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Summary. The microcirculation of the bullfrog kidney was studied by scanning electron microscopy of the corrosion casts. The bullfrog kidney derives its blood supply from a dual origin: one is from the posterior half of the body via the renal portal veins and the dorso-lumbar veins, the other is from the urogenital arteries.

The renal portal veins are linked with the hepatic portal system through the anterior abdominal vein which might serve as a transport route of the potentially renal portal blood to the kidney.

The glomerulus consists of several lobules of anastomosing capillaries which are intercalated between the afferent and efferent arteriole. The efferent arteriole of the glomerulus runs some distance ventrad without branching to join the peritubular sinusoidal capillaries near the ventral surface of the kidney. Usually each glomerulus has a single efferent arteriole, but double efferent arterioles may rarely occur. Near the medial border of the kidney the glomeruli are small, and laterally they become progressively larger.

It is well known that the bullfrog kidneys are paired organs of flattened spheroid shape located retroperitoneally in the dorsal wall of the abdominal cavity on both sides of the vertebral column. The renal portal system is the fundamental vascular feature common to fish, amphibia, reptiles, birds and the mesonephros of fetal mammals. It is indispensable for comprehension of the microcirculation of the amphibian kidney to clarify the venous system associated with the kidney, which nevertheless does not seem to have been studied sufficiently. Therefore the first part of this paper will deal with the venous system associated with the kidney.

The vascular architecture of the glomerulus has been a subject of controversy. Some early investigators (JOHNSTON, 1899; OHTA and TAJIRI, 1954; HALL, 1955; BOYER, 1956) reported that the glomerulus in man and various vertebrates, amphibia included, consisted of a network of anastomosing capillaries. Others, however, reported that the glomerulus is a system of capillary loops (VIMTRUP, 1928; MÖLLENDORF, 1930; WILMER, 1941; ELIAS, 1957; BARGMANN, 1967). The studies of these early authors were based on the light microscope observations of corrosion casts (VIMTRUP, 1928; OHTA and TAJIRI, 1954; HALL, 1955; ELIAS, 1957) and of serial sections of injected
kidneys (JOHNSTON, 1899; VIMTRUP, 1928; HALL, 1955; BOYER, 1956; ELIAS, 1957). However, these methods are, as pointed out elsewhere, insufficient for demonstrating the exact three-dimensional arrangement of fine vessels such as those of the glomerular capillaries.

Recently application of scanning electron microscopy (SEM) to study of vascular casts revealed that the glomerulus of the rat kidney consisted of lobules each of which was composed of an anastomosing capillary network (MURAKAMI, 1971, 1972). The vascular injection method with methyl methacrylate was established by TANIGUCHI et al. (1952) for light microscope study of microcirculation and came to be applied to SEM studies by MURAKAMI (1971). Although this method produces excellent vascular casts, the procedure preparing the injection material is rather complicated and troublesome. By using a new, commercially available injection medium (Mercox, Oken Shyoji Co. Ltd.), the authors re-examined the entire vascular arrangement of the bullfrog kidney under the SEM.

MATERIALS AND METHODS

Bullfrogs, Rana catesbeiana of 15–20 cm in body length were used. Some of them were dissected macroscopically, and the arterial and venous systems associated with the kidney were observed. Others were used for preparation of vascular casts. After ligating one side of the aortic arch, a cannula was inserted into the opposite arch and perfused with a saline solution through the cannula. Methyl methacrylate injection medium (Mercox, Oken Shyoji K. K.) was then injected through the cannula. After the injected medium was sufficiently polymerized, the tissues were corroded by immersion in a 10–20% NaOH solution (60–80°C) and washed gently in running water. The vascular casts thus prepared were frozen in water, cut into suitable blocks with a razor blade and air dried. They were fixed on metal stubs with silver paste, microdissected under a stereomicroscope in order to expose interesting structures, and evaporated with gold or platinum-palladium. The microdissected specimens were observed in a SEM (JSM-U3) with an accelerating voltage of 5 kV (for details of the technique see: OHTANI and MURAKAMI, 1978: OHTANI, 1979).

