

THE ARTERIOLÆ RECTÆ OF THE MAMMALIAN KIDNEY.¹

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WITH 4 TEXT FIGURES.

In a comprehensive and relatively recent contribution on the blood supply of the mammalian kidney, Golubew¹ calls attention to the differences of views still existing concerning the minute anatomy of this organ and states that of these controversial questions special mention may be made of the "vasa recta of Henle and Donders or of the arteriolæ rectæ of authors." A study of the literature which is fully reviewed by Golubew leads him to state that at the time of his communication three views were current pertaining to the origin of the arteriolæ rectæ. According to one view, these vessels arise from the vasa efferentia of the glomeruli which lie nearest to the pyramid of the kidney, a view early expressed by Bowman who was followed by Gerlach, Kölliker, and Ludwig in their earlier writings. According to another view, recognition and prominence are given to the arterial branches forming straight medullary vessels which arise directly from the renal vessels and their branches without the interposition of glomeruli and known as the arteriolæ rectæ veræ. According to a further view maintained by Huschke and other observers, the origin of the arteriolæ rectæ was traced to the capillary plexuses surrounding the tubules of the cortex of the kidney. Steinach, who denies the existence of arterial straight medullary branches, presents a view which cannot be included in the above classification and may be disregarded as his observations have not met with acceptance. Virchow and many other observers who have followed him have to some extent harmonized these conflicting views by assuming what may be regarded as a middle position in that they recognize the arteriolæ rectæ veræ, vessels

¹Golubew: Ueber die Blutgefäße der Niere der Säugetiere und des Menschen. International monatsschr. f. Anat. u. Physiol., Bd. X, 1893. Gives references to literature appearing before the date of his publication.

which arise directly from the renal vessels, but concede the presence of straight medullary vessels which have their origin in the efferent branches of the glomeruli situated in the deeper layers of the cortex and known as the arteriolæ rectæ spuria. Golubew, whose very careful work has justly received merited consideration, describes and figures both arteriolæ rectæ veræ and spuria. A study of the diagrams of the renal circulation as found in the recent text-books of Anatomy and Histology warrants the conclusion that the majority of the present day writers believe in the double origin of the arteriolæ rectæ, namely in part directly from the renal vessels, for the remainder, from the efferent branches of glomeruli.

Of the various methods that have been used in the study of the arteriolæ rectæ, the injection methods in one form or another are given preference. Golubew used colored gelatin masses injected through either the renal artery or vein, but more particularly a solution of silver nitrate which was injected into the vessels after these had been thoroughly washed out with distilled water. The silver nitrate was injected under low pressure and the injection interrupted as soon as reduction of silver was evident in the capsule of the kidney, after which the vessels were again washed out with distilled water, the organ divided into pieces, placed in alcohol and exposed to light. Free hand sections, dehydrated and cleared in oil of cloves and mounted in damar were used for study. Corrosion preparations of the renal vessels obtained mainly with the celloidin method have enabled Brödel² and others who have confirmed him to extend our knowledge of the general distribution, relations, and manner of termination of the renal vessels. The results thus obtained have also been confirmed in Roentgen photographs taken after suitable injection of the renal vessels. Particular attention was, however, not given to the arteriolæ rectæ by these observers.

The observations here briefly to be recorded were made on a series of corrosion preparations of the renal vessels of the dog, cat, rabbit, rat, and guinea pig made after a method which is a modification of one suggested by Krassuskaja.³

This observer recommended an injection mass consisting of photoxylin (or celloidin), camphor and acetone, colored by the addition of pigments rubbed up in acetone. (For a red color, cinnabar is suggested; for a blue, Berlin blue; a yellow, chrome yellow; a black, asphalt.) The mass may be

² Max Brödel: The Intrinsic Blood-Vessels of the Kidney and Their Significance in the Nephrotomy. Proc. Ass. Amer. Anat., 1901.

³ A. Krassuskaja, as reviewed by Stieda in *Ergeb. Anat. u. Entwickl.*, Bd. XIII, 1903, p. 521.

filtered through flannel or muslin. Injection may be made by means of an ordinary syringe; it is only necessary to fill the cannula with acetone. The tissue or organ is placed into hydrochloric acid 12 to 24 hours after the injection and is removed from the acid after two or three days and washed in flowing water. The pigments suggested by Krassuskaja are not soluble in acetone and are, therefore, only held in suspension. The mass did not seem to me suitable for injecting capillaries and other exceedingly fine tubular structures. This led to a modification of it and the mass now used in this laboratory is as follows:

To obtain a stock solution, 30 grms. of photoxylin are dissolved in 550 cc. of acetone, which requires about 24 hours. Twenty grms. of camphor are dissolved in 50 cc. of acetone. The two solutions are then thoroughly mixed

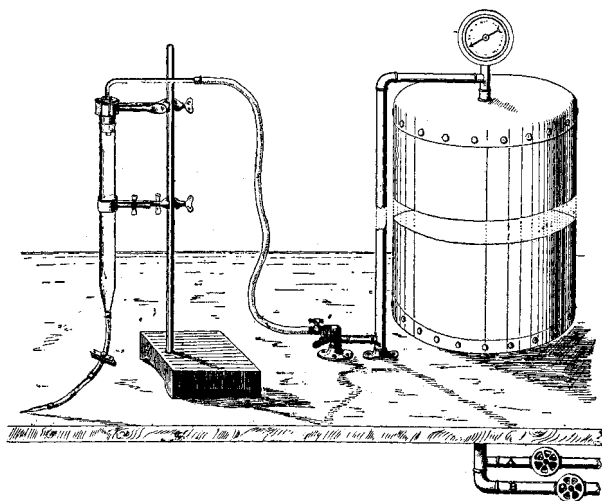


FIG. 1. Injection apparatus: A, pipe carrying water to tank; B, conveying water from tank and connected with waste-pipe. For further details see text (page 394).

