Cubical Anatomy of Several Ducts and Vessels by Injection Method of Acrylic Resin

VI. On the vascular system of the kidney in *Macacus cynomolgus*

By

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(With 25 figures in 3 plates, and 1 table)

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Preface

Previously, by means of the acrylic resin injection method, Ohta and Tajiri in this laboratory have reported finer arterial ramifications beyond the arcuate artery in some mammalian kidneys in 1954. So far, works on the renal vasculature of other monkeys and apes have been presented only by Morison ('26), Uchino ('50) and Takahata et al. ('58). The authors observe the renal vasculature of *Macacus cynomolgus* and obtain some important views in comparison with the renal circulation of other mammals.

Materials and Methods

Three of *Macacus cynomolgus* about two years old are used. For injecting the acrylic resin and making corrosion specimens, the method by Taniguchi, Ohta and Tajiri ('52) and its supplement ('55) are adopted. Injected kidneys are made into six cor-
rosions, and the half of them are injected into both artery and vein, and the other half into the artery alone. The renal artery is injected

in situ with the red-coloured resin through a cannula inserted into the renal artery or the abdominal aorta, and the renal vein with the blue-coloured resin through the renal vein. Observation and micrometry are effected on the corrosions under the microscope and binocular magnifier. Thicknesses and lengths of afferent arterioles, the size of glomeruli in shape of oval or globoid and thicknesses of efferent arterioles are measured respectively on more than 100 parts of each item in the cortex corticis, cortex proper and corticomedulla.

Observations

A. Arterial system

Intercorticomedullary Artery, its Secondary and Interlobular Artery

Neither long intercorticomedullary nor arcuate artery is found. The artery and its secondary are generally short. But, a few of the secondaries are somewhat longer and oblique to the renal surface. Interlobular artery, left the above arteries, does not show any specific feature. But, its end is peculiar to the monkey in use. Three forms are shown under:

(1) The first type is evident in most cases. The end of the interlobular artery divides, in the superficialmost cortex and the deep of the cortex corticis, into two or three branches which make a bend at angles of 45-90°; or the end bends without splitting. Both run in the cortex corticis in a short distance tangentially to the renal surface, and each ramifies not more than seven or eight afferent arterioles (Figs. 4, 5, 6 and 7), and many of them show a tendency to droop inwards.

(2) The end of the interlobular, without bending, divides into ten or less afferent arterioles in the cortex corticis, which spread umbrellawisely in a tangential surface. These afferents not only spread tangentially, but many of them display a common tendency with the first type (Figs. 8 and 9).

(3) The interlobular in the superficial of the cortex, without bending, splits into several penicillar afferents which go ahead to the renal surface, and the efferent arteriole deriving from the glomerulus proceeds to the renal surface (Fig. 10).

Afferent Arteriole

Thicknesses of afferent arterioles are about the same in the cortex corticis, cortex proper and corticomedulla, though somewhat

larger in the last. Besides, the length of the afferent is the most in the same zone (Table).

Glomerulus

Almost of the whole glomeruli are in shape of ellipsoid, of which the vasculo-urinary polar diameter is shorter than the other (Figs. 12 and 13). While, in some glomeruli both diameters are almost the same or rather vice versa (Fig. 14). A fovea possessing Macula densa is smaller than in other mammals (Fig. 15).

Efferent Arteriole

Two efferents, starting from the vascular pole of a glomerulus, are observed as an abnormal case, but few in the superficial layer of the cortex only. In this case, their thicknesses are almost the same (Figs. 19 and 20), or at times one of them is much lesser as an accessory and splits into capillaries after a short distance, while the other one is average (Fig. 21). Thicknesses of the efferents in the cortex corticis and proper have few differences, but of those in the corticomedullary larger by about 1.2 times (Table).

In the medulla, the efferent divides into several arteriolae rectae medullares, which proceed towards the renal papilla all in parallel. As characteristics in the medulla, the thickness of the efferent at the portion just after the glomerulus is generally finer than that of just before arteriolae rectae medullares, and among those rectae few anastomoses are observed. Besides, at first fine rectae increase gradually their thicknesses (Fig. 17). These thickened rectae break in shape of a hacked end and do not show any recurring feature towards the cortex.

