

# Cerebral Blood Vessel Morphology

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## 1. Introduction

The most important function of blood vessels is to supply the entire body with blood pumped from the heart. Consequently, the circulatory system has often been described as a complex structure comprising many diverging pipes that together form a life-giving network. However, blood vessels also have a regulatory role, which is to supply each system of the body with an appropriate volume of blood. There are various methods of determining blood vessel distributions, and there is still room to improve methods for viewing and analyzing the morphology of these vessels.

Blood vessels are generally classified into types based on whether they form the aorta (large artery), arterioles (small artery), capillaries, venules (small veins), or veins, each of which has a different role and structure. For example, arterioles with a diameter  $< 100 \mu\text{m}$  regulate blood pressure and local blood flow, while capillaries exchange matter between blood and organs. Veins not only carry blood back to the heart, but also temporarily store blood.

The brains of higher animals are controlled by higher order nerves with diverse structures and functions: this is reflected by the diversity of cerebral blood vessels and differences based on their location. Blood flow and capillary density vary greatly in each region. Moreover, cerebral blood vessels have various flow and distribution parameters that are characteristic for each animal species. The degree of development of the animal depends greatly on the size and structure of its brain.

## 2. Characteristics of Cerebral Blood Circulation

Although the brain accounts for approximately 2–3% of body weight, the amount of circulating blood can reach up to 15%. The brains of higher animals are supplied with blood from the internal carotid (artery at the neck) and vertebral arteries. These arteries form a unique junction, known as the circle of Willis, at the base of the brain. The anterior, middle, and posterior cerebral arteries exit here and supply blood to each part of the brain (Fig. 1).

Cerebral arteries are divided into cortical (of surface tissue) and central branches. The former flows along the cortical surface of the cerebrum and diverges repeatedly, gradually becoming smaller, and eventually forming an arteriole

that enters the cortex at an angle close to  $90^\circ$  from the brain surface. The central branch directly enters the parenchyma (inner tissue) as a small branch from a large blood vessel close to the circle of Willis and sends blood to the basal ganglia (masses of nerve cells located slightly below the center of brain hemisphere) and thalamus (tissue connected to various sensory organs) inside the brain. The central branch is also known as the perforating branch because of its morphology (Fig. 2). The central branch is a common site for vascular lesions (defect of blood vessel) such as hypertensive cerebral bleeding, and there are currently many studies of blood flow and pathological changes in this area.

## 3. Visualization of Cerebral Blood Vessels

Recently, it has become possible to observe blood vessels clearly through X-ray images. However, the resolution for observing blood flow in vessels smaller than arterioles remains inadequate. Figure 3 depicts a blood vessel specimen obtained from a cat brain. In this image, most of the arteries are  $< 50 \mu\text{m}$  in diameter. The intravascular lumen (vacant part) was visualized by injecting silicone resin into the blood vessel and by clearing the surrounding tissue with methyl salicylic acid. Micrographs of the specimen were taken and the blood flow could be traced by joining many images together. Repeated divergences and bending or snaking can be seen.

In Fig. 4, blood vessels close to the circle of Willis in a cat brain are shown. Strong bending and snaking was found even in the large arteries. This is a characteristic of the brains of higher animals. Blood flow characteristics differ depending on the animal; blood vessels in the brains of mice and rats are often straight, and bending and snaking are rarely seen.

## 4. Quantitative Evaluation of the Vascular System

It is important to understand vascular architecture in various organs from a biofluid mechanical point of view. Suwa (1969) conducted a systematic study in an attempt to answer this problem. At the time of dissection, they injected acrylic resin into blood vessels, and after polymerization, they dissolved the tissue with a strong alkali to create a resin mold of the blood vessels. They then measured the length and diameter of each blood vessel and calculated the pressure drop in the blood vessel by applying modified Hagen–

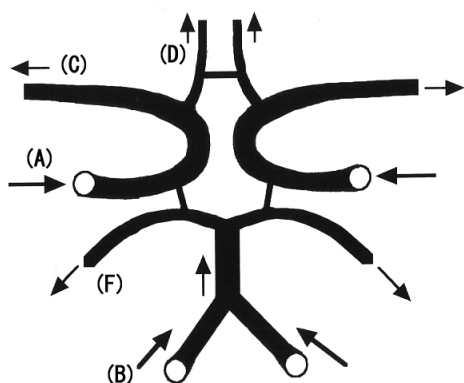


Fig. 1. Schematic illustration of the circle of Willis. (A): internal carotid artery, (B): vertebral artery, (C): middle cerebral artery, (D): anterior cerebral artery, and (E): posterior cerebral artery.