in a bottle with a well-fitting glass stopper. This stock solution may be kept for a long time. After experimenting for a long time, it was found that Alkanin⁴ answered very well for the purpose of a red color. It is readily soluble in acetone, is not washed out of the preparation with water, alcohol, or xylol, and is not decolorized in the hydrochloric acid. It is the only substance soluble in acetone and meeting the other requirements which I have thus far been able to find. The preparation of alkanin first used was one that had been in the laboratory a long time and had become hard and brittle. The alkanin, as obtained from Gruebler, is in the form of a thick paste. Later observations have shown that the dried form answers the purpose better than a fresher preparation. The injection mass now used is made by

⁴ Fettlösliches Roth, Gruebler, also written Alcanin.

adding 0.3 to 0.5 grms. of the alkanin rubbed up in 20 cc. of acetone to 80 cc. of the stock solution, thoroughly mixed by stirring in a mortar and then filtered through absorbent cotton with the aid of a Chapman suction pump. For purposes of injection, I have made use of compressed air, obtained by connecting a water tank with the laboratory water pipe. The tank is provided with a pressure gauge, from which the pressure obtained is read. The pressure is conveyed to the table by means of a gas-pipe, provided with a stop-cock. The injection mass is placed in a large glass tube with 3 cm. lumen and about 20 cm. long, held upright by clamping the same to a support. The upper end of the tube is provided with a perforated rubber cork, which can be clamped in tightly. A rubber tube leads from the end of the pipe bringing the compressed air to the table to a short glass tube fastened in the rubber cork, by means of which the pressure is conveyed to the injection mass. To the lower end of the glass tube, which tapers, is attached a rubber tube, provided with a clamp, by means of which connection may be made with the cannula. The simplicity of this apparatus commends itself. It is shown in Fig. 1. As is usual in injections, better results are obtained by injecting a limited area, that is directly through the blood-vessel supplying the organ to be studied. It has not been found necessary to wash out the blood-vessels before injecting. The animal is bled as freely as possible by severing the neck-vessels before death. The administration of amyl nitrite does not appear to influence materially the completeness of the injection. The injection is to be made soon after the death of the animal. The cannula is first filled with normal salt, and the salt solution renewed by means of a pipette until it remains clear in the cannula. It is then replaced with acetone, which is likewise renewed several times to dehydrate the interior of the cannula. If the area to be injected is very small, a portion of the acetone is withdrawn from the cannula and this is filled with the injection mass. Better results are obtained by using relatively high pressure. In injecting the renal arteries of the dog, cat, and rabbit, a pressure of 20 to 25 pounds, as registered by the gauge connected with the tank, gave the best injection; for smaller animals, 12 to 15 pounds. Better results are also obtained if the full pressure to be used is thrown onto the mass as quickly as possible. The pressure is maintained for five to ten minutes. Before removing the cannula from the vessel, the vessel should be tied distal to the cannula, so as to avoid a back flow. A 75 per cent solution of hydrochloric acid (sp. gr. 1.20) is used for macerating the parts to be removed. The entire organ may be placed in this macerating fluid, or, as it is often desirable to study a corrosion in small pieces, the organ may be cut into segments as desired and these placed into the macerating fluid. The injected tissue may be placed into the macerating fluid 10 to 20 minutes after the completion of the injection; there is no advantage in waiting 12 to 24 hours, as recommended by Krassuskaja. Pieces with one diameter not more than 1 cm. are thoroughly macerated in 18 to 24 hours. The macerated pieces are then transferred to a large dish of water and the softened tissues removed by playing water against them with a dropper provided with a rubber bulb. It is not advisable to use a stream of water with considerable force, as the delicate parts of the corrosion are likely to be injured. After the corrosion has been thoroughly cleaned, it may be allowed

to dry or it may be studied in water. I have found it advantageous to mount in balsam the parts to be studied particularly. If this is desired, the thoroughly cleansed corrosions are placed in distilled water for several hours, are then dehydrated in absolute alcohol, transferred to xylol and mounted in balsam, the cover glass being supported by fragments of glass of the required thickness. These preparations should be viewed with a binocular microscope giving stereoscopic vision.

This method has proven very satisfactory in the study of the renal vessels, as it has often been possible to obtain corrosions in which the course of the vessels could be readily followed through their several divisions until the capillaries are reached. In such preparations, a confusion of arterial and venous branches is not possible. The method enables a definite solution of the course and divisions of the major branches of the renal artery, of the radiate cortical branches (*arteriæ interlobulares*), of the origin of the afferent branches to the glomeruli and of the fate of the efferent glomerular branches. It is the purpose at this time to consider primarily the *arteriolæ rectæ* and other efferent glomerular branches; a fuller consideration of the renal vessels, both arterial and venous, is reserved for further contribution.

