RESEARCHES

INTO THE

STRUCTURE AND PHYSIOLOGY OF THE KIDNEY.

By C. E. Isaacs, M.D.,

DEMONSTRATOR OF ANATOMY IN THE UNIVERSITY OF THE CITY OF NEW YORK.

READ MARCH 5, 1856.

Within a few years past, great progress has been made in the pathology of the kidney, and it is therefore much to be desired that our knowledge of its anatomy should be as complete as possible, since every scientific examination of the diseased organ, or even of its secretion, is based upon our knowledge of the healthy structure, and must ever refer to this as its standard. We owe much to the researches of Malpighi and of Laurentius Bellini, who first discovered the tubular structure of the kidney, but we are greatly indebted to Bowman, Toynbee, Johnson, Henle, Gerlach, Bidder, Kölliker, and other living authors, for our present knowledge of the subject. I was induced to enter upon a long-extended investigation of the minute structure of the kidney, from the fact that the highest authorities were then, and are still at variance, with regard to some of the most important points in the anatomy of this organ. Thus the connection of the Malpighian body with the uriniferous tube, so strongly maintained by Bowman, is denied *in toto* by Huschke, Müller, and Hyrtl, of Vienna.

The existence of ciliated epithelium in the uriniferous tubes of the higher animals, of nucleated cells upon the Malpighian coil or tuft, of a fibrous matrix, and the arrangement of the venous plexus, &c., are subjects upon which much difference of opinion exists among anatomists. It was evidently necessary that these points should be determined before we could arrive at a satisfactory physiology and pathology of the kidney. I was next led to inquire, why so many excellent observers had obtained such entirely different results, and the explanation seemed to be, that their means of investigation were insufficient. Thus some, as Bowman, had relied chiefly upon the appearances obtained by injection, while others had trusted almost entirely to those derived from specimens viewed as transparent objects under the microscope. Bowman, although sometimes employing the latter method, obtained nearly all his plates (except those which are diagrammatic) from specimens procured by the process of injection.

Toynbee, by the same method, arrived at entirely different results. It seemed, then, to me, that some other means of investigation were desirable, and especially some method by which the substance of the kidney could be rendered transparent; and that if this could be effected, it might be ascertained whose views (if any) were correct, and the true structure would probably then be determined. Accordingly, after numerous experiments with various chemical reagents, I at length arrived at the knowledge of certain processes, which have not only been useful by giving transparency to small portions and thin sections of the organ, but have often enabled them to be viewed both as opaque and as transparent objects.

In this manner, the observations have been rendered much less liable to error. I have not, however, limited myself to the use of these processes, but have also employed all the usual means, as injections, &c., &c. With all these aids, then, and without any preconceived theory, I entered upon an extensive and long-continued series of observations, and have given plates of the structures, as they were seen in the field of the microscope. I do not propose, in this paper, to enter upon all the details of the minute structure of the kidney, but at present shall merely refer to some points, to which it seems necessary at least to allude, in order that the subsequent remarks should be clearly comprehended.

The structure of the kidney is essentially tubular, each kidney, according to Huschke, containing more than two millions of minute tubes. These tubes are convoluted in the cortical portion, but straight in the pyramidal, and are each composed of a highly elastic, structureless, transparent, "basement" membrane. The integrity of the tube being of the highest importance during life, this membrane has been endowed with the quality of strongly resisting injurious influences, and even powerful chemical reagents. In virtue of this last-named property, we are enabled to show clearly the tubes of the kidney, by certain processes hereafter to be described. All the uriniferous tubes are lined internally by nucleated epithelial cells, by means of which the urine is separated, as it is believed, from the blood of the surrounding capillaries. The epithelial cells of the convoluted are generally thicker than those of the straight tubes.

Plate 1 exhibits the epithelium of the uriniferous tubes of the healthy human kidney.

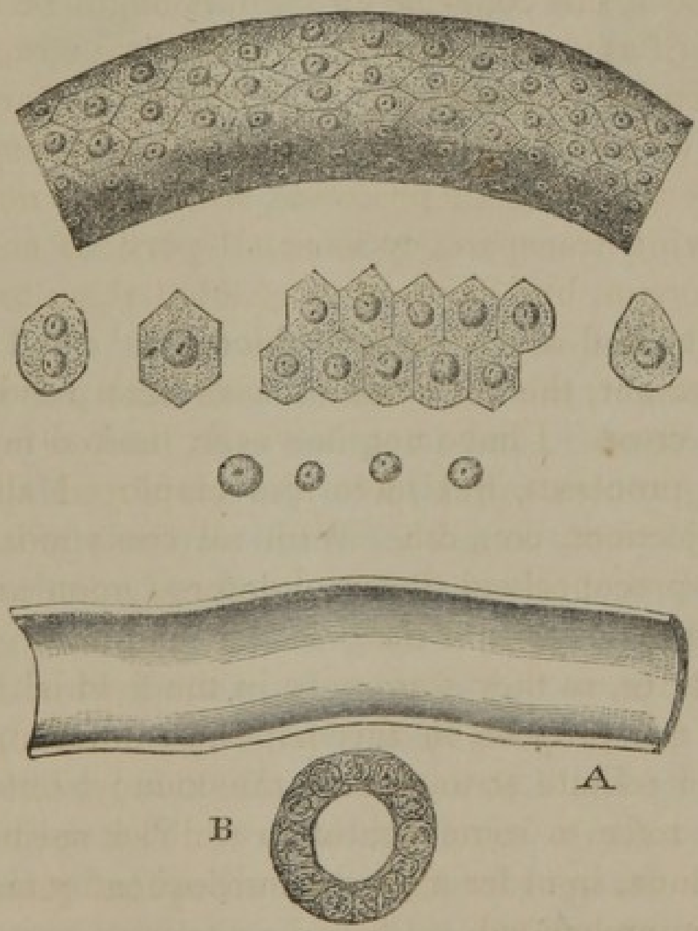

Plate 1.

The first figure in Plate 1 exhibits a convoluted tube lined by nucleated epithelial cells. The figure immediately below this shows the manner in which the cells, most of which are polygonal, are arranged. To the right of these is seen an oval-shaped cell; to the left, a cell containing two nuclei; and next to this is a polygonal cell, more highly magnified. Four separate nuclei of cells are also seen. A represents a uriniferous tube, the epithelium of which has been washed away, leaving only its basement membrane. This figure is diagrammatic. B is a transverse ring-like section of a uriniferous tube, showing its central canal, surrounded by epithelial cells.

In Plate 2, A exhibits one of the straight tubes in the pyramidal portion of the kidney. It is lined by polygonal, rounded,

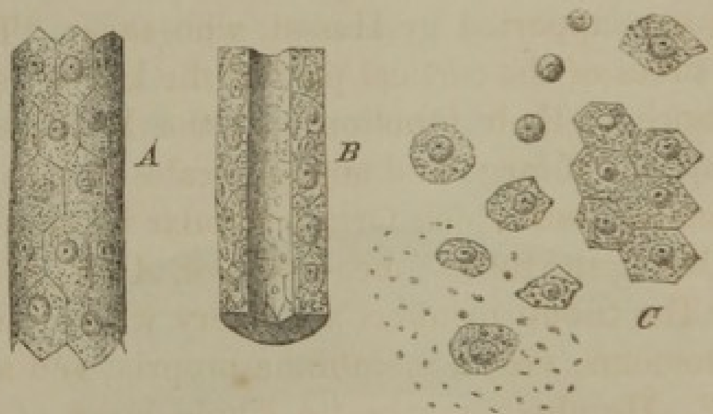

Plate 2.

and oval nucleated cells. B shows the central canal in the interior of a straight tube. C exhibits several polygonal cells. Some oval, rounded, and irregular cells, and a few separate nuclei and granules can also be perceived. Magnified 400 diameters. Most of the epithelial cells are polygonal, although many are oval, and others of a rounded or irregularly-rounded shape. They all contain finely granular matter, and a nucleus, which is itself composed of granules, among which one or two nucleoli can generally be observed. The contents of the cells are believed by Kölliker to contain albumen; he considers the granules to be also a protein substance. The epithelium very soon becomes changed from decomposition, or by the action of water, which expands the cells, and sometimes causes them to burst, when the tubes are found to contain merely nuclei and granular matter. In examining the epithelium, *it is therefore very important* to obtain the kidney in as fresh condition as possible, and instead of water, to use a solution of albumen in water or urine. The acids dissolve the wall of the cells, leaving only the nuclei and granules; the nuclei finally disappear. By the action of caustic alkalies, everything in the cell is dissolved except the granules.

According to some very high authorities, the tubes of the cortical portion of the kidney are lined by the spheroidal or "glandular" epithelium. See Mr. Bowman's paper; also G. Johnson, on Diseases of the Kidney, pages 33 and 56. But in plates No. 1 and 2, it is shown that the uriniferous tubes are lined by the pavement or tesselated epithelium; and I find that, on this point, I am supported by Hassal, who says: "The epithelium of the tubes of the cortical part of the kidney, save within a short distance of their junction with the Malpighian dilatations, is composed of large and angular scales or cells, which are coarsely granular, and which form a regular layer of pavement epithelium, lining the tubes," &c.—*Micros. Anat.*, p. 444. Kölliker says, "The tubuli uriniferi are every where composed of the same elements, viz., a membrana propria, and a tesselated epithelium." He also remarks, "a single layer of *polygonal*, moderately thick cells, surrounds the cavity of the tubulus," &c. —*Micros. Anat.*, p. 599.

I believe that the description which is given in this paper will always be verified by actual observation of specimens of the kidney, provided they are in a perfectly fresh and healthy condition. It is, however, extremely difficult to meet with specimens of the kidney which are sufficiently so to exhibit the perfectly normal epithelium, and I therefore made every exertion to obtain the organs in a satisfactory condition, for this purpose. I am well aware that we often see the tubes containing rounded, and irregularly rounded, epithelium, as described by authors; but I believe that when this appearance is seen, the kidney is either not fresh, or is in a pathological condition, or that the epithelium has been changed by the mode of examination. Kölliker says: "By the usual method of examination in water, the cells expand, owing to its absorption, and become vesicularly distended, so that their polygonal form and regular arrangement are lost, the renal ducts appearing to be filled with larger rounded cells, and no longer to possess any cavity. In kidneys not quite fresh, these changes proceed spontaneously."—*Micros. Anat.*, p. 599.

In urinary diseases, where the epithelium is thrown off, either as loose cells, or in the form of casts, these cells are generally observed of a more or less rounded form, with an unusual amount of granular matter between and among them, arising from their disintegration. By most physiologists, it is considered that the epithelial cells are concerned in separating from the blood all the proximate elements of the urine, and they believe that this idea is confirmed by the fact that these cells are of the rounded, spheroidal, or "*glandular*" variety.

How far these cells are concerned in the secretion of the urine, will be hereafter considered. For the present, it may be said, that the rounded form would not appear to be necessary in order that they might effect this secretion, inasmuch as the hepatic cells, which are concerned in the separation or secretion of bile, are of the tesselated variety, and of an irregular polygonal form.—See Kölliker, *Micros. Anat.*, p. 532. He says, "The hepatic cells resemble tesselated epithelium cells in form, except that they are more irregular." It will be remembered, that of all secretions, the bile is the most complex. The epithelial cells are liable to many important pathological changes, to which the limits of this paper will merely permit an allusion. They sometimes contain, or are mixed with, blood, pus, oil globules, crystals of lithic, or oxalic acid, &c. The cells themselves may be thrown off as a fibrinous cast, or they may become disintegrated or broken down, and obstruct the tube, thus interfering with the excretion and secretion of the urine, and consequently with the circulation, and nutrition of the kidney. See G. Johnson's excellent work on the Kidney, and other recent authors on its diseases. In fishes, frogs, snakes, turtles, &c., the uriniferous tubes are lined by ciliated epithelial cells, by the action of which the current of urine in the tube is directed and urged onward towards the ureter.

Authorities, however, are not agreed as to its existence in the mammalia.

Hassal says that this has been doubted or denied by Huschke, Reichert and Bidder, while Bischoff, Valentin, Pappenheim, Gerlach, and Kölliker are of the contrary and affirmative opinion, and that he has himself seen ciliary motion in the kidney of the sheep, rabbit and horse. During the last three or four years, I had occasionally examined the kidney in the higher animals, as soon as possible after death, with the view of detecting ciliary motion. After many examinations, having uniformly failed in obtaining any evidence of its presence, I had become much inclined to doubt its existence; but being desirous of testing the question more extensively, I resorted to the large establishments, in this city, for killing oxen, sheep, dogs, rats, &c., and examined the kidneys immediately after the death of the animal. I may here mention, that every precaution was taken not to confound molecular with ciliary motion, as has probably been done by some observers. Some of the scraped substance of the kidney was gently agitated, in a test tube, containing a solution of albumen, and a drop of this fluid was then placed under the microscope. Thin sections were also used. In some animals no motion could be perceived, but in the dog I observed currents taking place, in the fluid, and also within the uriniferous tubes. The epithelial cells would frequently disengage themselves from the sides of the tube, and pass along for a considerable distance, and after emerging from the mouth of the tube, would assume a rotatory motion. Sometimes nearly all the epithelial cells would pass out of a tube, in the space of fifteen or twenty minutes, leaving it almost denuded of its internal epithelial lining. I have also seen isolated cells, having a vibratory or rotatory movement. These appearances I have noticed, upon eight occasions, in the kidneys of dogs. Such motions generally cease, in these animals, in less than an hour after death; but, at one time, I noticed their continuance for more than three hours after the animal was killed. I have often seen appearances similar to the preceding in the kidneys of the ox and sheep. Nevertheless, it must be stated, that after very numerous and careful observations, I have never seen the epithelial cells actually provided with cilia, except upon one occasion, when I observed a single cell apparently fringed with cilia, and in active rotatory motion. This was in the kidney of the ox. In these examinations, I made use of various magnifying powers, and especially the Nos. 5 and 7 objectives of Natchet, and the ¼ objective of Powell & Lealand, but the result has been as above stated. In examining minute portions of the oyster and clam, which possess ciliary motion, we sometimes observe particles of a rounded or irregular shape, and which cause currents in the fluid in which they float, but we cannot always discern that these particles have cilia attached to them, although they may have a rapid, and apparently an independent rotatory or vibratory motion. What is observed in the kidneys of the dog, sheep, and ox, certainly seems to be much more powerful, and different in its nature from molecular motion. Reasoning from the appearances in the oyster and clam, as well as from analogy in many of the lower animals, it may be concluded that ciliary motion does exist in those of a higher grade, although it is, in them, very imperfect, or, as it might perhaps be said, in a rudimentary condition.

In some of the inferior animals, where the urine is excreted in the semi-fluid state, a much greater necessity exists that this fluid should be rapidly propelled in its course through the uriniferous tubes, and, accordingly, we here find ciliary motion in its most perfect condition. I have never seen it in the human kidney, even after many careful examinations. If it exists, which is probable, it ceases very soon after death, when it rarely happens that we can obtain an opportunity of examining it.

The uriniferous tubes of the kidney present an immense internal secreting surface, which, according to Valentin, is almost six times as large as the whole surface of the skin. The substance of the kidney is very vascular; most, *but not all* of the terminal twigs of the renal artery, in the cortical portion of the kidney, ending in the Malpighian coil or tuft of capillaries, while the veins returning the blood from this coil enter into the capillary venous plexus, through whose meshes the convoluted tubes pursue their tortuous course.