RESULTS

The bullfrog kidney receives blood from the hind limbs through the renal portal vein continuous with the common iliac vein which is formed by the joining of the external iliac vein and the satic vein. Blood also enters from the dorso-lumbar body wall by way of another portal vessel, the dorso-lumbar vein. The femoral vein ramifies into two branches, the external iliac and pelvic vein. The pelvic vein, after connecting with the epigastric vein, goes medially in the ventral abdominal wall. The right and left pelvic vein join each other and form the anterior abdominal vein which goes cephalad in the anterior abdominal wall and joins the hepatic portal system (Fig. 1).

The renal portal vein runs cephalad at the dorso-lateral surface of the kidney and issues numerous branches which continue branching and anastomosing to form

Fig. 2. Overview of the vascular casts of the bullfrog kidney. A ventral view, B dorsal view. *pvc* Posterior vena cava, *da* dorsal aorta, *rpv* renal portal vein. × 1.5
the venous network, completely covering the dorsal surface of the kidney (Fig. 2B, 3). From the venous network of the dorsal surface issue numerous sinusoidal capillaries which run, anastomosing each other, towards the ventral surface and converge into the renal efferent veins (Fig. 1, 4, 5). These renal efferent veins are gathered into the posterior vena cava (Fig. 1, 2A).

Four to seven renal arteries (urogenital arteries) arise segmentally from the dorsal aorta. Each of them ramifies into right and left branches which go to the right and left kidney respectively. They divide further into several branches each of which, penetrating the kidney, forms the arcuate artery (Fig. 4). Small arteries are given off from the arcuate arteries radially towards the ventral surface of the kidney. These small arteries issue afferent arterioles of the glomeruli which lie at the ventral third of the organ (Fig. 4). The efferent arteriole of the glomerulus runs some distance ventrad without anastomosing and near the ventral surface joins the sinusoidal capillaries issued from the branches of the renal portal veins (Fig. 4-6).
Fig. 4. Scanning electron micrograph showing the transverse section of the vascular cast of the bullfrog right kidney. Note that the glomeruli located medially are small and laterally they are progressively larger. *urga* Urogenital artery, *rpv* renal portal vein, *rev* renal efferent vein, *V* ventral side, *D* dorsal side, *M* medial side, *L* lateral side. Bar 1 mm
Fig. 5. Schematic drawing of the vascular distribution associated with a glomerulus (G). a Afferent arteriole of the glomerulus, e Efferent arteriole of the glomerulus, urga urogenital artery, rpv renal portal vein, rev renal efferent vein.

Fig. 6. Scanning electron micrograph showing glomeruli (G), and their afferent (a) and efferent (e) arterioles. Arrows indicate the junction sites between the efferent arterioles and the sinusoidal capillaries (SC). Bar 100 μm.
The sinusoidal capillaries in the bullfrog kidney, as measured in vascular casts, are 50–60 μm in diameter.

The glomerulus of the bullfrog kidney consists of several lobules of capillaries. These lobules are intercalated between the afferent and efferent arterioles and conglomerate into a rounded mass (Fig. 5–7). The cast of the afferent arteriole, just before entering the glomerulus, has marked constrictions which suggest occurrence of a sphincter. After the marked constrictions, the afferent arteriole becomes thicker and is divided into two to five lobular branches each of which forms the lobule of the anastomosing capillary network (Fig. 8, 9). All the capillaries, more or less, curve and twist to form capillary loops.

It turns at the urinary pole of the glomerulus towards the vascular pole to be collected into the efferent arteriole (Fig. 5, 6). The efferent arteriole leaves the glomerulus and runs parallel to the afferent arteriole for a short distance (approximately 30–50 μm). Then it turns to the opposing direction to the afferent arteriole and
runs some distance, neither branching nor anastomosing with other efferent arteries, to join the sinusoidal capillaries issued from the branches of the renal portal vein (Fig. 6). Usually each glomerulus has a single efferent arteriole, but in rare cases double efferent arterioles are issued from a glomerulus (Fig. 7).

Variations in size of the glomerulus were clearly observed. Near the medial border the glomeruli are small and more laterally they become progressively larger (Fig. 4).