As is well known, the renal artery, on entering the hilus of the kidney, divides into branches which, after division, course in the peripheral part of the pyramid near the junction of the medullary and cortical portions. (This statement has reference to the kidneys particularly studied, namely, those with a single pyramid.) These major branches, which in their course undergo several subdivisions, have a direction which is in the main parallel to the surface of the kidney; they describe, therefore, arcs with convexity outward, and constitute the arterial branches designated as arcuate arteries (*arteriæ arciformes*). From the convex side of these arcuate arteries, there arise at intervals of 2 to 5 mm. branches which very generally form an acute angle with the arcuate artery and pass with slight inclination toward the cortex. The length of these branches varies, and from their outer side, that toward the cortex, there arise short branches at relatively close intervals which pass toward the periphery of the kidney and very generally subdivide into several branches from which arise the so-called interlobular arteries (*arteriæ interlobulares*). The arcuate arteries ultimately terminate in smaller branches which also give origin to interlobular arteries. Golubew simply states that from the convex side of these arches (*arteriæ arcuatæ*), as also from the terminal divisions, arise the interlobular arteries. Von Ebner⁵ after mentioning

⁵ In Kœlliker's Handbuch, Vol. III, Pt. 1, page 369.

the arteriæ arciformes, states that "from the cortical side of these there arise with great regularity and mostly at right angles small arteries which, after several or more repeated divisions, end in fine branches of 135 to 220 μ caliber, which, with a straight course, pass outward between the cortical fasciculi (Rindenfascikeln) or lobules and are most appropriately termed the arteriæ interlobulares." If the designation arteriæ arciformes is retained for arterial branches having an arched course, relatively large branches arising from these and passing through two to three further subdivisions need to be recognized before arterial branches known as the arteriæ interlobulares are reached. The usual description of the interlobular arteries is also open to question. Arterial branches passing quite regularly with radial course through the cortex as generally diagrammed are seldom met with. This must be evident to one who has had opportunity to observe numerous kidney sections of material injected with a colored gelatine mass, as usually given to classes, and to note the relative infrequency with which sections are met showing interlobular arteries which may be traced from the deeper portion of the cortex to the periphery. Branching of the interlobular vessels at various levels of their course is frequently met with; certain ones pass only through a portion of the cortex, others again break up in the deeper portions of the cortex into clusters of smaller branches (afferent glomerular branches). These details are shown in the figures presented. If the interlobular arteries are to be regarded as associated with vascular units, it must be conceded that such units must vary greatly in shape and in relative position and recognition must be given to the fact that of the probable functional activity of each uriniferous tubule structurally associated with an interlobular artery, only a portion of this functional activity is associated with the portion of the uriniferous tubule which falls within the vascular area of an interlobular artery, as the loops of Henle of such tubules are generally situated outside of such a vascular area.

It seemed desirable to discuss thus briefly certain points in the arterial vascular system of the mammalian kidney in order that emphasis may be given to the statement that afferent glomerular branches arise from all the branches of the renal artery, beginning with the arteriæ arciformes, and that all the branches with the few exceptions to be mentioned terminate in glomeruli. The main exceptions are found in the A. nutriciæ pelvis renalis and within the sinus renalis the arteriæ recurrentes. These branches, especially the latter, are readily recognized in corrosions, although their relations to the structures which they supply are not evident in such preparations. The arrangement of their terminal

branches is, however, such that they are not to be confused with the arteriolæ rectæ. They generally arise from primary branches of the renal arteries. Other exceptions will be noted later. In corrosions of very fully injected material, there are often observed small branches arising generally from the concave side of the arcuate arteries, beginning with about the third division of these, which can be traced to glomeruli; they are, therefore, afferent glomerular vessels. These small branches are not numerous. Their length varies from 1 mm. to much less than that. They generally end in only one glomerulus, though now and then such an afferent glomerular branch divides to supply two glomeruli. On the branches which arise from the convex side of the arcuate arteries and through their second and third divisions, afferent glomerular branches become more numerous, the number increasing with each successive division of these arterial branches. These afferent glomerular branches generally arise from the under surface (toward medulla) or the sides of these larger arterial stems, though now and then from the upper surface, in which event the branch bends downward to reach the respective glomerulus. Such afferent glomerular branches vary in length and arrangement. Branches ending in a single glomerulus are met with; clusters of two, three, four, or even more afferent branches, each ending in a glomerulus are also seen. Numerous afferent glomerular branches arise from the arterial branches which divide to form the interlobular arteries. Here also they may arise singly or in small groups or a small arterial twig may divide into four, six to eight branches, each ending in a glomerulus. From the interlobular arteries, as is generally stated, arise at all levels through the cortex and from all sides numerous afferent glomerular branches. Attention may, however, be drawn to the fact that the arrangement of afferent glomerular branches arising from the interlobular arteries is not a regular one, single afferent branches or clusters consisting of two to five or even more such branches resulting from a division of small lateral twigs of the interlobular arteries are met with. The terminal portions of such interlobular branches as reach the periphery of the cortex, ultimately divide into afferent glomerular branches. The number of such terminal afferent glomerular branches thus formed in the periphery of the cortex varies with different interlobular arteries. The figures presented will serve to elucidate this statement. It should, however, be stated that Figs. 2, 3, and 4 are drawn from actual preparations and are not composite pictures, and it will be readily understood that not all of the preparations present all of the details with equal clearness and perfection. Even when care is taken to cut and tease out certain portions

of a corrosion, selected for mounting and special study, which may readily be done under the binocular stereoscopic microscope, there are broken off during the manipulation small portions which thus become detached from the preparation. In Figs. 3 and 4, for instance, the peripheral portions of the interlobular arteries are not in every instance fully injected, giving the impression that certain of the interlobular arteries present peripheral branches which do not end in glomeruli. Other corrossions in which the peripheral branches of the interlobular arteries were more fully injected, but in which the injection in other details was not wholly successful will serve to show that the interlobular arteries end at the periphery of the cortex in branches which are recognized as afferent glomerular branches.