In Plate 3, A is a small branch of the renal artery; B, a smaller branch, which divides into two twigs, one of which

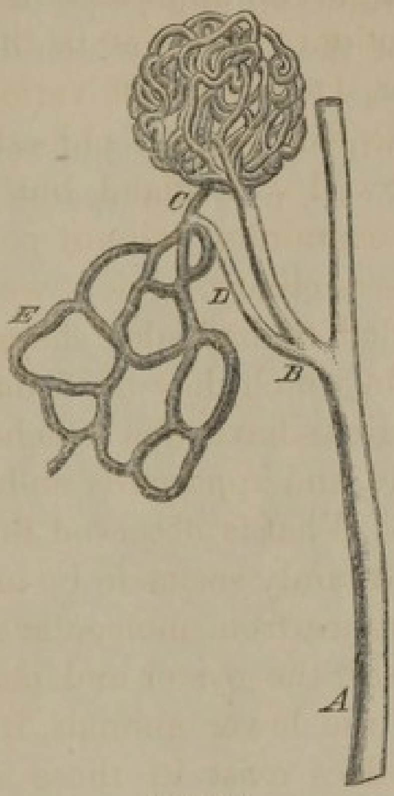

Plate 3.

supports at its extremity the Malpighian coil or tuft of capillaries; the other enters into the venous plexus, marked E. C, a vein which returns the blood of the Malpighian coil into the venous plexus, E. D, an arterial twig, communicating with the venous plexus. Magnified 130 diameters.

In reference to this point, Mr. Toynbee says: "The single trunk which emerges from the corpus (Malpighianum) sometimes unites with another, proceeding from an arterial branch, which is entirely unconnected with the corpora." Since writing the preceding remarks, I have found a paper upon the Anatomy and Physiology of the Kidneys, by Dr. R. McDonnell, published in the Glasgow Medical Journal, October 1854. Speaking of the branches of the renal artery, he says: "They give off some small twigs, which furnish capillaries to the straight urinary tubules, and are ultimately lost on the boundary between the medullary and cortical portions, in small vessels, *of which only a small part passes into the capillary system of the cortex*, while by far the greatest part passes on to, and pervades the Malpighian capsules." It will thus be seen that the venous plexus contains a certain amount of arterial blood, derived from those minute twigs of the renal artery, in the cortical portion of the kidney, which do not enter the Malpighian capsules. (See Plate 3.)

Plate 4 shows the injected plexus of veins on the surface of the kidney of the sheep, and the spaces which exist in this

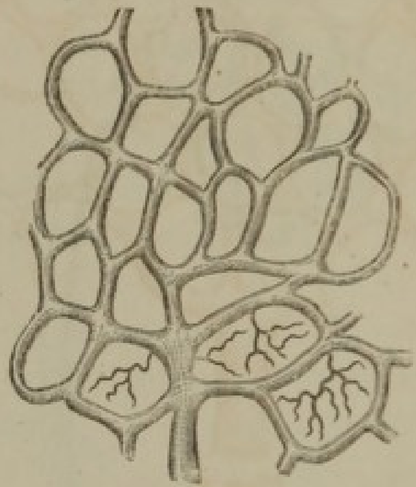

Plate 4.

venous network. In these spaces the so-called lobules of the kidney are contained. Three of the spaces show small venous branches, which run around and among the tubes on the surface of the organ. Viewed as an *opaque* object, and magnified 40 diameters.

Plate 5 shows a portion of the above specimen made trans-

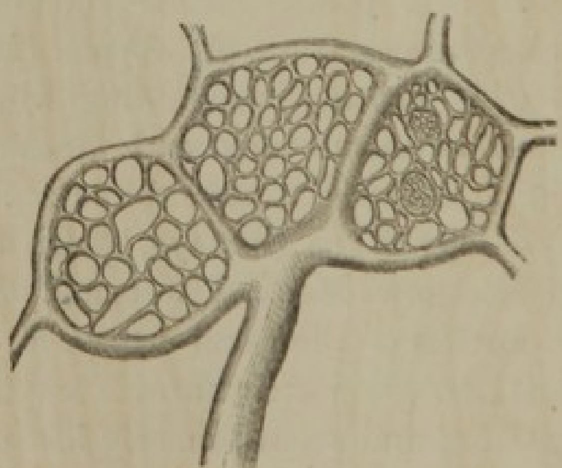

Plate 5.

parent by chloroform, and viewed by transmitted light. Magnified 80 diameters. The venous spaces are seen to be occupied by tubes. The dark line around each tube is a capillary vein. In one of the spaces, two Malpighian bodies can be seen, surrounded by tubes.

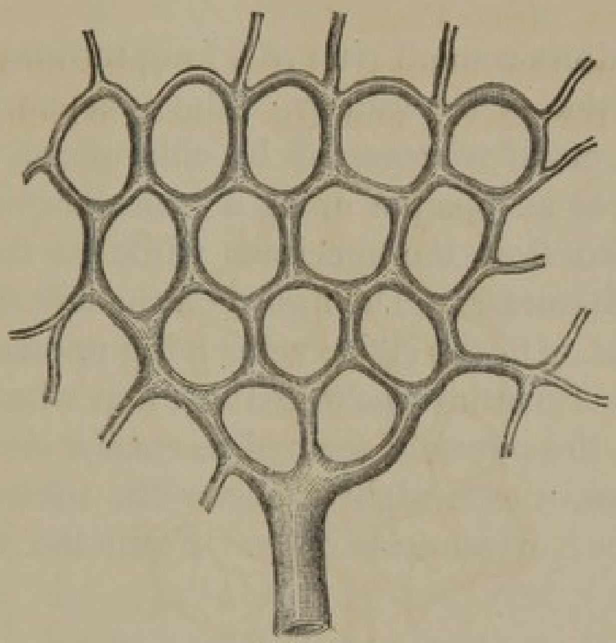

Plate 6.

Plate 6 shows a part of one of the three venous spaces in

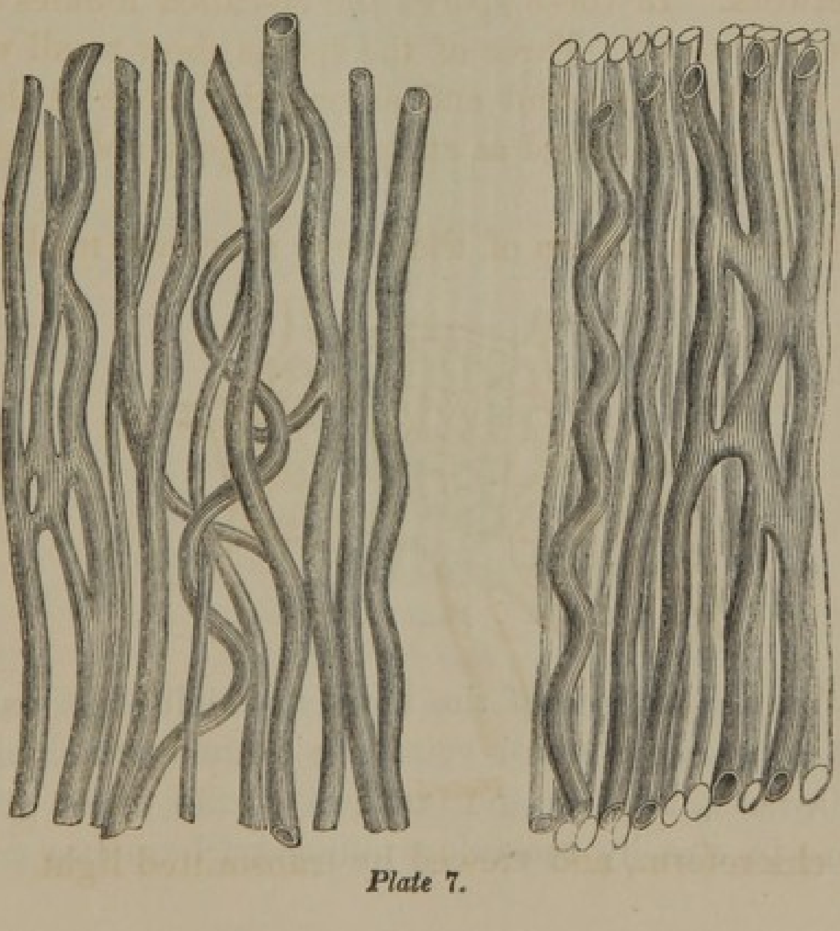

Plate 7.

Plate 5, but much more highly magnified; viz., 130 diameters. A venous trunk is here seen to form a mesh or network of capillary veins, which surrounds the uriniferous tubes. Rendered transparent by chloroform, and viewed by transmitted light.

Plate 7 exhibits a small part of a longitudinal section of the pyramidal portion of the kidney. The specimen was injected from the vein, made transparent by chloroform, and could be viewed either as an opaque or as a transparent object. This plate was drawn from the specimen while in the latter state. Magnified 90 diameters. The figure on the left shows the veins of the pyramids. On the right, veins lying upon and amidst the straight tubes. So numerous were they, that when viewed as an opaque object, the pyramid seemed to consist entirely of veins.

Plate 8 shows the straight tubes. The tubes are drawn as having their cut extremities open. From the minute venous

A

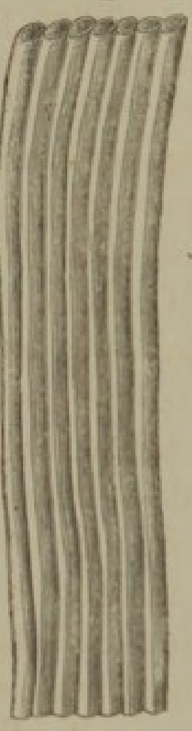

Plate 8.

network on the surface of the kidney, which often exhibits a stellated appearance, small veins are formed, which descend, or pass inwards, between the fasciculi of the tubes, gradually increasing in size by receiving numerous branches from the interior of the cortical portion. The venous trunks, which have thus been formed, join the veins which lie around the periphery of the pyramids, and which return the blood of those bodies. By these means, a venous trunk of considerable size is formed, which unites with others (originating in a similar manner) to constitute the branches of the renal vein. The general arrangement of the minute arteries, the Malpighian bodies attached to them, and that of the venous plexus, may be shown by successful injections. By this process the tubes may sometimes be very beautifully shown, but their peculiar connection with the Malpighian coil, or tuft of capillaries, their basement membrane, and its epithelial lining, and the cellular framework, or matrix of the kidney, can only be clearly and satisfactorily exhibited when these parts are viewed as transparent objects under the microscope. To view the tubes of the kidney in their normal condition, very thin sections or scrapings of the cut surface of the organ may be put into a test-tube with water, agitated for a few minutes, placed on a slide of glass, covered by a thin slip, and then examined under the microscope. The most distinct and beautiful views of the form and arrangement of the Malpighian bodies and tubes of the kidney can be obtained by the process about to be described, which enables us to study thin sections of the substance of the kidney as transparent objects. Occasionally the connection of the tube with the Malpighian body can be seen, as well as the attachment of the latter to the terminal arterial twig. Small pieces of the organ are put into a test-tube, with about half an ounce of water, to which three drops of pure sulphuric acid are then added, when it is boiled for one or two minutes. A thin section being now placed under the microscope, the tubes will be most clearly and distinctly exhibited. If too much acid be used, it will dissolve all the minute vessels and capillaries, but not the Malpighian tuft or coil. This is worthy of notice, as showing a great difference in the chemical constitution, and consequently in the organization, of these different parts.

Plate 9 shows the convoluted tubes A, passing into straight tubes B. C is a Malpighian body, connected with a convoluted uriniferous tube. This tube is seen to pass downwards, and become continuous, with a straight one. D a Malpighian body, with the uriniferous tube connected with it. Magnified 80 diameters. I have succeeded in exhibiting the tubes of the kidney,

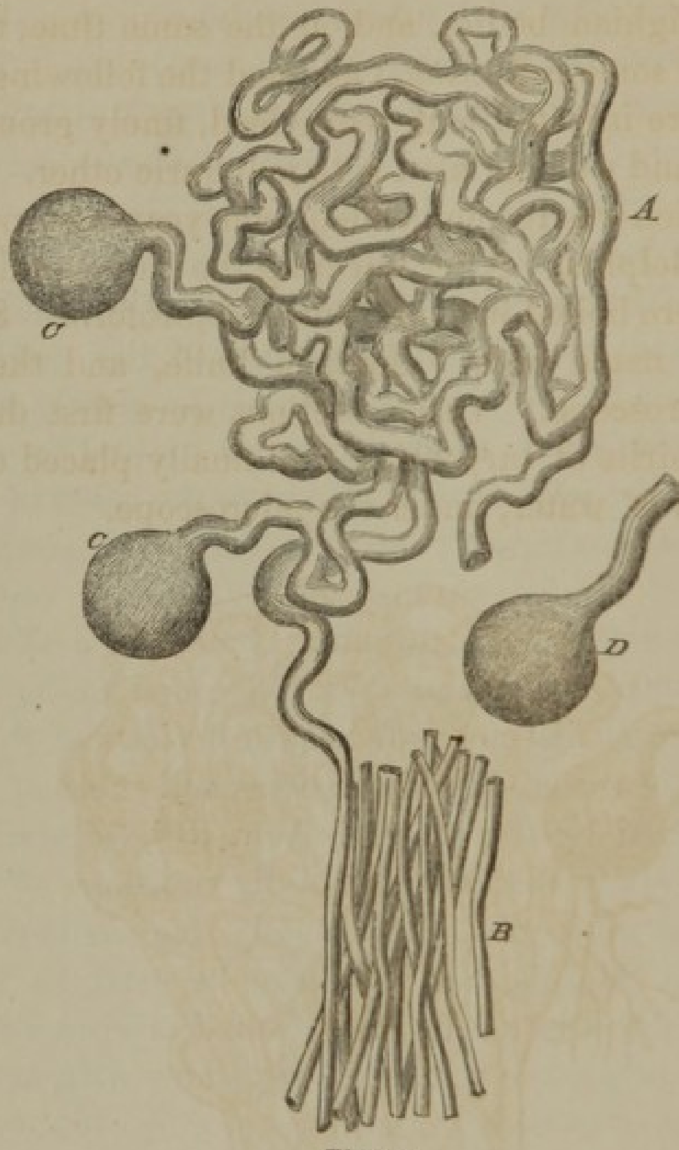

Plate 9.

very distinctly, by boiling small pieces of the organ in diluted chloroform, and also in solution of chlorate of potassa, which last is useful in giving a clear view of the surface of the kidney when congested, as it shows the venous plexus and the tubes, and acts but slowly upon the blood globules. Muriatic, acetic, and nitric acids, also exhibit the tubuli with considerable distinctness; the last however, is apt to discolor the tubes. I have also tried the effect of many other chemical reagents, among others, the phosphoric, chromic, boracic, tartaric, and citric acids, the alkalies, and their carbonates, various salts, &c. Some of these chemical agents act strongly upon the blood vessels, and are apt to destroy them, unless used in a very diluted state. As, however, it was very desirable to show the vessels in connection with the Malpighian bodies, and, at the same time, to exhibit the tubes, after some reflection, I adopted the following plan:— The vessels were injected with white lead, finely ground in oil, (artist's tubes) and well agitated with sulphuric ether. This material for injection was recommended some years ago by Dr. Goddard, of Philadelphia. After injecting the kidney, small pieces of the organ were boiled in very diluted chloroform. Some thin sections were made with Valentin's knife, and then placed under the microscope. Other sections were first dried, then immersed in spirits of turpentine, and finally placed on a glass slide, in a drop of water, under the microscope.