Arterial Branches near the Renal Hilus

Peculiar aspects not seen in other species are found near the renal hilus. Branches, directly rising from the anterior and posterior branches of the renal artery, run along the parenchymal margin of the hilus towards the lateral side. They pass tangentially and somewhat radially just beneath the fibrous capsule and diverge into short branches close to the hilus and then the branches spread into the afferents (Fig. 1). These branches in thickness are about 240μ almost as thick as the interlobulars. In one kidney, such branches, one to three on the anterior side as well as the posterior, are recognizable. The authors' opinion is to call them *Aa. subcapsulares hili renali*.

Aa. perforantes adipocapsulares

These are continuances of some interlobular arteries. The ends (90-120 μ) of them, without dividing into the afferents, perforate through the capsule vertically or obliquely to the renal surface (Fig. 18). Then, they run into Capsula adiposa and spread into capillaries, but few in number in the monkey used. Penetrating portions are limited at the lateral margin of the kidney.

Direct Vessels to the Parenchyma

Sources of direct vessels, not passing through glomeruli, are the intercorticomedullary artery, its secondary and the interlobular. Arteriolae rectae verae s. medullares rising from the former two are not so many observed (Fig. 25). A few of direct vessels on the way of the interlobular are also observed (Figs. 22 and 23). Arteriolae stellatae at peripheries of the interlobulars are found in the superficialmost cortex (Fig. 24).

B. Venous system

Venous system of the cortex does not show a good development in general.

Stellate Veins

The stellates are not shown on the surface of corrossions, because they are situated in the depths of the cortex corticis. So the whole aspect of them are not given to see until capillary plexuses entering them are removed (Fig. 3). The branching feature of the stellates is irregular, from narrow angle to wide. Each branch of the stellates is unequal in thickness (80-250 μ) and makes curves in variable depths and zig-zag in horizontal. Raised edges of the curving branches often come in touch with the under surface of Capsula fibrosa. Any characteristic leaf-nerve figures, made of venous capillary plexuses and venules, pouring into the stellates in dog and cat (Ohta '54), are not observed.

Interlobular Veins, Superficial and Deep Cortical Veins

Veins, taking courses from the superficial layer of the cortex to the corticomedullary, are nothing but continuances of stellate veins. These continuances are variable in thickness (200-350 μ) and pour into the intercorticomedullary veins or the interlobulars. Superficial (70-96 μ) and deep (100-120 μ) cortical veins are not developed

typically. Hence, venous branches often rise from various depths of the cortical parenchyma and run tangentially or obliquely, then pour into intercorticomedullary veins, the secondaries of them or interlobulars. Among all these veins, the branches or part of them running to the renal surface subrectangularly, are parallel with interlobular arteries.

Venous Branches from the Medullary Parenchyma

Venous capillaries from the medullary parenchyma flow directly or via venules into intercorticomedullary veins or the secondaries of them, or sometimes into venous branches running obliquely in the deep cortical layer.

Venous Branches near the Renal Hilus

In 2-3 mm. wide zone around the renal hilus, no stellate veins are found. But, in place of the stellates, several veins (96-190 μ) which rise from this limited region run right beneath the fibrous capsule, collecting the venous blood of that superficial region, towards the ridge of the hilus, and pour directly into the anterior and posterior branches of the renal vein (Fig. 2), or into interlobular veins. These veins have similar features to Aa. subcapsulares hili renali. The authors wish to call them Vv. *subcapsulares hili renali*.

Vv. perforantes adipocapsulares

The veins (190-240 μ) collect blood from distributing territories of the same named arteries, and run close with or apart from them. Then they pour into interlobular veins which are continuances of the stellates (Fig. 18).