As is well understood, each glomerulus constitutes a rete mirabile, its branches uniting to form a single efferent vessel, the vas efferens, which is regarded as an arterial and not a venous structure. The efferent glomerular vessels, soon after leaving the glomeruli, divide to form capillaries, the disposition of which differs in the different portions of the kidney. The efferent branches of the glomeruli, the afferent branches of which arise from the arcuate arteries and from the successive branches of these until the interlobular arteries are reached, as also the efferent branches of a varying number of the glomeruli the afferent branches of which spring from the lowermost portions of the interlobular arteries, divide into bundles of long, slender branches and capillaries which pass into the medulla of the kidney, constituting the arteriolæ rectæ of writers, more specifically stated the arteriolæ rectæ spuria. The efferent branches of the remaining glomeruli divide to form capillary plexuses which surround the segments of the renal tubules found in the cortex, the efferent branches of the glomeruli situated in the outermost portion of the cortex passing into the peripheral cortical region free from glomeruli, before forming capillary plexuses. It may here be emphasized that there is not a difference of kind in the capillary plexuses formed from the efferent glomerular branches in the different parts of the kidney, but one of plexus arrangement determined by the character and arrangement of the tubular structures found in the different regions of the kidney.

As has been previously stated, the majority of recent writers recognize the existence of terminal arterial branches which end in capillaries in the kidney substance, with which glomeruli are not associated, such branches conveying arterial blood to the kidney tubule or portions thereof, which has not passed through a glomerulus. Such branches are recog-

nized in the boundary zone and medulla as arteriolæ rectæ veræ and in the peripheral portion of the cortex as end branches of the interlobular arteries. The criticism may be made that the corrosion method employed is not suitable for determining the existence or non-existence of such branches, as the possibility of their being present without being injected must be considered. It would seem, however, reasonable to suppose that arteriolæ rectæ veræ should be more readily injected than arteriolæ rectæ spuria, since in injecting the former it would not be necessary for the injection mass to pass through the glomerular capillaries before reaching the branches and capillaries constituting the arteriolæ rectæ. The venæ rectæ are very readily injected through the veins. In the rat, guinea pig, and rabbit and practically without exception in the cat, the arteriolæ rectæ observed in my corrosions could readily be traced to the efferent glomerular vessels. In these forms then, the existence of arteriolæ rectæ veræ may be denied with the possibility of very rare exceptions in the cat. A similar conclusion is reached by Petraraja, whose account I have, however, seen only in review, as his original publication was inaccessible to me.* In the dog, I have now and then observed arterial twigs which terminate directly in arteriolæ rectæ—arteriolæ rectæ veræ—these constitute, however, a very small per cent, the great majority resulting from a division of efferent glomerular branches. In the dog there may be further observed what may be designated as very small glomeruli, which appear fully injected as a capillary network may generally be made out in the corrosion, the efferent branch ending in typical arteriolæ rectæ. These very small glomeruli (?) are also not numerous. Golubew has described and figured for the dog and the cat what he has termed “retia mirabilia renum nova” situated in the deeper portion of the cortical substance and the boundary zone. Being aware of these observations of Golubew, I sought for confirmation of them in the corrosion preparations at my disposal, as it seemed likely that they should be injected as readily as the glomerular vessels. Such retia mirabilia have not been found, unless, as seems to me probable, what has been spoken of as very small glomeruli may constitute the structure described by Golubew as new renal retia mirabilia. From the fact that the efferent vessels of such structures always end, so far as I have been able to determine, in arteriolæ rectæ, I have been led to conclude that they represent the remains of normal glomeruli associated in their development with urinifer-

* Petraraja: *Sulle arteriolæ rectæ del rene*. *Monit. Zool. ital.*, Bd. 15, 1904. Reviewed in *Jahresberichte über die Fortschritte der Anatomie und Entwicklungsgeschichte*. Neue Folge, Bd. X, 3 Abth. 1. Teil, 1905.

ous tubules, which tubules have later disappeared, a portion of the glomerular plexus with afferent and efferent vessels remaining intact as a rete mirabile, the degree of retrogressive change varying with different glomeruli and in some instances going on to a complete obliteration of the glomerular plexus, the afferent and efferent vessels alone remaining as a continuous structure. As has been expressed to me—"The mill-dam remaining after the mill has disappeared and in some few instances the dam itself disappearing." According to this hypothesis (for the sub-

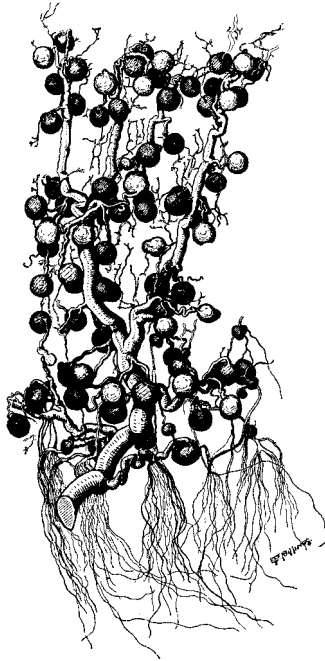


FIG. 2. Corrosion preparation of terminal arterial branches from kidney of dog.