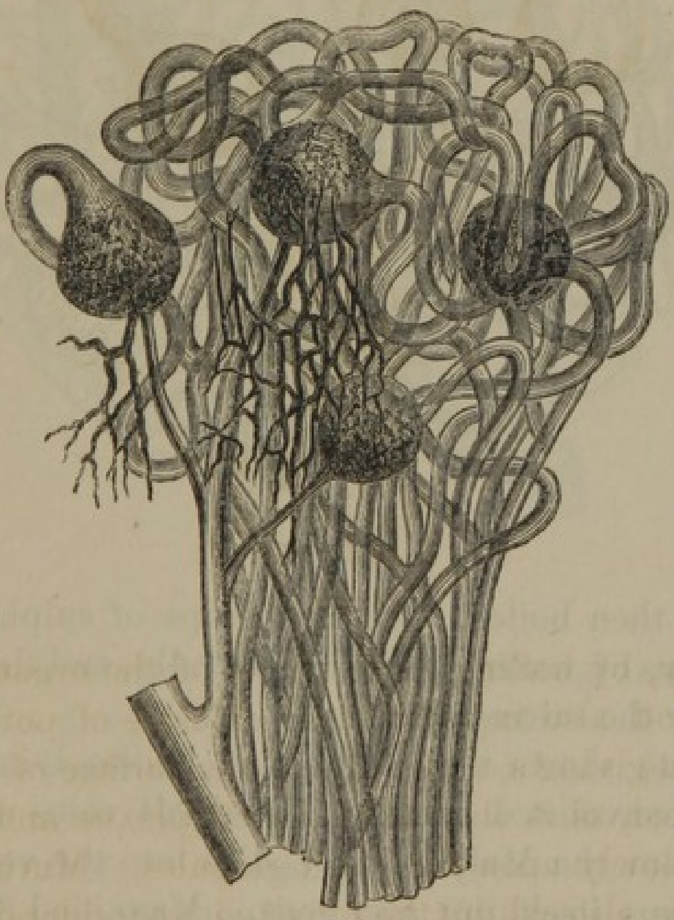

Plate 10.

Plate 10 exhibits a portion of the kidney of the sheep, prepared as above.

The Malpighian bodies, and the small arterial twigs, upon which they are placed, are seen lying among, or in the midst the convoluted tubes. The capillary venous plexus is also seen upon, and in the midst of the tubes, or the tubes may be said to lie in a mesh or network of this plexus. Magnified 80 diameters.

Plate 11 exhibits a thin section of the kidney of the sheep, also injected with white lead.

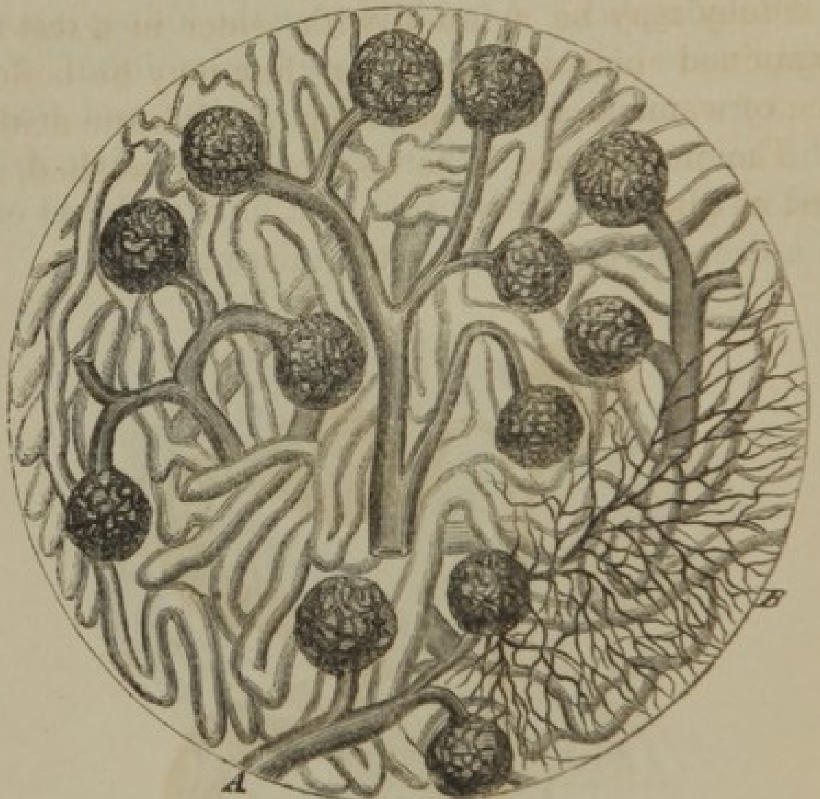

Plate 11.

This was then boiled, with two drops of sulphuric acid, in three drachms of water, washed repeatedly, and thin slices then placed under the microscope.

This Plate shows the Malpighian bodies lying among or amidst the convoluted tubes. The small veins which return the blood from the Malpighian bodies into the venous plexus, and the plexus itself, are also seen. Magnified 80 diameters. The epithelium of the tubes and their basement membrane, may be seen by the process already described, but inasmuch as water has a tendency to break down the epithelial cells, I resorted to the use of a solution of albumen in fresh urine. Thin sections, or scrapings of the kidney, may be agitated in this fluid, and then placed under the miscroscope.

One of the most difficult questions in the minute anatomy of the kidney is whether any connection exists between the Malpighian body and the uriniferous tube, and if so, what is the true nature of that connection? Having been much disappointed in my repeated attempts to ascertain the truth in this matter, I adopted the following processes:—Fine scrapings of the kidney may be agitated with water in a test tube, and then examined microscopically, or they may be boiled in half an ounce of water, to which one drop of sulphuric acid has been added. The precipitate is to be repeatedly washed, and then examined as above.

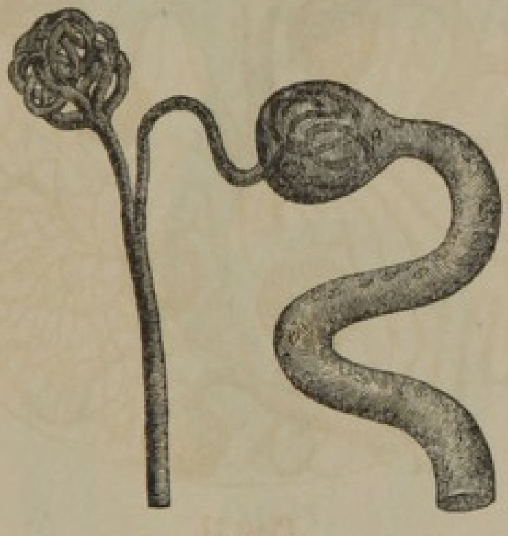

Plate 12.

Plate 12 is a view obtained by agitating scrapings of the kidney of the sheep, (which had been previously injected with chrome yellow and sulphuric ether) in a test tube, with water. Among the minute fragments was one, from which the above drawing was taken. A small artery is here seen, dividing intc two branches, each supporting a Malpighian tuft, or coil of capillaries. To one of these is attached the expanded extremity of the convoluted uriniferous tube. Magnified 130 diameters.

Plate 13 shows a minute artery, passing to the expanded extremity, or capsule of the uriniferous tube. The artery has been filled, and the Malpighian coil, or tuft of capillaries, has been ruptured by the injected material, which has thus passed

Plate 13.

into the uriniferous tube. From the kidney of the deer. Magnified 80 diameters. Drawn by Dr. Armenius Oemler.

Plate 14 exhibits the uriniferous tube and capsule, injected from the ureter, with white lead. From the kidney of the moose. Magnified 80 diameters. I have also succeeded in showing the connection of the tubes with the Malpighian body, by suspending small pieces of the kidney in the vapor of alcohol for two or three weeks, and then placing very thin sections of the organ in water, in a test tube, and agitating occasionally for 24 or 36 hours, and then subjecting very small portions to

Plate 14.

the microscope. In this manner, I have obtained some exceedingly clear and beautiful views.

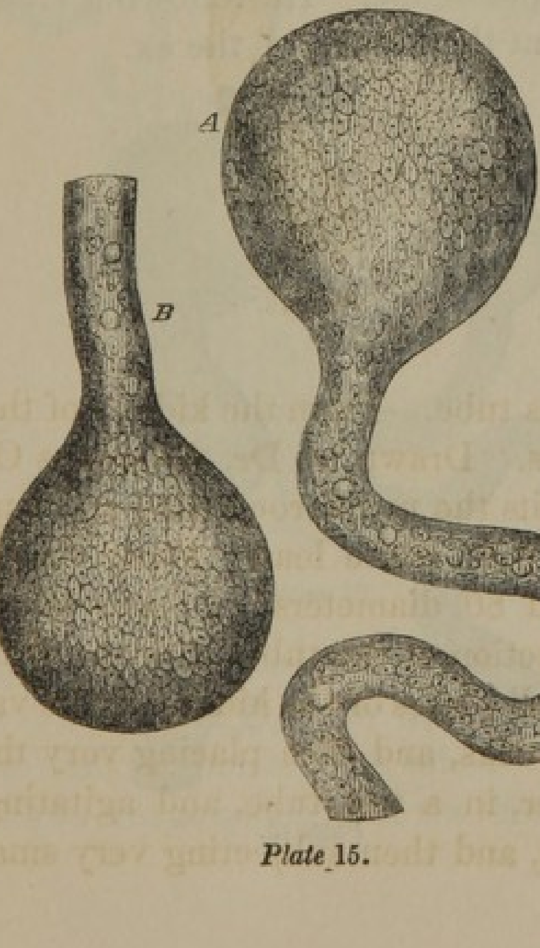

Plate 15.

Plate 15 exhibits the above named parts from the kidney of the cat, obtained by the process just described.

A and B represent the Malpighian bodies. Nucleated epithelial cells are seen, which line the interior of the capsule, and are also placed upon the Malpighian coil, or tuft of capillaries. The tubes also contain epithelium, and some oil globules, which are almost always to be found in the kidney of cats.

The wall of the tube, or basement membrane, can be traced up to the point where it expands to form the capsule, or covering of the Malpighian coil or tuft of capillaries. The tuft, covered by the capsule, constitutes the Malpighian body. Magnified 250 diameters. A process, however, which I would particularly recommend, is the following. Put into a test tube half an ounce of water, and add to it two or three drops of chloroform; a small portion of the fine scrapings of the kidney (about the size of a large pistol ball) is then to be dropped into the fluid, and the tube, with its contents, heated over a spirit lamp, but not sufficiently to cause boiling; the fluid is to be poured off from the deposit, which is to be carefully and repeatedly washed with pure water, and small portions are then to be placed under the microscope. The following view was obtained by this process from the kidney of the ox.

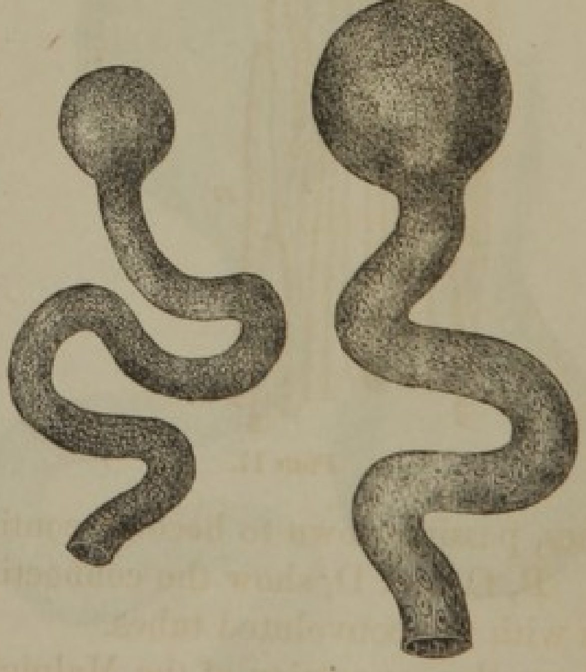

Plate 16.

Plate 16 exhibits a Malpighian body, and its connection with the uriniferous tube. The smaller object is magnified 50 diameters. The same object, on the left hand, magnified 80 diameters. Epithelial cells are seen through the capsule of the Malpighian tuft, and within the uriniferous tubes.

Plate 17 exhibits a thin section of the kidney of the sheep, obtained also by the process just described. Magnified 40 diameters. Drawn by Dr. Armenius Oemler. A exhibits the

Plate 17.

convoluted tubes, passing down to become continuous with the straight tubes. B, C, and D, show the connection of the Malpighian bodies with the convoluted tubes.

Plate 18 shows the connection of the Malpighian body with the [uriniferous tube. From the kidney of a cat, in which the right renal vein had been tied, and the ureter of the left kidney

Plate 18.

also ligated. The animal died in fifty-six hours after the operation, stupor and increasing coma having supervened some hours before death. The specimen appears dark, from the blood in the tubes and Malpighian body.

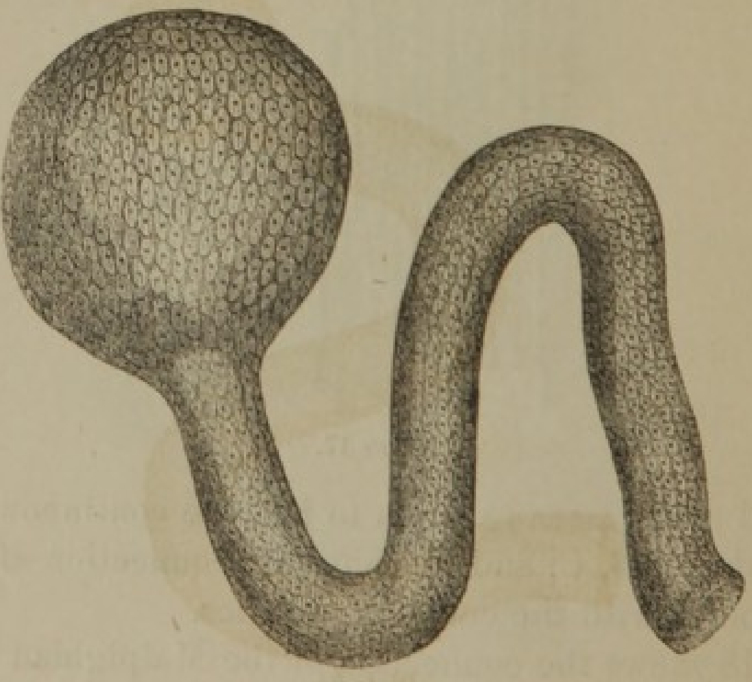

Plate 19.

Plate 19 is a view of the Malpighian body, and its connection with the uriniferous tube. Epithelial cells are seen within the tube, and through the capsule of the Malpighian tuft or coil. This view was obtained by agitating scrapings of the kidney in a solution of albumen in urine. From the kidney of the sheep. Magnified 400 diameters.

