventrolateral region of the brainstem than in the ventromedial region.
A : upper pons
B : lower pons
C : upper medulla oblongata
D : lower medulla oblongata
arrow : basilar artery

d) Short circumferential branches (SCBs)

The cranial basilar artery had approximately 7 SCBs running between the LCB on both sides, and their origin diameters were about 40 μm. There were only 1 to 2 SCBs arising from the caudal basilar artery.

3. Contact microangiograms (Fig. 5)

The perforating arteries branched at right angles from the circumferential branches and penetrated into the brainstem perpendicularly. These perforating arteries had no anastomoses inside the brainstem.

DISCUSSION

In an animal experiment, especially when studying the experimental cerebral ischemia, it is important to understand the cerebral vascular anatomy involved. Having precise knowledge about the vascular anatomy of the brain facilitate easier recognition of detailed pathological lesions. However, there are only a few reports[1-3,5,6] describing the microvascular anatomy of the brain particularly the microvascular architecture of the brainstem in cats. The vascular anatomy of the brain can be observed using angiograms, molded vascular models and contact microangiograms. Angiography can be performed in living animals. Using this method it is possible to measure the diameter of blood vessels accurately under physiological conditions. Molded vascular models and contact microangiograms are particularly suitable for observing the presence of arterial anastomoses. The procedures for these two methods, however, are complicated. Care must be taken not to injure fine branches during preparation. In the present study, the diameter and course of major branches of the basilar artery were investigated by angiography. The arterial anastomoses were evaluated both between circumferential branches and between perforating arteries using molded vascular models and contact microangiograms. In contact microangiograms, the perforating arteries had no anastomoses, indicating that the perforating arteries are end-arteries in cats. It has been reported that the perforating arteries of the brainstem are end-arteries in human[4]. The frequency of anastomoses was higher and the diameters of the anastomotic vessels were larger in the ventrolateral region of the cat brainstem than in the ventromedial region. Both the SCBs and the LCBs were considered to be important vessels that perfuse the ventromedial region, while LCBs per-

Table 1. Diameters of vessels in vertebrobasilar system
The original segment of BA is larger than the terminal segment of VA, because the original segment of BA consists of the union of bilateral terminal segments of VA.
Note that the S.D. is very small which shows that the size of the artery is stable in cats.

Diameters of vessels

	Vessels	Mean (mm)	Maximum (mm)	Minimum (mm)	S.D. (mm)
1	Terminal segment of the VA	0.73	0.97	0.58	0.10
2	Original segment of the BA	0.77	1.02	0.62	0.09
3	Terminal segment of the BA	0.62	0.78	0.52	0.06
4	Original segment of the ICA	0.53	0.75	0.40	0.07
5	Original segment of the PCA	0.54	0.75	0.37	0.07
6	Original segment of the SCA	0.52	0.67	0.38	0.07
7	Original segment of r. caud.	0.62	0.90	0.43	0.13
8	Original segment of tr. basil.	0.60	0.83	0.37	0.09

(n=33)

fuse the ventrolateral region. These facts suggest that the ventromedial region of the brainstem is more easily damaged than the ventrolateral region when the basilar artery is occluded experimentally.

CONCLUSIONS

1. The microvascular architecture of the brainstem was observed in cats using vertebral angiography, molded vascular models and contact microangiograms.

2. We derived five main conclusion.

1) A caudal ramus of the internal carotid artery was found in all animals. Both the internal carotid and vertebrobasilar systems supplied the brainstem.

2) Paramedian branches penetrated in a retrograde fashion from the cranial basilar artery.

3) Paramedian branches penetrated in an anterograde fashion from the caudal basilar artery.

4) Arterial anastomoses were noted between the circumferential arteries. The frequency of arterial anastomoses was higher and the diameters of the anastomotic vessels were larger in the ventrolateral region of the brainstem than in the ventromedial region.

5) Regarding the perforating arteries, the arterial anastomoses were present outside the brainstem. No arterial anastomoses were found inside the brainstem.

(Received June 1, 1990)
(Accepted August 9, 1990)

REFERENCES

1. **Gillilan, L. A.** 1967. Comparative study of the extrinsic and instrinsic arterial blood supply to brains of submammalian vertebrates. J. Comp. Neur. **130**: 175–196.
2. **Gillilan, L. A.** 1976. Extra- and intra-cranial blood supply to brains of dog and cat. AM. J. Anat. **146**: 237–254.
3. **Gillilan, L. A. and Markesbery, W. R.** 1963 Arteriovenous shunts in the blood supply to the brains of some common laboratory animals with special attention to the rete mirabile conjugatum of the cat. J. Comp. Neur. **121**: 305–311.
4. **Hachinski, V. and Norris, J. W.** 1985. The vascular infrastructure. pp. 27–40. *In*, The acute stroke. F. A. Davis Company. Philadelphia.
5. **Motozato, Y.** 1956. Experimental studies on the angioarchitecture and the function of the cerebral artery. Acta Medica. **26**: 27–30.
6. **Nishimaru, Y.** 1963. Arterial anastomoses in the dog brain. F. A. Medica. **54**: 998–1006.