stantiation of which it is difficult to obtain definite data, as my attempts to obtain corrosion preparations of the arterial system of foetal kidneys and of kidneys of new-born dogs have not been successful), the arterial twigs which end in arteriolæ rectæ without the interposition of glomeruli—arteriolæ rectæ veræ—and the arterial twigs in the course of which are found retia mirabilia prior to ending in arteriolæ rectæ are to be regarded as derived from glomeruli with afferent and efferent vessels, the glomerulus in each instance degenerating in whole or in part consequent to the disappearance of the uriniferous tubule with which said glomerulus

was structurally associated. If this interpretation be correct, the arterial vascular supply of the dog forms only an apparent exception to the general statement that all the arteriolæ rectæ are formed by a division of efferent glomerular branches, the few arteriolæ rectæ veræ noted being regarded as developed from arteriolæ rectæ spuriaë on the disappearance of the uriniferous tubule structurally associated with the glomerulus which thus degenerates. Golubew has further described arterial twigs, which after division present one branch, which may be very short, and which forms an afferent glomerular vessel, the other branch passing by but in close contiguity to the glomerulus and dividing to form arteriolæ

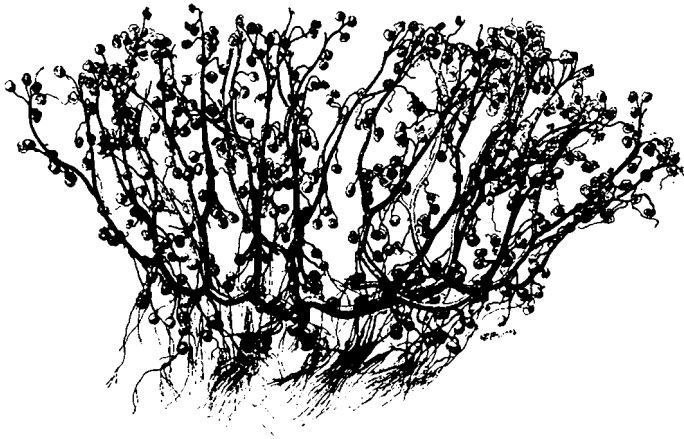


FIG. 3. Corrosion preparation of terminal arterial branches from kidney of cat.

rectæ—thus arteriolæ rectæ veræ. This I have not observed and must regard it as an error of observation for which the method used by him (silver nitrate injection) is responsible, as is clearly the case in the following observation, shown in his Fig. 2, Plate XXIV. Here is shown an arterial branch having a horizontal course, from the under side of which there arise several branches (six) which divide to form arteriolæ rectæ veræ. The preparation is taken from the base of the renal pyramid of the dog's kidney injected with silver nitrate. The structure figured was undoubtedly a small vein receiving several groups of venulæ rectæ, as in corrosion preparations of the venous system of the dog's kidney, such small vessels having a horizontal course and receiving on their under side small branches formed by the union of straight capillaries are frequently met with, but are traceable to larger venous stems. In corrosion

preparations of the rat's kidney, I am able to confirm the observation made by Golubew that the efferent glomerular branches which form the arteriolæ rectæ give off side branches which form capillary networks at the level of the base of the renal pyramid. Such side branches of the efferent glomerular vessels destined to form arteriolæ rectæ I have observed also in the kidneys of the other animals studied, though they are not nearly so numerous as in the white rat. So far as may be determined in corrosion preparations in which the peripheral portions of the interlobular arteries appeared completely injected, these end in afferent glomerular branches and do not present terminal branches which end directly in capillaries in the peripheral portion of the renal cortex. Now and then, and more particularly in the dog, have I found an interlobular branch which did not completely break up into branches within the renal cortex, but could be traced beyond the outer border of the cortex anastomosing, as would appear, with capsular branches. Afferent glomerular branches arise from such interlobular branches to near the peripheral part of the cortex. The question may be asked whether the "arteria capsularis glomerulifera" described by Golubew may not be interlobular arteries of the above type imperfectly injected from the outside. As I have not attempted corrosion injection through the aorta after tying the renal arteries, I am not able to decide this point.

In this account, no mention has been made of observations on the human kidney with reference to the points more particularly under discussion. The limited human material at my disposal has not been fresh enough to enable capillary injection with subsequent corrosion by the method used. In the attempts made the injection mass could readily be forced into the glomeruli, but only to a limited extent into the efferent glomerular vessels, as a rupture of the glomerular vessels in many places allowed its escape into the space enclosed by Bowman's capsule and then into the uriniferous tubules in which it would pass to about the beginning of the descending limb of the loop of Henle, giving excellent and instructive corrosions of the proximal convoluted portions of the uriniferous tubules. Similar observations were made on injecting through the renal vessels of the kidneys of animals several hours after death. It is hoped that this method may prove useful in the hands of others with access to fresh human material in determining the origin of the arteriolæ rectæ and the existence or non-existence of terminal arterial branches not directly associated with glomeruli.

From observations made on corrosion preparations of the dog, cat, rabbit, guinea pig, and rat, in which it is possible to trace the renal

arteries through their several branchings to their termination, including the branches which go to the glomeruli, the glomeruli themselves, the branches leaving the glomeruli, and often the capillary plexuses formed by these, the conclusion seems warranted that practically all of the blood found in the capillaries surrounding the different portions of the uriniferous tubules is blood that has first passed through the glomerular vessels. This was so clearly stated by Bowman many years ago that it seems but just to use his own words to give further emphasis to this point. In Bowman's classical contribution to the anatomy of the kidney is found



FIG. 4. Corrosion preparation of terminal arterial branches of kidney of rabbit.

the statement: "According to my own observations, the circulation through the kidney may be stated to be as follows:—All the blood of the renal artery (with the exception of a small quantity distributed to the capsule, surrounding fat, and the coats of the larger vessels) enters the capillary tufts of the Malpighian bodies; thence it passes into the capillary plexus surrounding the uriniferous tubes and it finally leaves the organ through the branches of the renal vein." With this clear and correct statement of facts, dating back to 1842, it is somewhat surprising that even at the present time, there should be a question as to the existence or non-existence of terminal branches of the renal artery which end in

⁷Bowman: *On the Structure and Use of the Malpighian Bodies of the Kidney, with Observations on the Circulation through that Gland.* Philosoph. Trans. of the Royal Society of London, 1842, p. 57.

capillaries about uriniferous tubules without being directly associated with glomeruli.