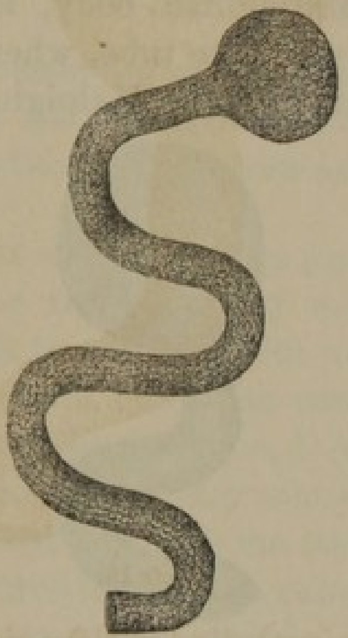

Plate 20.

Plate 20 represents the Malpighian body and uriniferous

Plate 21.

tube connected with it. Obtained by agitating scrapings of the organ, with water, in a test-tube. From the kidney of the gray squirrel. Magnified 80 diameters. These parts appear to be smaller in the squirrel than in any of the other animals to which reference has been made.

Plate 21 exhibits the connection of the convoluted uriniferous tube with the Malpighian body, in the kidney of the common domestic fowl. The tube, where it passes up to form the capsule, or covering for the Malpighian tuft, does not pre-

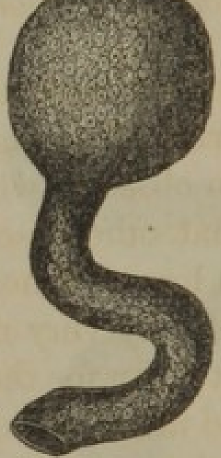

Plate 22.

sent the constriction usually seen in the kidneys of the mammalia. Magnified 250 diameters.

Plate 22 also shows the connection of the uriniferous tube

Plate 23.

with the Malpighian body. From the kidney of a large snake, obtained from the river Amazon. Magnified 400 diameters.

Plate 23 likewise exhibits the connection of the Malpighian body with the uriniferous tube. From the kidney of a large fish (haddock). Magnified 400 diameters.

Conclusion as to the connection of the Malpighian tuft, or coil of capillaries with the convoluted uriniferous tube, and a statement of the opinions of authors upon this subject.

By the employment of the various processes, which I have described, even at the risk of being considered as tedious, because they enable us to observe, with comparatively greater clearness and facility, what otherwise cannot be seen without great difficulty and much loss of time, I have satisfied myself, beyond the slightest doubt, by very many and repeated observations, conducted almost daily for the last twelve months:

1. That the convoluted uriniferous tubes terminate by forming an expanded extremity or capsule, which embraces the Malpighian tuft, or coil of capillaries, as was first correctly described by Mr. Bowman, in his excellent paper upon the kidney. I am, however, well aware that very different views upon this point have been held by Toynbee, Müller, Gerlach, Bidder, and other authors.

Some indeed have even denied that any connection existed between the Malpighian body and the uriniferous tube. Thus Hüschke says: "These corpuscles (the Malpighian) are without any connection with the uriniferous ducts." Müller observes: "Fines ductuum uriniferorum in corpora Malpighiana desinere, certissime falsa assertio est." And again, he says: "Falsissima est opinio de connexu ullo quopiam inter corpora Malpighiana sanguifera et ductuum uriniferorum fines."

In a paper published in the *London Medical Times*, April, 1846, Professor Hyrtl, of Vienna, maintains that "the Malpighian capsules have no connection with the urinary tubules, but open into the lymphatics."—(*British and Foreign Medical Review*, 1846.) Mr. Toynbee, in his plates of injected kidneys, represents the uriniferous tube as penetrating the capsule of the Malpighian tuft, then twisting into a coil within the capsule, and finally emerging from the capsule. Gerlach says that the Malpighian capsule is not a blind termination of a uriniferous duct, but, on the contrary, a retraction, introversion, or diverticulum of the same membrane which forms the urine tubes. He, however, correctly describes the Malpighian tuft as covered by nucleated cells. (See his Beiträge zur Structurlehre der Niere, in Müller Archiv., 1845.) According to Bidder, the Malpighian tuft or coil is pushed into an expanded portion of the uriniferous tube, the coil being *external* to the cavity of the dilated extremity of the tube, the relation of the two being similar to that of the head within a double nightcap. (See Bidder, in Müller Archiv., 1845.)

This difference of opinion, even among such high authorities, may probably be accounted for, inasmuch as it is very difficult, by employing the usual means of examination, to obtain any minute portion of the organ which will show the tube connected to the Malpighian body. Moreover, in examining any thin section of the kidney (as is usually done) for this purpose, it is to be remembered that the Malpighian body is always embraced in a ring of the fibrous matrix, and that at the neck of the tube, or its commencement of expansion into the capsule, is its weakest part, and where it is most easily, and indeed almost always, torn across, especially when traction is made upon it, as is usually done, in tearing out the specimen with needles. On the contrary, by using *scrapings* of the organ (as here recommended) agitated in water, which softens and removes many of the adhering portions of the matrix, which last holds and confines the Malpighian body, this can be washed out, and not unfrequently with the convoluted tube attached to it. (See Plates 15, 16, 19, 20, 21, 22.)

I may now remark, that having had no particular theory to influence my investigations, my sole object has been to ascertain what was the real structure, and to represent accurately what I have so frequently observed. I refer, also, with much satisfaction, to the testimony of others, to whom I showed the specimens, under the microscope, and particularly to Drs. J. P.

Batchelder, J. M. Minor, formerly Surgeon of the U. S. Navy, Professors J. T. Metcalfe, George T. Elliot, and Alfred C. Post, Drs. Stephen Smith, J. S. Goulay, John T. McNulty, George A. Peters, T. C. Finnell, and many others, who were satisfied that the structure was strictly that which has been represented in the plates here given. Within the last week, I have met with a paper on the structure of the kidney, in some of the mollusca, and in birds and serpents, by Dr. Busch, of Berlin, in the last August number of Müller's Archiv, for 1855. He says:—"My experiments on snakes have fully convinced me that the glomerulus (or Malpighian coil) is truly situated in the expanded end of a uriniferous tube." "Dass der glomerulus wirklich, in einer kapsel, dem erweiterten ende, eines Harn canälchens, gelegen sei."

His description is very similar to that of Bowman, but he differs from him in representing the Malpighian tuft as covered by nucleated cells. A plate of the structure in the snake is also given.

On the termination of the convoluted uriniferous tubes.

The convoluted tubes form loops, and also become continuous with the straight tubes, but I have never seen blind extremities, or the anastomoses of the tubes, as described and figured by Toynbee and others, except in the kidney of frogs, fish, and turtles. I would not wish, however, to be understood as denying their existence.

On the question whether nucleated cells exist upon the Malpighian tuft or coil of capillaries.

Much difference of opinion on this point still prevails among anatomists, and, as will be seen hereafter, the determination of this subject is very important in reference to the physiology of the kidney. The epithelium of the tuft is, perhaps, best seen in the kidney of frogs, snakes, etc., but I am not aware that any anatomist has satisfactorily demonstrated it in that of the higher animals.

In the investigation of this subject, it seemed to be very difficult to ascertain the true arrangement, and for the following reasons :—In looking at the Malpighian body, which consists of the tuft or coil of capillaries, and the expanded extremity of the uriniferous tube, or the capsule, as it is called, we observe a number of cells, which seem to lie on the surface of the Malpighian body, but which are really on the inner surface of the capsule. See Plate 19. As the capsule embraces the tuft or coil, and ordinarily is closely applied to it, it results that the cells lining the interior of the capsule must conceal those which are on the tuft, if indeed such there exist.

It would thus seem almost impossible, in looking at a Malpighian body, to decide whether the cells which we see *apparently* upon its surface, are really those on the inside of and lining the capsule, or whether they are on the tuft, and are perceived through the transparent capsule, or, lastly, are they the cells, both of the tuft and of the interior of the capsule ?

After much reflection as to the best plan of determining this point, I adopted the following processes :—

1. By injecting watery and etherial solutions into the ureter, I succeeded in bursting the capsule, the Malpighian tuft or coil having been previously only slightly, and as was intended imperfectly injected from the artery. Epithelial cells could, then be seen upon the uninjected and transparent edges of the tuft or coil.

Plate 24, Fig. 1, exhibits a Malpighian tuft. Broken fragments of the injected vessels are seen within it. They had been injected with chrome yellow, and appear black when the specimen is viewed by transmitted light. The uriniferous tube had been distended by the injection from the ureter, and its expanded extremity, or capsule, had been burst, and can be perceived lying in shreds at the sides of the tuft, which is now uncovered by the capsule. Nucleated cells can be seen upon the naked and uninjected parts of the tuft.

From the kidney of the black bear. Magnified 80 diameters.

Fig. 2. In this specimen the capsule had been scratched off with a needle, and then the naked tuft somewhat torn under

the microscope. In Fig. 3, some small fragments of the tuft are here seen with nucleated cells on their surface.

Plate 24.

4. The capsule was torn off from a Malpighian body with a needle. In doing this, the capsule became reversed, so as to give a view of its internal surface, upon which small nucleated cells could be clearly and distinctly seen. The surface of the naked tuft was covered by cells of much larger size than those upon the interior of the capsule. Upon the application of dilute nitric acid, the wall of the cells of the capsule was dissolved, while comparatively little effect was produced upon those of the tuft, thus showing a difference in their chemical

constitution and organization. In Plate 25, A is the uriniferous tube; B, cells on the tuft; C, reversed and inner surface of the

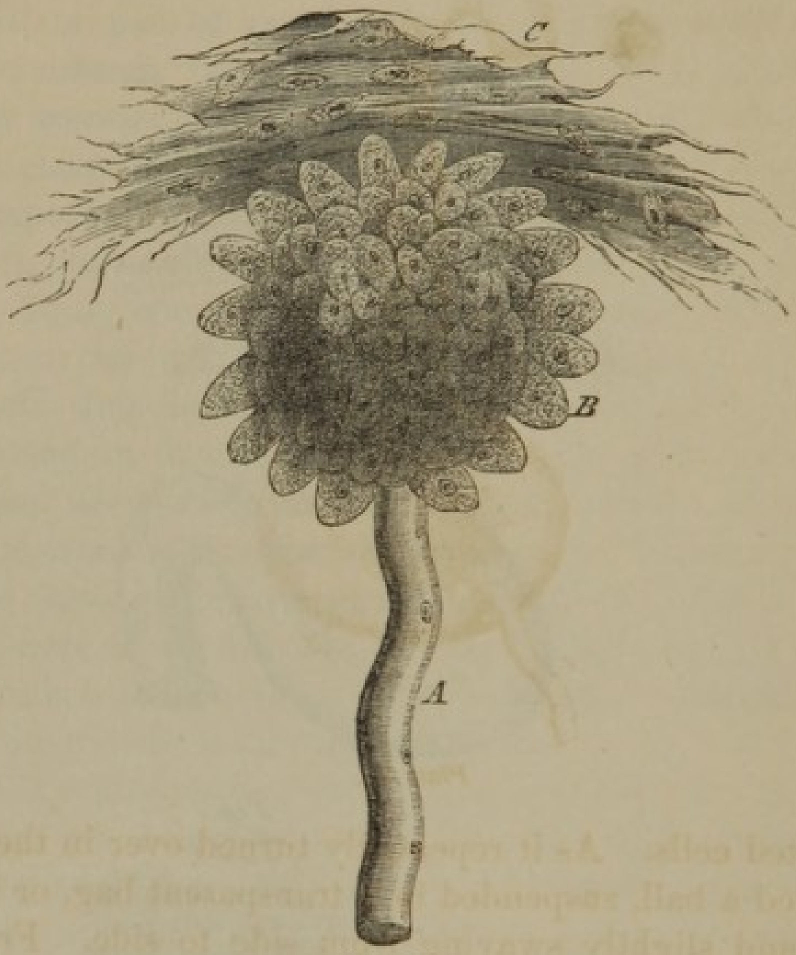

Plate 25.

capsule, covered by cells differing in their appearance and chemical reactions from those on the tuft. From the kidney of the raccoon. Magnified 400 diameters.

5. Fine scrapings of the kidney were agitated occasionally for two or three days, in a test tube, the water having been frequently changed. By this method, the epithelial cells within the capsule were washed out, so that the space thus left between the tuft and the capsule became filled with water, which had soaked through the capsule. See Plate 26. At A is seen the uriniferous tube. A few cells yet remain in its interior. B denotes the capsule. At C is perceived the minute arterial vessel which enters the tuft.

By slight agitation, while the specimen was floating in the water, under the microscope, it could be rolled over and over, so as to show various points of the surface of the tuft, covered

Plate 26.

by nucleated cells. As it repeatedly turned over in the water, it resembled a ball, suspended in a transparent bag, or bladder of water, and slightly swaying from side to side. From the kidney of the cat. Magnified 250 diameters. By the different processes just mentioned, I consider the existence of nucleated cells upon the surface of the Malpighian tuft, and, consequently, its analogy with the other secreting organs, as conclusively demonstrated.

Conclusions as to the Functions of the Malpighian Body.

According to Mr. Bowman, the Malpighian coil or tuft of capillaries lies entirely *naked* in its capsule, and its office is simply that of separating water from the blood, while the urea, lithic acid, and salts, are separated by the epithelial cells of the tubes from the blood of the venous plexus which surrounds them. These views, and some others, of Mr. Bowman, which will soon be presented, have been so extensively adopted, and copied into the text-books on physiology, that they deserve our most attentive consideration.

1. It is probable, that in other organs, water is never separated from the blood, simply as such, in any case whatever; but that it then always contains albuminous substances, and certain salts, and not unfrequently other materials. Nor do we find that a peculiar or special arrangement of vessels is required, even for the exhalation of serous fluids, but that, on the contrary, they may exude, or pass by simple exosmosis, through the minute vessels of any of the organs which are composed of soft and yielding tissues. Thus, the cerebro-spinal fluid permeates the vessels of the pia mater and the areolar tissue, and the serous membranes are moistened by a fluid, or, even in health, may contain a small quantity, exhaled from capillaries which are most simple in their arrangement. On the contrary, the Malpighian coil or tuft is so complex, and so peculiarly formed, that in man, and in the higher animals, we shall find that no organ except the kidney contains the same, or even a similar structure. It would, therefore, scarcely appear necessary that the Malpighian tuft, which is so complex in its organization, should be needed merely for the purpose of separating water from the blood, which could be effected by a much more simple arrangement of vessels, as well as by the entire and extensive epithelial surface of the uriniferous tubes.

2. The presence of peculiar nucleated cells upon the Malpighian coil or tuft, would seem to denote that some of the constituents of the urine, besides water, are secreted by them.

3. In birds and reptiles the urine is secreted either in the semi-fluid, or, as in the latter class, almost in the solid form.