Table

		Cortex corticis		Cortex		Corticomedulla	
		Mean	S. D.	Mean	S. D.	Mean	S. D.
Glomerulus	longer axis	135 μ	20.6 μ	146 μ	31.3 μ	147 μ	20.6 μ
	shorter axis	110	28.5	124	20.9	111	25.5
Afferent	length	154	47.8	224	119.9	272	55.9
	thickness	24	5.9	26	7.7	32	6.9
Efferent	thickness	19	4.6	18	7.5	23	5.8

Discussion

There are many studies on the mammalian renal arterial system. In particular, on corrosion specimens, Morison, Trueta ('48), Uchino, Ohta et al. ('54), Daito ('55) and Takahata et al., have effected their observations in comparative anatomy. As to the monkey kidney, Uchino made his observation of *Pithecus rhesus* Audeb, *Cercopithecus aethiops* Linneus, *Macacus fuscatus* (Blyth.), *Pithecus cyclopis* (Swinhoe) and *Saimiri sciureus*; Morison of monkey; Takahata of gorilla. No works, however, have been seen on *Macacus cynomolgus*. The authors now have had an opportunity to observe that of the *Macacus* and to compare and discuss with the other monkeys, and should like to supplement the previous results, though only on six kidneys.

As to the end of the interlobular artery, Ludwig (1844) states that its termination splits into the capillary plexus on the surface without interpolating the glomerulus, besides, Kölliker (1854) defines as arriving at Tunica fibrosa and Capsula adiposa. Virchow (1857) and Huber ('06-'07) mention that the end divides into the afferents. Ohta and Tajiri see that the end reaches Tunica muscularis and the superficial portion of cortex and diverges into the afferents, or sometimes into Arteriolae stellatae. Takahata et al. find no Arteriolae stellatae in gorilla. By Daito, in man, the interlobulars make angles of 60-90° to the renal surface. In *Macacus cynomolgus*, characteristic types are shown, that is, in the cortex corticis the end of the interlobular divides into two or three branches or without diverging, and they bend at angles of 45-90°, then spread radially and tangentially to the renal surface. With regard to directions of the afferents in the cortex corticis, they go ahead to the renal surface vertically (subcapsular type by Morison), but few in this *Macacus*. Many of the afferents spread tangentially to the renal surface, and some reverse slightly towards the medulla in shape of an umbrella. On such features, however, no reports are seen. In the cortex corticis, the lengths of the afferents are about 3/5 times of those in other layers. Average lengths in other animals shown by Ohta and Tajiri are 248 μ in cattle, 293 μ in pig, 221 μ in dog, 233 μ in cat, 189 μ in man, while by Takahata inconstant in gorilla and by Daito 201 μ in man. But, as the values in cortex are measured without separating the cortex into three layers, the values in this paper cannot be compared with theirs. Thicknesses of

afferents in the corticomedulla are the most among these three layers. They coincide nearly with that in goat (31μ) and man (26μ) by Ohta and Tajiri. Daito states thicknesses in man are 30μ in the cortex corticis, 33μ in the cortex proper and 44μ in the corticomedulla. Takahata et al. report that they are $17-31\mu$ in gorilla.

The shape of glomeruli in this species is ellipsoid or globoid in all layers with the shorter axis vasculo-urinarily. The glomerulus in the cortex corticis is smallest. The size of the glomerulus resembles those of pig ($144\mu \times 130\mu$) and dog ($147\mu \times 123\mu$) shown by Ohta and Tajiri but smaller than those of gorilla by Takahata ($160-220\mu \times 140\mu$).

Two efferents from one glomerulus are found as described by Daito. These abnormal efferents have the same thicknesses, or one is finer than the other. The efferent supplying the medulla shows a characteristic feature that the thickness of efferent in the portion just after glomerulus is generally finer than that of just before the rectae medullares, which further increase gradually the thickness.

The rectae break in shape of a hacked end and do not show any recurring feature towards the cortex in all corrosions, notwithstanding complete injection is done in the cortex as far forth as the venous capillaries. Since the rectae near the hilus run disorderly, it seems that they recur to the cortex, but without connection with the venous branches directly.