**DISCUSSION**

It was confirmed that the bullfrog kidney receives blood from the hind limbs and pelvic region through the renal portal vein and from the dorso-lumbar body wall

![Fig. 8. Scanning electron micrograph of a replicated glomerulus. An afferent arteriole (a), after marked constrictions (arrows), is divided into four lobular branches (1, 2, 3, 4). An efferent arteriole (e) of the glomerulus runs parallel to the afferent arteriole for about 50 µm and then turns to the opposing direction. Bar 100 µm.](image-url)
through another portal vessel, the dorso-lumbar vein. Some of the venous flow from the hind limbs, however, may bypass the kidney by way of the anterior abdominal vein in the belly wall. According to AKESTER and MANN (1969) and AKESTER (1978), the center of the complex venous system in and around the avian kidney is equipped strategically with renal portal valves which are innervated by both noradrenergic and cholinergic fibers. Such valves are not observed in the bullfrog. Recently it has been shown that through the coccygeomesenteric vein in birds, blood flows to both the kidney and the liver, and this vein may serve as a direct route to carry the potentially renal blood to the kidney (AKESTER, 1967; PURTON, 1971; SHIMADA and STURKIE, 1973). Thus, it deserves phylogenetical interest that the anterior abdominal vein in the frog which corresponds to the coccygeomesenteric vein in birds also serves as a transport route of the potentially renal portal blood to the kidney. Although the physiological significance of this vein remains to be studied, it is interesting as it directly links the renal portal system with the hepatic

Fig. 9. Scanning electron micrograph of a replicated glomerulus. An afferent arteriole (a) is divided into three lobular branches (1, 2, 3) each of which forms a capillary network. SC peritubular sinusoidal capillary. Bar 100 μm
Attention may be called to the present finding that the glomerulus of the bullfrog consists of lobules or networks of anastomosing capillaries, which are very similar to those of the rat demonstrated by SEM (Murakami, 1972) and those of various vertebrates reported by early investigators (Johnston, 1899; Ohta and Tajiri, 1954; Hall, 1955; Boyer, 1956; Elias, 1957). According to Murakami (1972), the glomerular capillary tuft of the rat kidney is always divided into two to seven (usually three to five) lobules. The glomerular capillary tuft of the bullfrog, however, is simpler than that of the rat and is usually divided into two to four lobules.

The occurrence of double efferent arterioles in the mammalian glomerulus has been reported by many authors who used conventional light microscopes (Boening, 1936; Shonyo and Mann, 1944; Smith, 1956; Okano et al., 1959; Muto, 1961; Moffat and Fourmann, 1963). By the use of SEM Murakami et al. (1971) extensively investigated the double efferent arterioles in the rat. We also confirmed the existence of the double vessels in the bullfrog glomerulus. The double efferent arterioles, however, apparently have no functional significance.

Attention is also given to the variations in size and vascularization of the glomeruli. Near the medial border of the kidney, the glomeruli were small and laterally they were progressively larger. This fact was initially reported by Dawson (1951) who studied the Australian desert frog. He stated that the best developed glomeruli were those farthest from the dorsal aorta. However, in our study, the distance from the dorsal aorta to the best developed glomeruli was shorter than to less developed ones. The afferent vessels to the best developed glomeruli arose from the proximal part of the arcuate artery (Fig. 4). This fact possibly means that the glomeruli supplied most amply with arterial blood are the best developed ones.

ウシガエルの腎血管分布——銅型の走査電子顕微鏡による研究

大谷 修 と 内藤一郎

銅型の走査電子顕微鏡観察により ウシガエル腎の微小循環を調べた。ウシガエルの腎は二重の血液供給を受ける。一つは腎門脈と腰背靜脈により体の後半の血液を受け、他は泌尿生殖動脈からである。

腎門脈は、前腹靜脈によって肝門脈系とつながっている。前腹靜脈は潜在的な腎門脈血を腎に逆流可能性がある。

糸球体は吻合した毛細血管網からなる数個の小葉で構成され、輸入・輸出血管の間にある。輸出血管は、腹方に互に吻合することなく走った後、腎の腹側表面近くで、尿細管周囲の円柱毛細血管に吻合する。通常、輸出血管は1本であるが、稀に2本のことがある。腎の内側近くの糸球体は小さく、外側程大きい。
REFERENCES


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