Simon says: "The urine of serpents is excreted as a white, pultaceous, earthy mass, which soon stiffens on exposure to the air. It is composed, for the most part, of uric acid in combination with potassa, soda, and ammonia, together with phosphate of lime." (Simon, p. 562.) According to Prout, the urine of the boa-constrictor contains more than ninety per cent. of uric acid. The urine of the rattlesnake, analyzed by Simon, was composed almost entirely of uric acid and the urates. (See Simon, p. 54.) According to Jos. Jones, who has analyzed the urine of several species of snakes, their urine contained uric acid, always in combination with ammonia; he could not detect the presence of urea. (See his very valuable paper in the *American Journal of Medical Sciences*, April 1855.) Yet in these animals the Malpighian bodies exist, not only in the cortical portion, but throughout the entire kidney; and if, as asserted, their function is merely that of separating water from the blood, this fluid should be in excess; but it appears, on the contrary, that the urine is excreted almost in the solid state.

4. Will the entrance of foreign substances into the circulation, and their detection in the kidney and in the urine, throw any light upon the function of the Malpighian coil or tuft of capillaries? Let us examine carefully the following facts. According to Simon, after administration of the following substances, they can be detected in the urine:—Iodine and bromine, in combination either with ammonium, sodium, or potassium. Sulphur, ferrocyanide of potassium, salts of arsenic, antimony, iron, mercury, nickel, gold, silver, tin, lead, bismuth, copper, and manganese, have all been found in the urine. This was also the case with the organic acids—as the tartaric and citric acids. Meconic acid has been detected in the urine of animals poisoned with opium, as have also morphine and quinine. Coloring and odorous, or volatile substances, have often been recognized in the urine, as indigo, gamboge, rhubarb, madder, Indian fig (which colors the urine blood-red), garlic, turpentine, cubebs, and balsam copaiba. Alcohol has very often been found in the urine. Lehman, after taking phloridzin, discovered hippuric acid and oxalate of lime in his urine. I have myself repeatedly swallowed solutions of the ferrocyanide of potassium, and in fifteen or twenty minutes ascertained its presence in the urine by its striking a blue color with the salts of iron. I have also frequently taken small quantities of benzoic acid, and found, on microscopic examination of the urine, that it had been changed and separated from the kidney under the form of crystals of hippuric acid.

Urea has been given internally by some of the French physiologists, and has acted as a powerful diuretic, and on such occasions has been found in large quantity in the urine. Now then, it is admitted by Mr. Bowman that diuretics must enter the circulation and pass along with the blood of the renal artery into the Malpighian body. He even says: "Diuretics appear to act specially upon the Malpighian body, and various foreign substances, particularly salts, which when introduced into the blood, pass off by the urine with great freedom, and exude, in all probability, through this *bare* system of capillaries. The structure of the Malpighian body indicates this; the escape also of certain morbid products, occasionally found in the urine, seems to be from the Malpighian tufts. I allude especially to sugar, albumen, and the red particles of the blood; the two first of which would transude, while the last would escape only by rupture of vessels." (See Bowman, *Philosophical Transactions*, 1842.)

It is then conceded, and we have every reason to believe, that these foreign substances do actually pass through the renal artery, and consequently through the Malpighian tuft or coil; and if this tuft *can* separate all the various substances above enumerated as having been found in the urine, and especially the various salts and the urea, are we not justified in believing that in the performance of its normal function it does something more than merely separate the water from the blood?

The following is an interesting illustration of the capability of the Malpighian tuft for the separation or elimination of coloring matters. Within a few days past, my friend, Dr. J. C. Hutchison, of Brooklyn, has presented me with some specimens of diseased liver and kidneys taken from the body of a man who had been very intemperate for the last twenty years. The patient was deeply jaundiced for some time previous to death; the kidneys were slightly indurated. On making a microscopic examination of very thin sections of the kidney, I found that some of the convoluted uriniferous tubes contained particles of bile, and that some of the epithelial cells were stained of a deep yellow color by this substance. *The Malpighian bodies were of a slight yellow or brassy color.* On applying Pettenkoffer's test, the Malpighian bodies and the colored contents of the tubes showed a play of colors, and finally were reddened by the action of nitric acid. Thin sections of the kidney, steeped in water, colored it slightly yellow; and this fluid, acted on by nitric and by muriatic acid, assumed the usual varying colors, thus fully demonstrating the presence of bile. These facts seem to prove that the Malpighian tuft has the power of separating the coloring matter of the bile, and it would be difficult to explain its presence in the urine except on the supposition that it had passed through the coil or tuft.

Lastly—Simon, Marchand, and many others have detected urea in the blood of healthy animals. Valentin says: "It may be recognized in the blood, in the saliva, in the aqueous and vitreous humors, in dropsical fluids," &c. In cases of Bright's disease, and especially after extirpation of the kidneys, it is found in the blood in large proportion. According to Dr. Garrod, uric acid also exists ready formed in the blood, even in health, and can always be easily detected in that of gouty patients.

The coloring matters of the urine, and the various salts, as the phosphates, sulphates, and chlorides, pre-exist in the blood. This is also the case with the kreatine and kreatinine, which are derived from the disintegration of the muscular tissues. It is, then, proved that all the elements of urine are first formed in the blood, and subsequently separated by the kidney. Thus the blood which contains them *must* pass through the renal artery and the arterial terminal twig which supports the Malpighian body. The blood passes slowly through this vascular coil or tuft, and its velocity is also retarded in consequence of the small size of the "vas efferens," or the vein which returns the blood of the tuft into the venous plexus. (See Plate 10.) Here also the cells which lie immediately upon the tuft aid in the separation of the elements of the urine. (See Plate 25.)

If any constituent of the urine should escape separation from the blood while in the Malpighian body, it must then pass through the vas efferens into the venous plexus, the arrangement and function of which will now be considered.

It has been already stated, that according to Mr. Bowman, whose views are entitled to the highest respect, and have been almost generally adopted, the urea, lithic acid, and salts are separated by the epithelial lining of the tubes from the blood of the venous plexus which surrounds them. The minute vein which returns the blood of the Malpighian tuft or coil, or the "vas efferens," as it has been termed, is similar in its nature to the vena porta, and the blood of the venous plexus to that of portal blood; or, as he observes, "each efferent vessel is a portal vein in miniature. In support of his theory, he states that, "in serpents the kidney *receives* not only a renal artery, but also a '*large renal portal vein,*' bringing, for the secretion of urine, the venous blood of the hinder parts of the body, and giving off the capillaries which ramify upon the urine tubes." —(Bowman, *Philosophical Transactions*, 1842. See Plate 27, which is a view of the minute structure of the kidney in the boa-constrictor.)

In Plate 27 *A* is a small branch of the renal artery; *Af* a

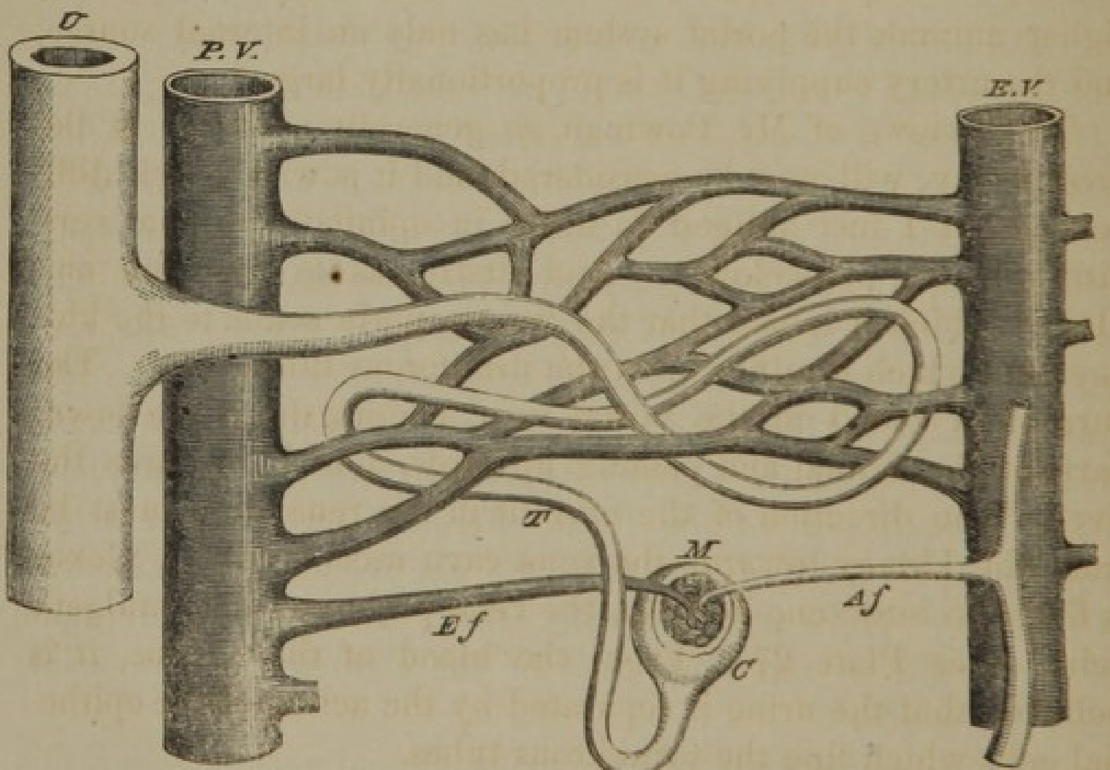

Plate 27.

small twig from it, passing on to expand into and form the Malpighian tuft or coil of capillaries; *Ef* is a vein returning the blood of the Malpighian coil; *M* the coil itself; *P V* the portal vein; *E V* the emulgent or renal vein; *C* the capsule of the Malpighian coil; *U* the ureter; *T* the uriniferous tube lying in the midst of the minute veins which pass from the portal to the emulgent or renal vein.

In further explanation of his views, Mr. Bowman remarks: "Thus the efferent vessels of the Malpighian bodies are radicles of the portal vein, and through the portal vein empty themselves into the plexus surrounding the uriniferous tubes. The only real difference between this form of kidney and that of the mammalia is that here is a vessel bringing blood that has already passed through the capillaries of distant parts, to be added to that coming from the Malpighian bodies, and to circulate with it through the plexus surrounding the tubes. The efferent vessels of the Malpighian bodies run up the surface in order to throw their blood through the whole extent of the capillary plexus, &c. The emulgent vein of the kidney answers to the hepatic vein of the liver. But in the kidney of the higher animals the portal system has only an internal source, and the artery supplying it is proportionally large."

These views of Mr. Bowman, so generally admitted at the present day, will now be considered, and it is with much diffidence, that I feel obliged to differ in opinion with that very distinguished physiologist. And firstly, as to the vein and plexus, which it is said that the "vena porta sends to the kidney, and which ramifies upon the uriniferous tubes," &c. The current of blood in the portal vein, coming from the lower parts of the animal and passing upwards, must be towards the liver. The direction of the current in the renal vein must be from the kidney towards the vena cava ascendens. A plexus is found to intervene between the vena porta and the emulgent vein. (See Plate 27.) From the blood of this plexus, it is believed that the urine is separated by the action of the epithelial cells which line the uriniferous tubes.

Now, it may be asked, why should this plexus exist, if not for this purpose? To which it might be answered, that by means of this vascular arrangement, a certain amount of portal blood, which is not required for the function of the liver of the serpent, or which might be injurious to its action, can be diverted from that organ by passing through the plexus into the emulgent vein. This is also probably a channel by which the lower organs of the body may temporarily relieve themselves when congested, by allowing the blood which returns from them into the portal vein to pass into the renal vein, and so on into the current of the general venous circulation. The "vas efferens," or the minute vein which returns the blood of the Malpighian tuft of the serpent, passes into or joins the portal vein. (See Plate 27.) Now, even in the boa, the blood of the "vas efferens" cannot strictly be regarded as portal blood, or at least, it does not as such influence the secretion of urine, unless perhaps when some obstruction occurs in the portal vein. Blood would then pass backwards, or regurgitate from the portal vein into the "vas efferens." But this would be accidental, and would not occur under ordinary circumstances. On the contrary, the blood of the "vas efferens" should be regarded as renal blood. It is, in fact, merely the returning blood of the Malpighian tuft, passing towards and emptying into the portal vein. (See Plate 26.) But the question might be asked, Why then does a portion of the venous blood of the kidney of the serpent return through the vas efferens into the portal vein?

To this it may be answered, that inasmuch as scarcely anything, with the exception of uric acid and urate of ammonia, is separated from the blood of the serpent in the process of urinary secretion, the venous blood of the kidney remains loaded with the elements of urea and of other products resulting from the decomposition of the tissues, and especially from the food of which these animals consume enormous quantities at a time. These elements, then, added to the blood of the vena porta, contribute to it something which is useful in the formation or secretion of the bile. The kidney of the serpent, therefore, by sending or contributing a portion of its venous blood to the liver, stands nearly in the same relation to that organ as do the chylopoietic viscera. Having thus far dissented from the views of Mr. Bowman respecting the peculiar vascular arrangement in the kidney of the serpent, it next remains to be considered whether a similar structure exists, as has been stated, in the human kidney. In the latter we find no communication between the portal and renal veins, nor any venous plexus resembling that which exists in the kidney of the serpent. Next, as to the analogy which has been drawn between the vas efferens of the kidney of the serpent and the same vessel in the human kidney, or in those of the higher animals. The vas efferens in the serpent returns its blood into the portal vein. The vas efferens of the human kidney returns its blood into a plexus, which may be said to be composed of the minute radicles of the branches of the renal vein. Thus far there is no resemblance between the vascular arrangement of the kidney of the boa and that of the higher animals. But this has been thought to exist between the vas efferens of the human kidney and the vena porta, and it has even been said, that "each efferent vessel is a portal vein in miniature." In order to prove this assertion, it would be necessary to show that the vas efferens originates by very many branches from the Malpighian tuft, in a manner similar to that by which the vena porta commences: viz., by numerous radicles from the abdominal viscera. Mr. Toynbee says: "In the healthy corpus Malpighianum it is impossible to ascertain with precision the manner in which the emerging vessel of the corpus (coil) takes its rise from the rete or coil; but, from an examination of the Malpighian body when morbidly enlarged, it would appear that it springs from the convoluted vessels by radicles of smaller dimensions than the convolutions themselves. In some instances the rete or coil seems to be formed by a single branch of a single vessel in which the artery terminates."

On examination of many injected Malpighian tufts, I have generally seen the vas efferens emerging from the tuft at a point very near to that at which the minute arterial twig, which supports the tuft, enters into it. (See Plates 3 and 9.) I have never been able clearly to perceive the mode in which it originates, and it is very difficult to ascertain this point. I have, however, never seen it commencing by radicles similar to those of the vena porta. But even allowing the arrangement to be exactly as described by Mr. Bowman, the analogy would appear to be a forced one, for the vena porta conveys blood from the intestines to an organ of entirely different structure, viz., the liver; whereas the vas efferens conducts blood from the Malpighian body of the kidney to a plexus belonging to the *same organ*, and in microscopical proximity to it. Moreover, as it emerges, it is frequently joined by an arterial branch; so that, after all, the so-called venous plexus is not strictly such, but contains a mixture of arterial and venous blood. (See Plate 3.)

It may then be concluded that the interpretation of the peculiar structure in the kidney of the boa-constrictor is not satisfactory, and that no such structure exists in the human kidney, or in that of the larger animals, and that the supposed analogy of the vas efferens of the human kidney with the vena porta should not be admitted, inasmuch as its mode of origin is not clearly ascertained, and at least does not appear to be similar to that of the vena porta; and even if it were as stated, it would not then be proved that *its function* was similar to that of that vessel. The reasons for this view have already been given. It has been attempted to explain the physiology of the human kidney by considerations of structure in the kidney of the boa-constrictor, an animal presenting an immense difference in its organization from that of man, or of the higher animals. The facts and arguments which have here been presented, in opposition to this view of the subject, it is hoped will be found to be satisfactory.