Arterial branches to the parenchyma called direct vessels are few in number as mentioned above. Arteriolae stellatae (Ohta and Tajiri) from the end of the interlobulars, and branches on the way of the interlobulars and from the intercorticomedullaries, are observed. In this species as well as other mammals, it is considered that these direct vessels are not morbid unless the appearing frequency of them is beyond bounds. Takahata et al. state that there are a few Arteriolae rectae verae in gorilla.

Near the hilus, branches diverged from the renal artery or its primaries, run right beneath the fibrous capsule and branch off to the afferents, are peculiar in *Macacus cynomolgus*. No earlier scholars describe on the above-mentioned arterial branches in either monkey or other mammals. The authors should call these branches *Aa. subcapsulares hili renali*.

Aa. perforantes adipocapsulares following the interlobulars produce the afferents in the cortex. Such interlobulars which continue

to the perforantes do not show any variation in the thickness compared with other interlobulars, the perforantes being not so thick as in some other mammals studied by Clara, and Ohta et al. Rather they seem to be an elongated type of Arteriolae stellatae by Ohta.

Venae stellatae are not so good developed as in dog and cat, but almost the same as in human kidney, by Steinach (1884), Spanner and Kiel (by Möllendorff, '30), and Ohta ('54). Uchino, however, states that the stellates develop in dog as well. Ohta announces that the stellates, showing some characteristic leaf-nerve figures constructed among well-developed stellate branches, laid right beneath the fibrous capsule, are recognizable in dog and cat. In *Macacus cynomolgus*, the stellates are situated in the cortex corticis, and they do not agree with Uchino's description. On the other hand peculiar venous branches, running right beneath the capsule, pour directly into the renal vein or its primaries, are observed near the hilus. These branches are the draining route of Aa. subcapsulares hili renali. So far, also no description on these veins is present. These veins show a miniaturized and undergrown type of subcapsular veins in cat (Ohta). On the same way of the artery, these veins are named *Vv. subcapsulares hili renali*.

Vv. perforantes adipocapsulares pour into origins of interlobular veins which are central nozzles of stellate veins, and the perforantes are returning ways of the arteries of the same name.

Conclusions

1. On kidneys of three monkeys (*Macacus cynomolgus*), fine arterial and venous vasculatures are studied by corrosion specimens injected with acrylic resin.

2. The end of the interlobular artery shows three forms as follows: (1) In the most superficial of the cortex, it divides into two or three branches; and they run tangentially to the renal surface, then each ramifies into afferent arterioles; (2) In the cortex corticis, it spreads into the afferents without bending, umbrella-likely in tangent to the surface; (3) In the same zone, it divides into the afferents in shape of penicillus going ahead to the surface, without bending.

3. As an abnormal instance, two efferents out of one glomerulus are observed.

4. Near the renal hilus, arterial branches rising from the renal artery or its primaries, run right beneath the fibrous capsule

and branch into the afferents. The branches are named *Aa. subcapsulares hili renali* by authors.

5. *Aa. perforantes adipocapsulares*, continuing from some of interlobular arteries, are found at the lateral margin of the kidney.

6. *Arteriolae rectae verae* and *Arteriolae stellatae* by Ohta et al., and direct vessels starting from the way of the interlobular artery, are found. But Ludwig's artery, Golubew's artery and *Retia mirabilia renum nova* are not observed.

7. Venous system in the cortex does not show good development. The whole view of the stellate vein is never seen without removing capillary plexuses over it because of location in the depths of the cortex corticis. The spreading extent of the stellates is irregular and somewhat small. They make curve in variable depths, and zig-zag.

8. Near the hilus, venous branches which present the same aspect as *Aa. subcapsulares hili renali* above-mentioned, are found instead of stellate veins. The authors' opinion is to call them *Vv. subcapsulares hili renali*.

9. *Vv. perforantes adipocapsulares* pour into some of interlobular veins.