There are, as is well known, two leading and opposing theories on the nature of urinary secretion tersely stated by Hans Meyer as follows in a recent summary of observations on renal function: "According to one of these theories, which was developed most fully by Heidenhain, we have to deal with a true secretory process by which water and perhaps the salts pass through the glomerulus, whereas the specific constituents of the urine are liberated from the tubules, so that the sum of both secretions is represented by the outflowing urine. According to the other hypothesis, which was first proposed by Ludwig and subsequently modified by his successors (in a biological sense), there goes on in the kidney, side by side with the glomerular activity, dependent essentially on the mechanical conditions of the circulation, and independently also on the secretion of certain urinary constituents, a process of resorption in the urinary tubules. Through this resorption the slightly concentrated secretion of the glomerulus, corresponding to the water of the blood, undergoes concentration to a point characteristic of the urine."

It is not my purpose here to discuss either of these theories. It may, however, be permitted to call brief attention to certain points in the structure of the uriniferous tubules in connection with an account of the relations of terminal branches of the renal arteries, points which, it seems to me, should be considered by the followers of either of the leading theories on the nature of urinary secretion.

In each uriniferous tubule, including the glomerular capsule, there may be recognized four types of epithelium with distinct regional distribution. (1) The flattened epithelial cells lining the glomerular capsule continuous with the flattened epithelium, probably syncytial in character covering the glomerulus; (2) the epithelium of the proximal convoluted portion, columnar in shape with striated protoplasm and striated inner border; (3) the peculiar flattened epithelium of the descending limb of Henle's loop; (4) the short columnar epithelium of the ascending limb, the distal convoluted portion and a portion of the junctional tubule, an epithelium with indistinct cell outline, with basal striation, but differing in structural detail and in reaction to stains from the epithelium of the proximal convoluted portion. These four types of epithelium are found, not only in the uriniferous tubules of the mammalian kidney, as determined by reconstruction in this laboratory, but also in the tubules of the simpler reptilian kidney (recently reconstructed in this laboratory and to be described in another communication) as also in the tubules of the amphibian kidney (mesonephros). The epithelium of the neck of the uriniferous tubules is here not especially considered; it differs from the other epithelia described, though it probably has little functional significance. If it is true, as stated by Starling in introducing the section on "The Mechanism of the Secretion of Urine" in Schaefer's Text-book of Physiology, that "a difference of function is invariably associated with a difference of structure, so that the interdependence of function and structure has become an axiom," we should be justified in postulating a difference of function to the different parts of the uriniferous tubules lined by the different types of epithelium, and the extent to which this may be done is, as it

appears to me, briefly as follows: The weight of evidence appears to substantiate the statement that the water, the sodium chloride and urea and probably other substances existing in a free state in the blood are secreted (pass out by filtration or transudation) by the glomerular epithelium. It is estimated that 1-12 to 1-14 of the volume of blood entering through the afferent glomerular vessels is abstracted during the course of the blood through the glomerular vessels, so that the blood leaving the glomeruli is thus proportionately concentrated. To this fact attention may be especially drawn, since, as has been shown, practically all the blood found in the capillaries surrounding the different parts of the uriniferous tubules is blood which has passed through the glomeruli. Uric acid and phosphoric acid appear to be specifically secreted, as their quantity cannot be increased by any of the known diuretics—Hans Meyer. The evidence is in favor of connecting this specific secretion with the epithelium of the proximal convoluted tubules. In confirmation of this may be cited the sodium sulphindigotate experiments of Heidenhain and Ribbert, the carmine injection experiments of Schmidt and Ribbert, the detection of uric acid granules in this epithelium and the presence of what has been regarded as secretory granules in the same epithelium. To what extent the presence of concentrated blood found in the capillaries surrounding the proximal convoluted tubules, having, as may be assumed, a larger per cent of uric acid, since this is apparently not secreted by the glomerular epithelial, favors the secretion of this substance by the epithelium of the proximal convoluted tubules, cannot be stated. The possibility of its doing so may, however, be considered. The experimental evidence appears to favor the view that there is a compensatory resorption of water (probably also certain salts in proportion to their diffusibility or permeability of the renal cells—Cushny) during the passage of the renal secretion through the tubules. That this resorption of water takes place in the loops of Henle is probable from the experiments of Ribbert, and Hausman and Hans Meyer who obtained an increased flow of urine of less concentration after removing the medullary portion of one kidney following extirpation of the other. The suggestion is here made that this resorption, more especially of the water, takes place in the descending limb of Henle's loop, largely owing to the peculiar flattened epithelium possessed by it. That the loops of Henle are longer than generally thought is shown by reconstruction, the larger per cent extending through or nearly through the entire medulla. These segments of the uriniferous tubules are in relation with capillaries conveying concentrated blood, favoring a resorption, since, as has been shown, the arteriolæ rectæ are formed almost without exception by a division of certain of the efferent glomerular vessels. The blood passing to the medulla through the arteriolæ rectæ is returned by the venulæ rectæ, which are, if one may judge by corrosion preparations, much more numerous than the arteriolæ. The loops of Henle are, therefore, in relation with numerous capillaries. Whether special function may be ascribed to the ascending limb of Henle's loop and the distal convoluted portion, which again has a special epithelium, is difficult to state. Heidenhain believed these tubular segments to possess a secretory function similar to that possessed by the proximal convoluted portions, bas-