It will be remembered, that to the epithelial cells which line the uriniferous tubes has been attributed the power of separating the urea, lithic acid, &c., from the blood of the venous plexus. How probable this opinion may be will appear from a consideration of the following facts: 1. The Malpighian tuft is covered by nucleated cells. 2. The proximate elements of the urine exist ready formed in the blood. 3. The blood thus containing these elements, as urea, lithic acid, salts, &c., &c., *must* pass into the renal artery, and consequently into the Malpighian tuft, where, owing to the arrangement of this coil of vessels, and also to the small size of the vas efferens, its course must be retarded. The constituents of the urine are thus placed under the most favorable circumstances for escaping from the tuft. 4. Foreign substances introduced into the blood must necessarily pass into the tuft, and some (as the coloring matter of the bile) have actually been detected in it.

From the foregoing facts it may be inferred that the Malpighian tuft separates many of the proximate elements of the urine (in combination with water) from the blood. It appears to be very difficult, or even impossible, to arrive at any other conclusion. There then remain other elements of the urine, which may perhaps be separated from the blood by the action of the cells of the tubes, as generally supposed. The argument, however, in support of this view, that these cells belong to the spheroidal or "*glandular*" variety of epithelium, and must therefore *necessarily* secrete the proximate elements is untenable, as it has been proved that the epithelium lining the tubes is really of the tessellated kind. On the other hand, this fact is not an objection to the opinion in favor of their secreting agency, because, as has been already mentioned, the bile, which is the most complex of all secretions, is separated by the hepatic cells, which are of very irregular form, and resemble tessellated epithelium. It is not probable that all the elements of the urine should pass through the renal artery and the Malpighian tuft, which appears to be specially constructed for their separation, and to offer every facility to their passage into the capsule of the uriniferous tube, merely that they might reach the venous plexus, where they could then be separated. However, it is not impossible that some one or more constituents of the urine, combined with water, may be separated by the agency of the epithelial cells of the tubes, as generally supposed, and perhaps also any element which may have escaped separation while passing through the Malpighian tuft. Comparative anatomy and chemical pathology will hereafter throw much light upon these obscure points of physiology.

Of the Fibrous Matrix of the Kidney.

Some of the most accurate observers have failed to detect the areolar, or the fibrous tissue, in the proper substance of the kidney. Henle, a most learned and excellent histologist, has even said: "Je n'ai jamais aperçu la moindre trace de tissu cellulaire entre les canalicules urinifères."—Henle, *Anat. Générale*, tome ii. p. 512. The fibrous matrix of the kidney was first described by Mr. Goodsir in 1842, and although this structure is of the greatest physiological and pathological importance, as will be shown hereafter, yet its existence has been, and is even now, doubted or denied by several authors. Professor Lionel Beale, of King's College, London, after describing the matrix, in his excellent work on the microscope, published in 1854, observes: "Of late much discussion has arisen with reference to the presence or absence of a fibrous matrix in the healthy human kidney, and observers are not agreed as to which is really the case."

Dr. George Johnson, in his valuable work on the kidney, remarks, that Rokitansky has fallen into the very grave error of representing the normal fibrous matrix as a product of disease. (Page 321.) And again, he states that Frerichs (a very high authority) doubts even the existence of the normal fibrous matrix. It appeared to me, therefore, that this subject required fresh investigation. I have never satisfactorily succeeded in exhibiting it by following the directions usually given for this purpose. It can, however, be always easily and distinctly shown by the following process: Very thin slices of the kidney are to be made with Valentin's knife, put into a long test-tube about one third full of water, and agitated from time to time for two or three hours.

Prepared in this manner, a thin section exhibits under the microscope a kind of mesh, network, or honeycomb arrangement—the cells of the honeycomb, however, having no bottom. In the natural condition of the kidney, the smaller cells or openings transmitted the tubes; the larger cells or openings were occupied by the Malpighian bodies; which last, together with the tubes, have now been washed out of the cells, although a few are often seen still remaining in situ. (See Plate 28.)

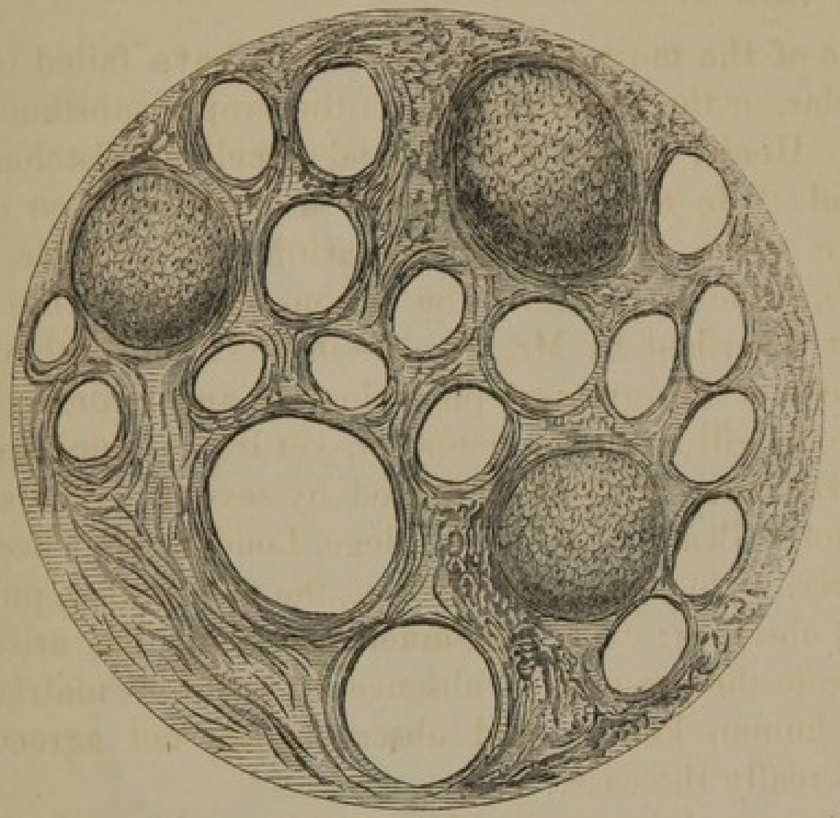

Plate 28.

This plate exhibits the fibrous matrix of the kidney of the rat. The smaller rounded spaces are for the tubes, the larger openings for the Malpighian bodies. Three of the last are also seen. Nucleated epithelial cells are seen through the capsule, and apparently upon the capsule, but really within it. Magnified 250 diameters.

Plate 29 shows the fibrous matrix of the kidney of the dog.

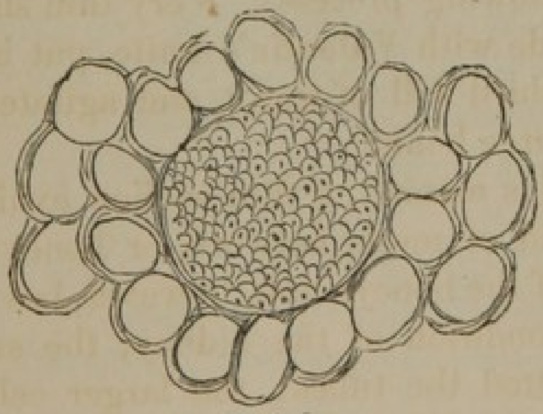

Plate 29.

A Malpighian body is seen in the centre, and surrounded by its own investment of fibrous tissue, and also by numerous ring-like cells for the tubes. Magnified 80 diameters.

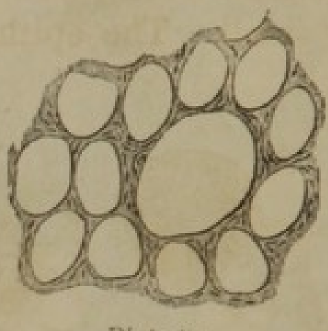

Plate 30.

Plate 30 shows the fibrous matrix of the kidney of the grey rabbit. Magnified 80 diameters.

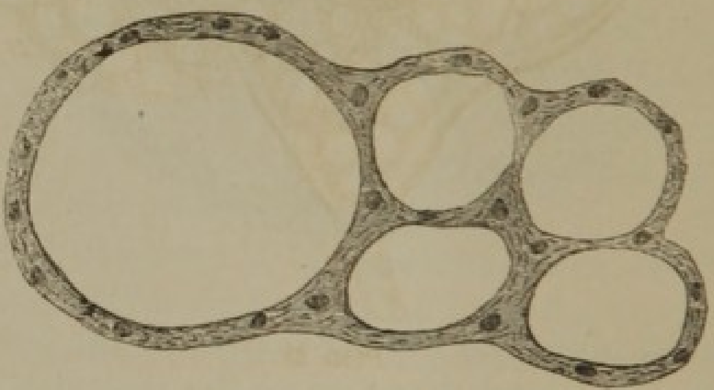

Plate 31.

Plate 31 exhibits the fibrous matrix of the kidney of the

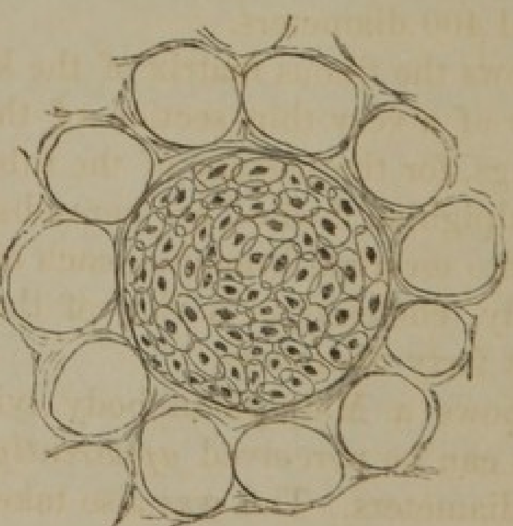

Plate 32.

raccoon. The cut orifices of capillaries can be seen in the meshes of the matrix. Magnified 400 diameters.

Plate 32 shows the fibrous meshes of the kidney of the grey squirrel. The Malphigian bodies and the uriniferous tubes of this animal are very small. The epithelial cells which are on

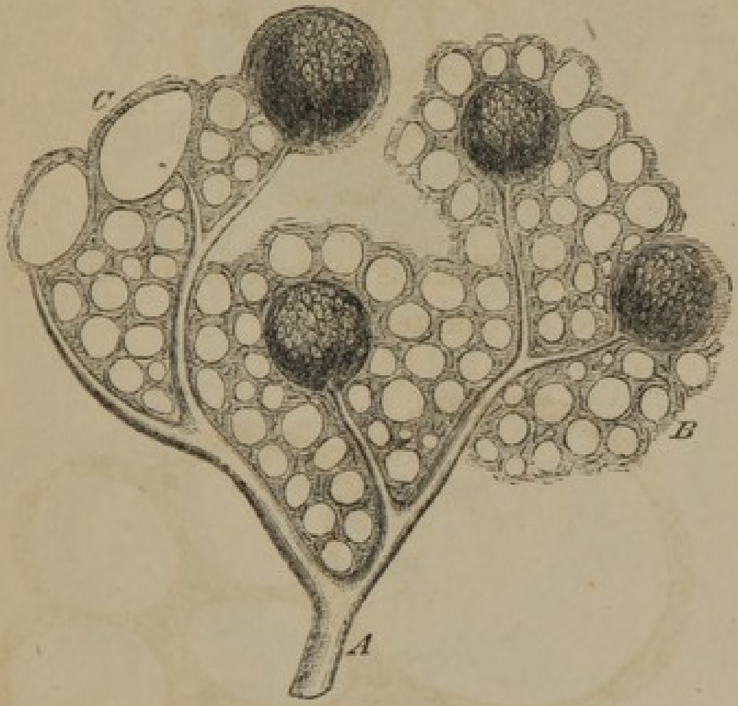

Plate 33.

the inner surface of the capsule and on the Malpighian tuft, are seen with great distinctness through the transparent capsule. Magnified 400 diameters.

Plate 33 shows the fibous matrix of the kidney of the hog. At *A* is a view of a very thin section of the kidney. Small rounded openings, for the passage of the tubes, and two larger ones for the Malpighian bodies, are here observed. At *B* an artery divides into terminal branches, each of which supports a Malpighian body, enclosed in a ring of the matrix. This is magnified about forty diameters.

Plate 34 shows a Malpighian body lying in its matrix. Nucleated cells can be perceived *apparently* upon its surface. Magnified 250 diameters. This was also taken from the kidney of the hog.

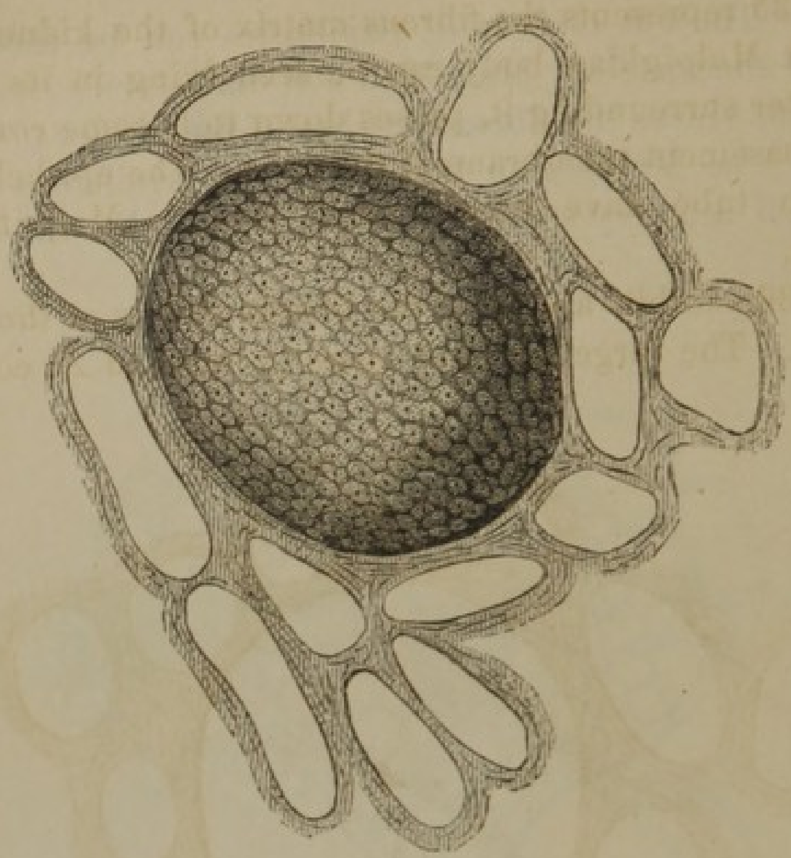

Plate 34.