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Key to abbreviations

<i>af</i> : Afferent arteriole	<i>ef</i> : Efferent arteriole
<i>cpc</i> : Capillary plexus in cortex	<i>g</i> : Glomerulus
<i>cpm</i> : Capillary plexus in medulla	

Explanation of figures

Plate I

- Fig. 1. Near the hilus, arterial branches named Aa. subcapsulares hili renali (↑) directly arise from posterior branches of the renal artery (←). C. × 8.5.
- Fig. 2. Near the hilus, venous branches named Vv. subcapsulares hili renali (↑, →) pour directly into the renal vein (↙). C. × 7.5.
- Fig. 3. Venae stellatae appear by removing capillary plexuses over them. Their courses are zig-zag in horizontal and curved in variable depths. Raised edges (→), fallen edges (↓). C. × 5.0.
- Figs. 4, 5 & 6. Superficial views of corrosions of the arterial system.
- Fig. 4. The end of interlobular artery (↓) runs in tangent to the renal surface. The end (↑) in the cortex corticis without bending divides into eight or so afferents. C. × 15.
- Fig. 5. The end of an interlobular bends in tangent to the surface (from left to right) (↓). Afferents and a stem of them (↙) derive from the end. C. × 35.
- Fig. 6. The end of an interlobular artery dichotomizes, and the branches (↖, ↗) turn to the afferents proceeding tangentially in the cortex. C. × 40.
- Fig. 7. The end of an interlobular artery (↓) divides into three (a, b, c) in the cortex. Stem of afferents (↑). C. × 45.

Plate II

- Figs. 8 & 9. Superficial views of corrosions similar to figs. 4, 5 & 6. The end of an interlobular artery ($\downarrow$) without bending in the cortex corticis, unlike figs. 4, 5 & 6, divides into eight or so afferents which spread umbrella-likely in the tangential surface. C. $\times 55$.
- Fig. 10. The interlobular artery ($\swarrow$) without bending, in the superficial of the cortex, splits into several penicillar afferents ($\rightarrow, \leftarrow$) which go ahead to the renal surface (Morison's subcapsular type). C. $\times 45$.
- Fig. 11. Very long afferent arteriole (850μ) ($\uparrow$). C. $\times 38$.
- Figs. 12 & 13. Glomeruli in shape of ellipsoid. Their vasculo-urinary polar diameters are shorter than the other. C. $\times 80$.
- Fig. 14. A glomerulus in which the vasculo-urinary polar diameter is longer than the other. C. $\times 75$.
- Fig. 15. Fovea interarteriosum ($\rightarrow$), in which Macula densa is involved. C. $\times 75$.
- Fig. 16. Glomerulus of Morison's corticomedullary type. C. $\times 45$.
- Fig. 17. Glomerulus of Morison's medullary type. The fine rectae increase gradually their thicknesses. C. $\times 35$.
- Fig. 18. A. perforans adipocapsularis ($\searrow$) continuing from the interlobular artery ($\rightarrow$). V. perforans adipocapsularis ($\nwarrow$) pouring into the interlobular vein ($\leftarrow$). Adiposal tissue ($\times$). C. $\times 10$.

Plate III

- Figs. 19 & 20. Two efferents of the same thickness derive from a glomerulus. C. $\times 75$. C. $\times 160$.
- Fig. 21. Two efferents derive from a glomerulus. One of them is normal ($\uparrow$), and the other very lesser in thickness as an accessory ($\downarrow$). C. $\times 75$.
- Figs. 22, 23, 24 & 25. Direct vessels to the renal parenchyma.
- Figs. 22 & 23. Two (Fig. 22, C. $\times 45$) and one (Fig. 23, C. $\times 65$) of arterioles ($\swarrow$), branching from the way of the interlobular artery ($\leftarrow$), spread into the parenchymal capillary plexus.
- Fig. 24. The end of the interlobular artery divides into two branches ($\rightarrow, \leftarrow$), which ramify into the capillary plexus without passing through the glomerulus in the cortex corticis (Ohta's Arteriolae stellatae). C. $\times 65$.
- Fig. 25. Arteriolae rectae verae ($\leftarrow$) and spuriae ($\rightarrow$) in the medulla. C. $\times 15$.