ing his conclusions on observations made after injecting sodium sulphindigotate. It would seem, however, that absorption of the dye by the epithelium of the ascending limb of Henle's loop and distal convoluted portions, after a concentration as a result of absorption of water in the descending limb is not excluded. Ribbert states distinctly that "a secretion of specific substances takes place only in the convoluted tubules of the first order, while in the loop of Henle, the distal convoluted portion and the collecting tubules, there takes place exclusively or for the greater part a resorption of water." He further draws attention to the fact that in normal kidneys of older individuals there are often found pale yellow granules, contained exclusively in the epithelium of the distal convoluted portions and parts of the loops, and, further, that toxic agents secreted by the kidney affect first the glomeruli and then the distal convoluted portions and in part the loops. It would appear, therefore, that a resorption takes place from these tubular segments perhaps of more specific substances than from the descending limb of Henle's loop.

(Excellent reviews of the literature bearing on renal secretion may be found in a number of recent publications—Ribbert, *Untersuchungen über die Normale und Pathologische Physiologie und Anatomie der Niere*, Bibliotheka Medica, 1896; Hans Meyer, *Herter Lectures*, Bull. Johns Hopkins Hospital, Nov. and Dec., 1905; R. Metzner, *Die Absonderung und Herausbeförderung des Harnes*, Nagel's Handbuch der Physiologie des Menschen, Bd. II, Erste Hälfte, 1906,—to which the interested reader is referred.)

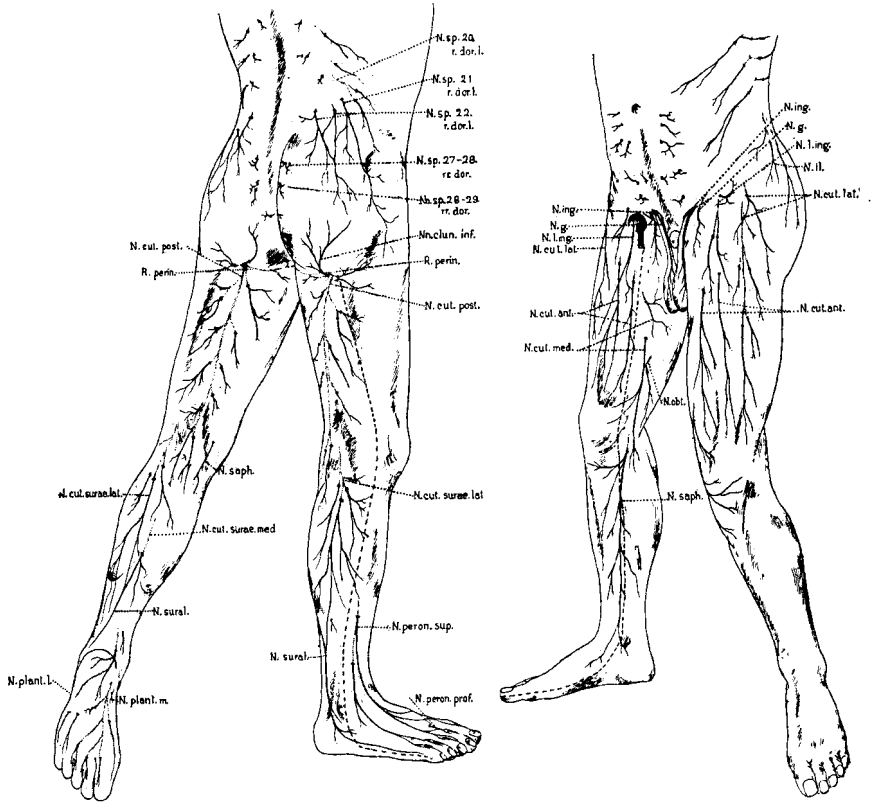


Fig. 2

Fig. 1

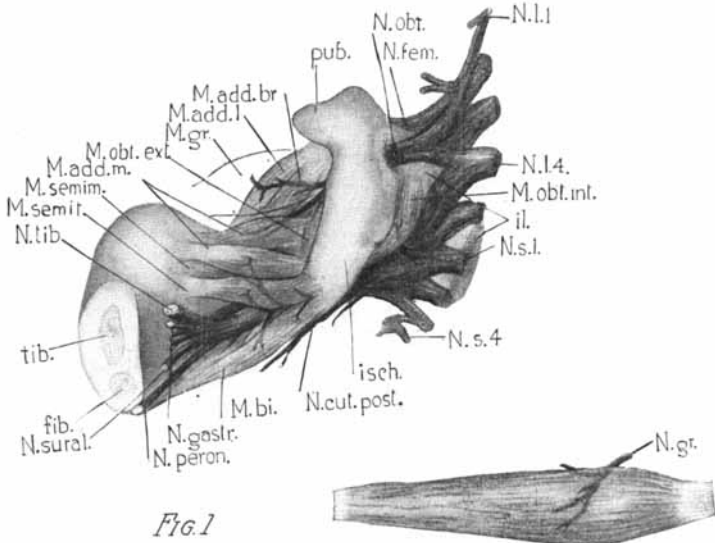


Fig. 1



Fig. a.

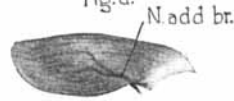


Fig. b.