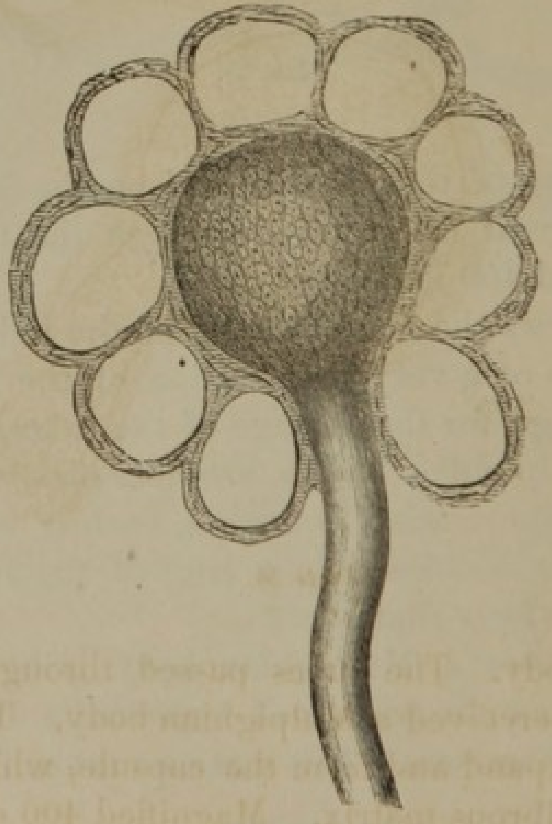

Plate 35.

Plate 35 represents the fibrous matrix of the kidney of the sheep. A Malpighian body can be seen lying in its capsule, which, after surrounding it, passes down to become continuous with the basement membrane of the tube. The epithelial cells lining the tube have been washed away. Magnified 250 diameters.

Plate 36 exhibits a view of the fibrous matrix of the kidney of the ox. The large rounded opening, marked *A*, contained

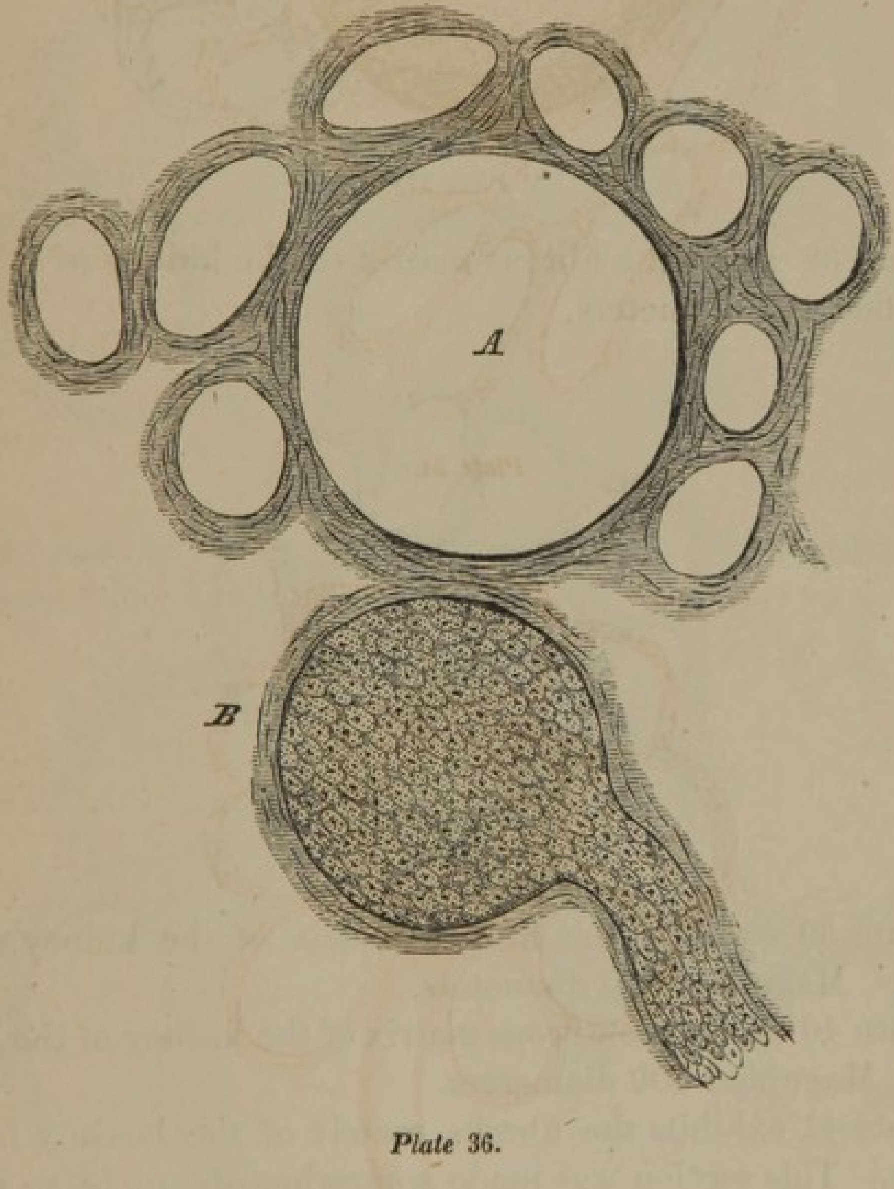

Plate 36.

a Malpighian body. The tubes passed through the smaller rings. At *B* is perceived a Malpighian body. The uriniferous tube is seen to expand and form the capsule, which is enclosed in a ring of the fibrous matrix. Magnified 400 diameters.

Plate 37 shows the fibrous matrix of the kidney of the horse. Magnified 400 diameters.

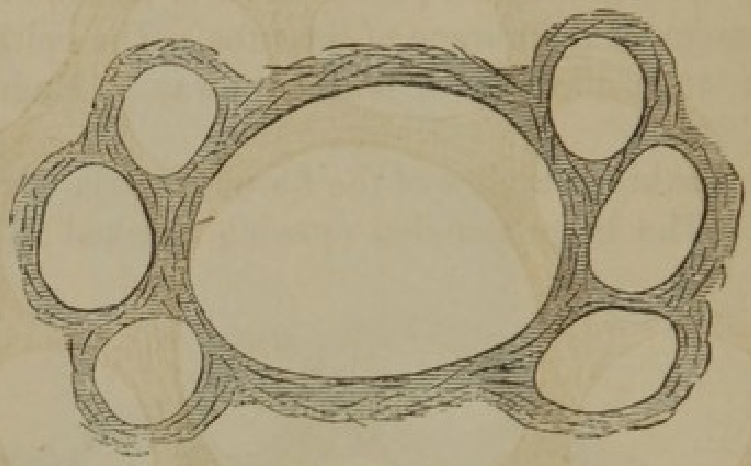

Plate 37.

Plate 38 shows the fibrous matrix of the kidney of the elk. Magnified 400 diameters.

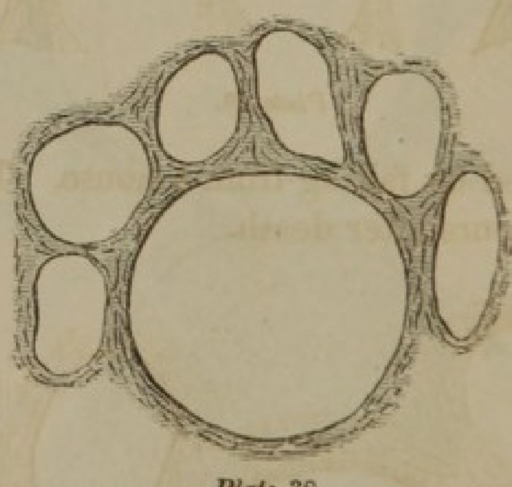

Plate 38.

Plate 39 exhibits the fibrous matrix of the kidney of the moose. Magnified 350 diameters.

Plate 40 shows the fibrous matrix of the kidney of the black bear. Magnified 400 diameters.

Plate 41 exhibits the fibrous matrix of the healthy human kidney. This section was made somewhat obliquely, so that it shows the matrix of the straight tubes which were contained in the elongated spaces, marked *E.* The rounded spaces for the convoluted tubes, and a larger one for the Malpighian body are also seen. Magnified 250 diameters. From a boy, sixteen

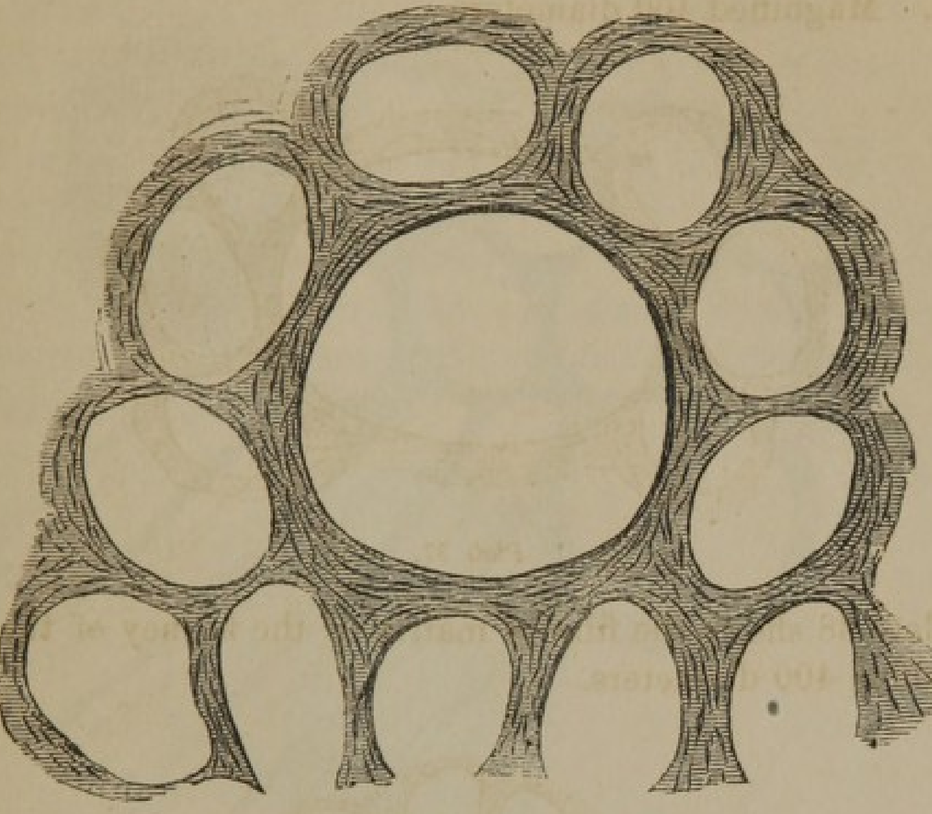

Plate 39.

years of age, killed by falling from a house. This kidney was examined a few hours after death.

Plate 40.

According to my experience, it is rare to find a human kidney which is *perfectly* healthy. This is particularly the case

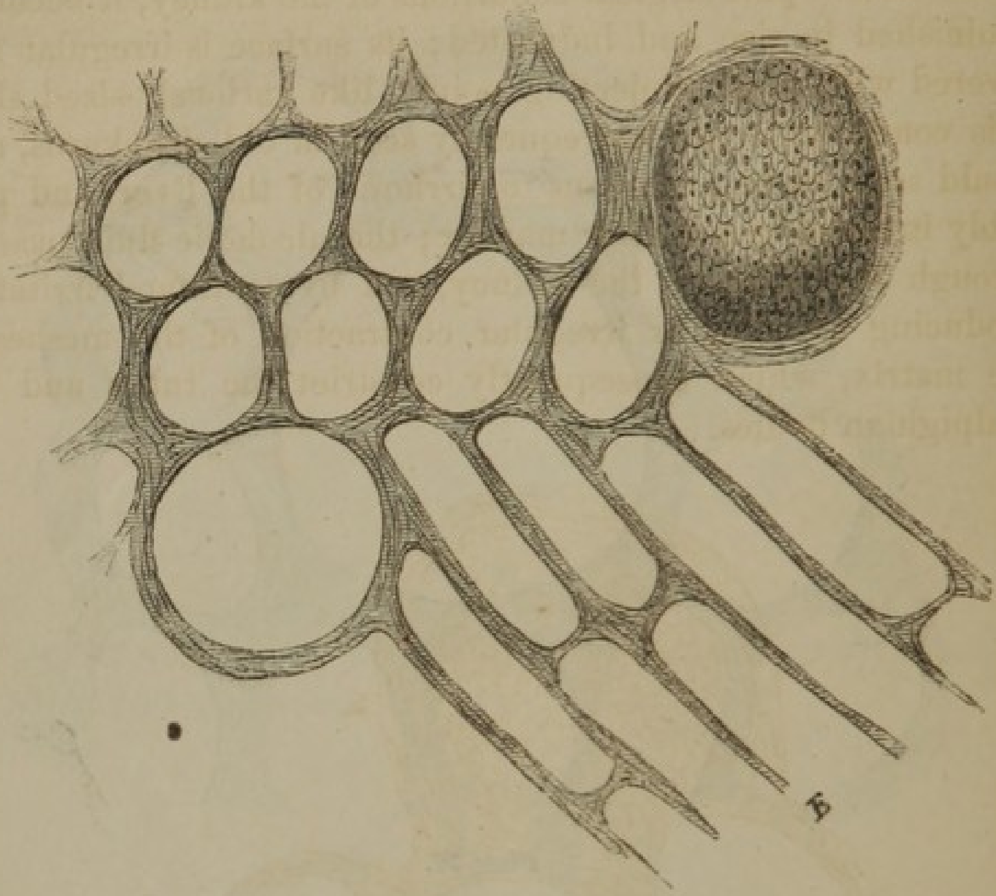

Plate 41.

in subjects in the dissecting-room, and in those who have died in large hospitals. Out of more than 500 subjects which I have examined in this city, I have seen but very few in which the kidney could be regarded as in an entirely healthy condition. Being very anxious to procure a perfectly healthy specimen of the organ, from which I could exhibit the matrix, I obtained a considerable number of kidneys from the bodies of persons killed by violence and accidents, but these were also found to be diseased, most probably from intemperance, &c. I at length procured the healthy organs, from which the present view of the matrix is here given.

From what has now been said and exhibited, it is evident that the fibrous matrix is really the skeleton, or frame-work, of the kidney. It consists of myriads of septa, or partitions, crossing each other in various directions, so as to form elongated spaces for the straight tubes, or rounded spaces, cells, or rings for the Malpighian bodies and convoluted tubes.

In certain pathological conditions of the kidney, it becomes diminished in size and indurated; its surface is irregular and covered with small projecting points, like variously-sized shot. This condition is not unfrequently seen in old drunkards, and would seem to be analogous to cirrhosis of the liver, and probably induced in a similar manner; the alcoholic fluid passing through the tubes of the kidney, and by continued irritation producing crisping, or irregular contraction of the meshes of the matrix, which consequently constrict the tubes and the Malpighian bodies.