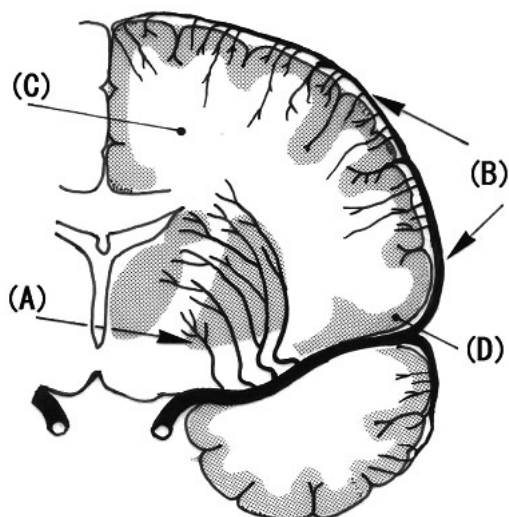


Fig. 2. Perforating arteries (A) and cortical arteries (B). (C): white matter and (D): grey matter.

Poiseuille's law (a law for flows through circular pipe) with considering the non-Newtonian nature of blood viscosity. This method was applied for all vessels from the main arteries to the capillaries. By charting the relationship between the vascular diameter and blood pressure drop, the vascular distribution of each structure and organ could be quantified. In the case of the cortical branch running along the brain surface, compared with other structures such as the kidneys, a blood pressure drop in blood vessels  $< 100 \mu\text{m}$  in diameter was common. This type of research targeting all vascular forms is important not only for clarifying the characteristics of cerebral circulation, but also for determining the mechanism of development of various vascular lesions.

Fractals are also often applied to blood vessels (Matsushita, 1992). However, since blood vessels diverge three-

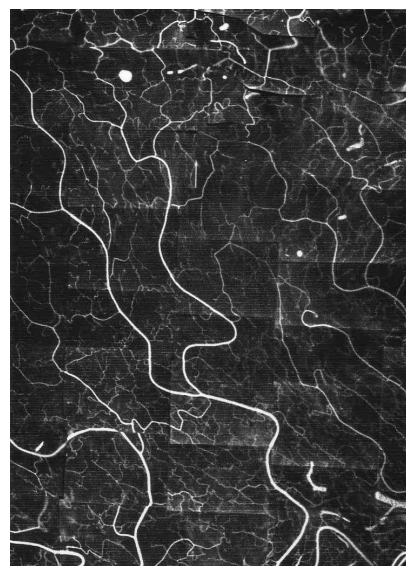


Fig. 3. Pial (soft membrane covering entire surface of brain) arteries distributing on the cortical surface of the brain.

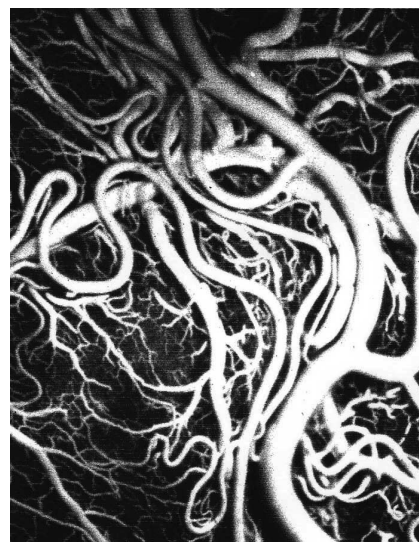


Fig. 4. Large arteries in the basal part of the brain.

dimensionally, analysis of computer images, as well as prepared specimens, is difficult. In a quasi-two-dimensional image of blood vessels on the surface of a cat brain (Fig. 3), the fractal dimension is roughly 1.7–1.8, but this value varies depending on the animal studied. Similar to the morphology of nerve dendrites, it is thought that the blood vessel distribution is more uniform than fractal structure, and the branching structure itself does not have rigorous self-similarities (Mandelbrot, 1983).

When an optimum principle is applied to blood vessels, we obtain a rational expression  $Q \propto D^3$  (cubic law) between the blood vessel diameter ( $D$ ) and its quantity of flow ( $Q$ ). Furthermore, through this principle, the functional relationship of the vascular diameter and branch angle at the vascular branching point is determined. Predictions made from these theories are considered suitable for explaining the morphology of the circulatory system. How-

ever, recent developments in vascular/blood flow measurement techniques have indicated that organisms deviate from the cubic law. Particularly in the case of the brain, strong bending and snaking can be seen, as shown in Figs. 3 and 4, which cannot be explained by the optimum principle. Further research to obtain more accurate measurements in organisms is required to derive the applicability of the optimum principle to organisms.

## References

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