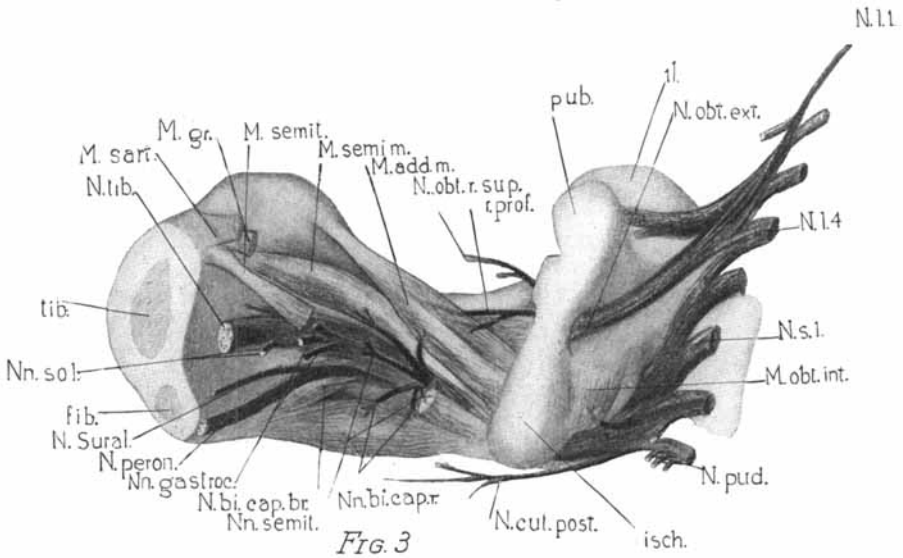


FIG. 3

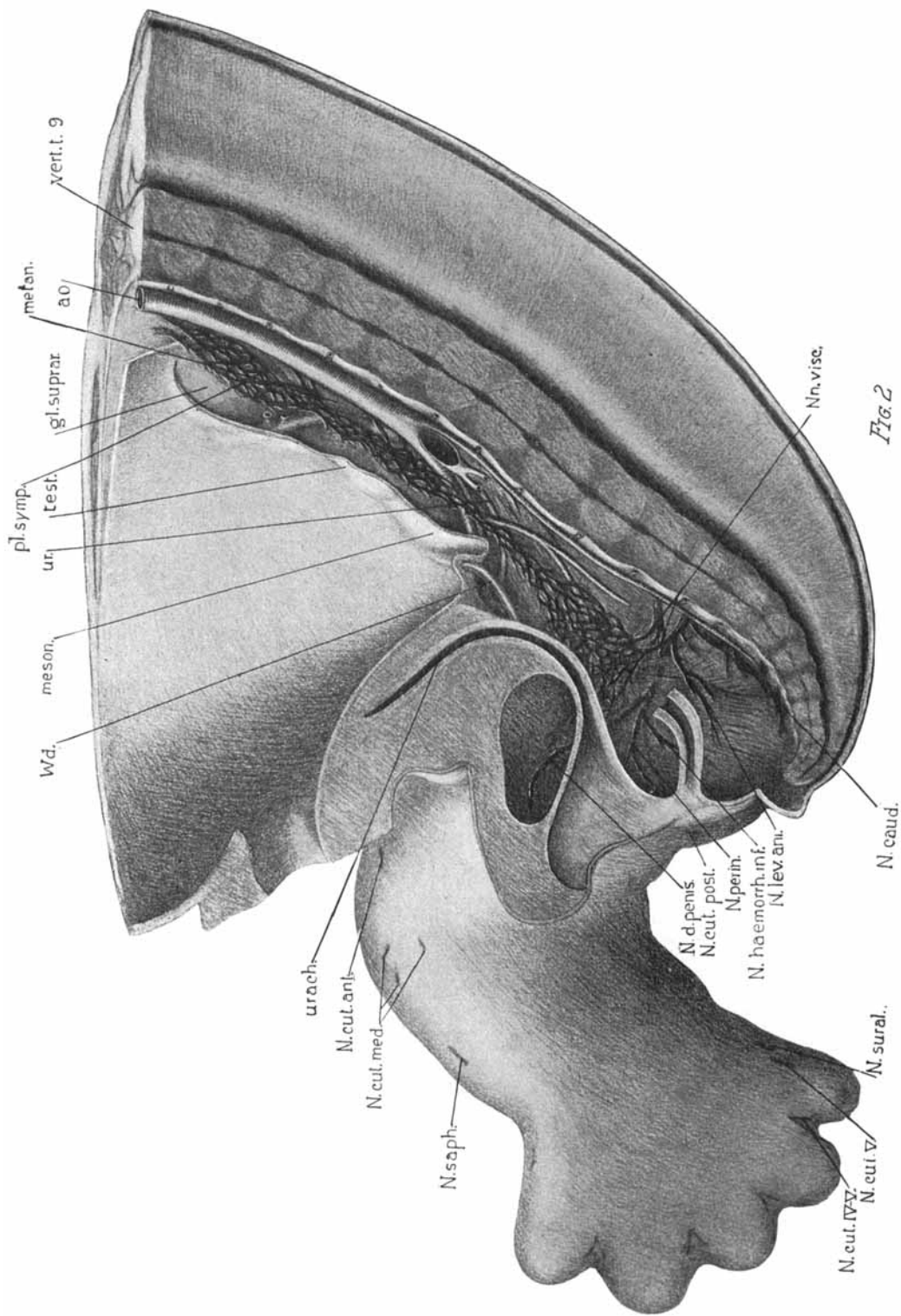


Fig. 2