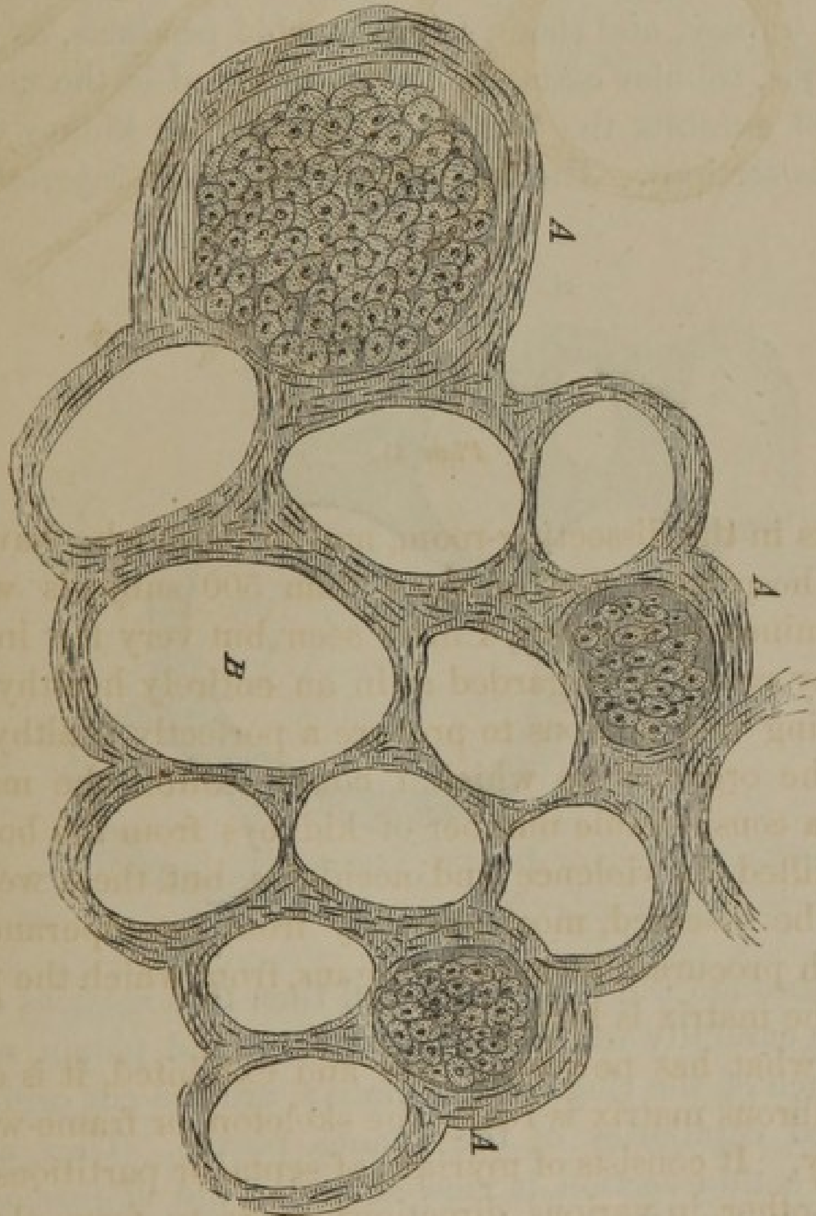

Plate 42.

Plate 42 shows the fibrous matrix of the kidney of a negro.

It was in a condition precisely similar to that just described. The Malpighian bodies were of various size—some of them very small. (See letters *A A A.*) The thickness of the meshes of the matrix was much greater than in the preceding specimen. Magnified 250 diameters.

Thickening and induration of the matrix may produce injurious effects otherwise than by constriction of the tubes and Malpighian bodies. The minute vessels and capillaries pass through the substance of the fibrous rings. Consequently, induration and contraction of the matrix, by direct pressure on the vessels, must greatly interfere with the circulation, nutrition, and secretion of the kidney, and thus various morbid products, as blood, albumen, pus, tubular casts, &c., may be found in the urine.

Plate 43 exhibits the fibrous matrix of the kidney of the sheep (cross section). The kidney had first been injected with

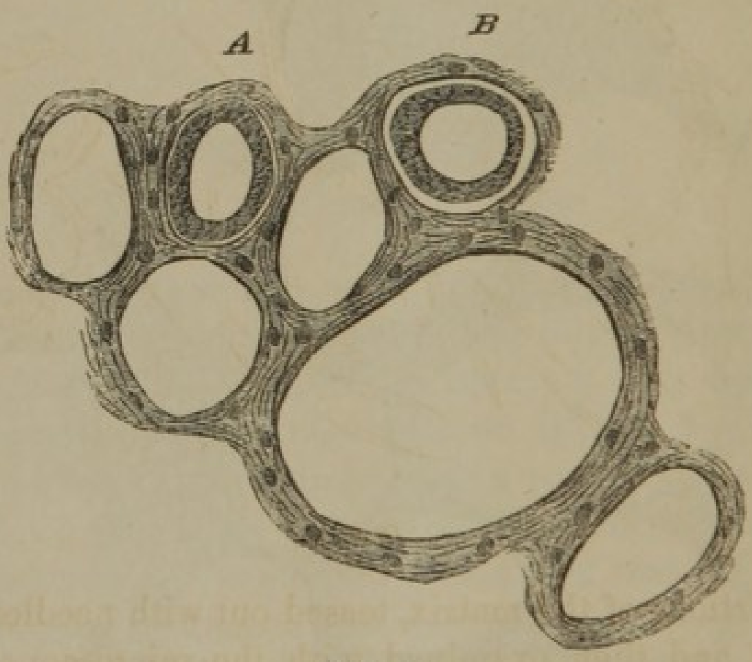

Plate 43.

vermilion through the renal vein, and then thin sections of the organ were carefully washed. The dark, round points, seen in the substance of the rings of the matrix, are the cut orifices of the injected capillaries of the venous plexus. They appear dark when a thin section is viewed under the microscope by transmitted light. Two of the fibrous rings, *A B*, contain a ring-like section of a uriniferous tube, which is still lined by its epithelium, and its canal may be seen in the centre. Magnified 400 diameters.

To examine into the *nature* of the fibrous matrix, it is necessary to obtain a portion of it unconnected with the tubes, Malpighian bodies, or other parts. After repeated washings and examinations under the microscope, I at length found some thin sections free from any other tissue. On the addition of dilute acetic acid, the matrix became swollen, cloudy, softened, and easily torn or broken, and a number of elongated bodies, or nuclei, appeared scattered through it.

Plate 44 shows the fibrous matrix of the healthy human kidney, treated with acetic acid. Magnified 250 diameters.

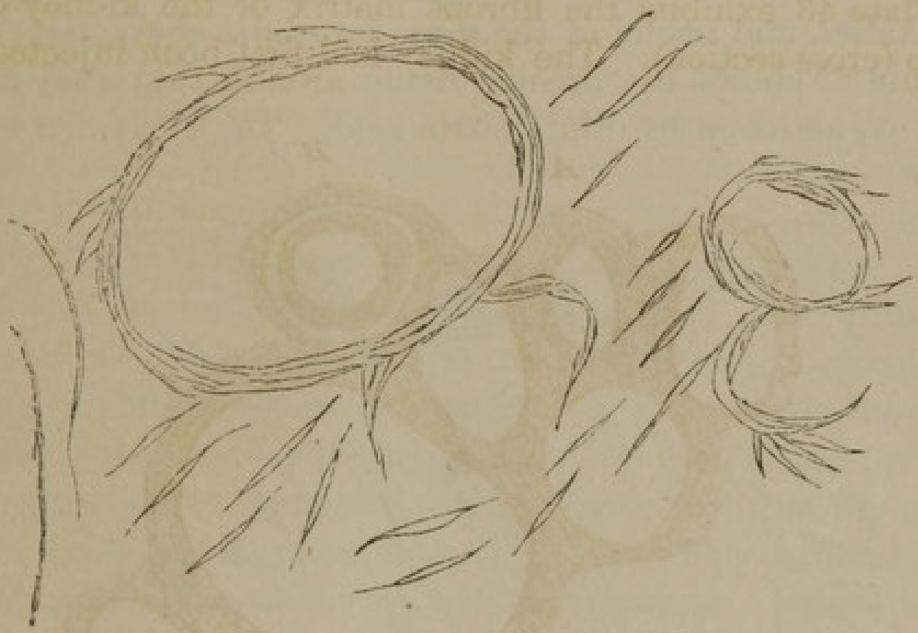

Plate 44.

Small portions of the matrix, teased out with needles, in a drop of water, and then examined with the microscope, presented the appearance usually exhibited by white fibrous tissue in other organs, with this exception, that no trace could be found in the matrix of yellow elastic tissue. This last would probably have been injurious, by compressing the Malpighian bodies, and more especially the vessels and uriniferous tubes. It may be presumed, also, that the elasticity of the latter would render the presence of the yellow tissue unnecessary. Hassal, however, says that, " the tubes as well as their globular terminations, are all enclosed in a frame-work constituted of a nucleated form of elastic tissue."—*Micros. Anat.*, vol. i., p. 443. This is very different from what I have observed. While engaged in examining the matrix, I carefully compared it with the white fibrous tissue of tendon, and also with the areolar tissue surrounding the renal artery of the ox just before it enters the hilum, or fissure of the kidney. It is very similar in appearance to both these tissues, and indeed so much resembled the areolar tissue, that no one could have distinguished the difference, with this exception—that in the last could be perceived some fibres of the yellow elastic tissue, while none of these could be seen upon the most careful examination of the matrix. These tissues all exhibited similar reactions with acids and alkalies, and nuclei of the same form and character.

Plate 45 shows the areolar tissue around the renal artery of the ox, acted on by dilute nitric acid. The elongated nuclei

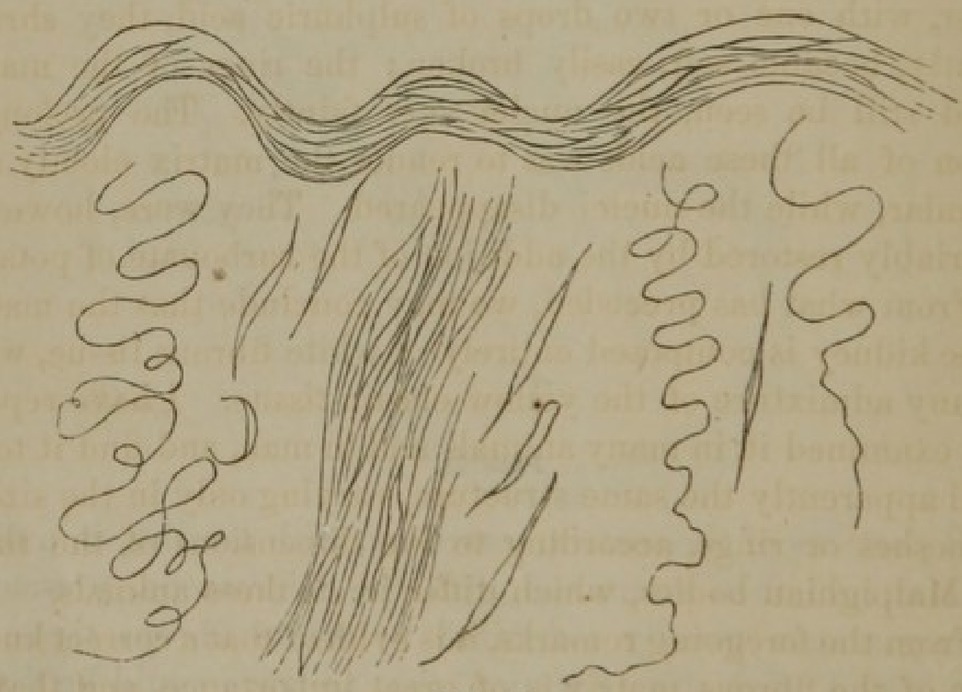

Plate 45.

are seen in the white and waving fibrous tissue. The yellow, elastic fibres are curled like the tendrils of a grape-vine. When the matrix was treated with nitric acid, similar nuclei appeared, but the matrix was not so much softened, or so easily torn or broken. Magnified 250 diameters.

Plate 46 represents the matrix of the healthy human kidney acted on by dilute nitric acid. Magnified 250 diameters.

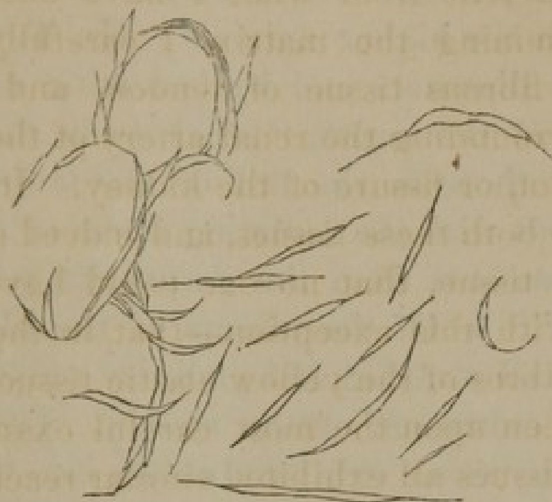

Plate 46.

The action of muriatic and phosphoric acids was similar to that of the nitric. When portions of the matrix were boiled in water, with one or two drops of sulphuric acid, they shrunk slightly, became soft, easily broken; the rings of the matrix could still be seen, the nuclei very faintly. The prolonged action of all these acids was to render the matrix cloudy and granular, while the nuclei disappeared. They were, however, invariably restored by the addition of the carbonate of potassa.

From what has preceded, we may conclude that the matrix of the kidney is composed entirely of white fibrous tissue, without any admixture of the yellow elastic tissue. I have repeatedly examined it, in many animals and in man, and find it to be in all apparently the same structure, varying only in the size of its meshes or rings, according to the dimensions of the tubes and Malpighian bodies, which differ in all these animals.

From the foregoing remarks, it is evident that a correct knowledge of the fibrous matrix is of great importance, and that its microscopical and chemical investigation, in all cases of diseased kidney, would probably furnish interesting and valuable results.

Something may here be said relative to the proper substance, or parenchyma of the kidney. This consists: 1. Of the uriniferous tubes; 2. Of the arteries, veins, and intermediate capillary plexus—all which have already been described; 3. Of the lymphatics—of which we know almost nothing, although Hyrtl thinks that they communicate with the Malpighian bodies; 4. Of the nerves—whose mode of termination is unknown, at least in the higher animals. Mr. Toynbee believes that the nervous filaments end by becoming continuous with the parenchyma of the organ, "precisely in the same way as he has observed those in the tail of the tadpole to become directly continuous with the radiating fibres of stellate corpuscles, and the filaments from the corpuscles to communicate with each other." 5. Of the plasma of the blood; 6. Occasionally a few small rounded and granular nuclei can be seen scattered in the substance of the matrix. Lastly, it may be asked, whether any other structure enters into the composition of the parenchyma? Some have supposed that certain peculiar corpuscles, or cells, were also present in this substance; but, after very many and repeated observations, I have not been able to perceive any other cells than those contained in the uriniferous tubes. These cells seem to be united by means of a slightly opaque, amorphous fluid, containing granules, and which is rendered transparent by dilute boiling acids. Many careful observations have not enabled me to discover any other structures entering into the composition of the parenchyma or proper substance of the kidney, than those above stated.

Before concluding this treatise, it may be well to consider what facts or deductions have been brought forward which may be regarded as new, or of an original character, or as tending to confirm or disprove the views of the best authorities on the subject.

1. Certain processes have been recommended for displaying the structure of the kidney, which, so far as I know, have not hitherto been employed. At the same time, views exactly similar (although not always so clear and extensive) have been obtained in the most simple manner, and where no chemical agent has been used, so that the various processes, although entirely different, yet confirm each other.

2. Contrary to the opinions of some of the highest authorities (see G. Johnson, *On Diseases of the Kidney*, p. 35), the epithelium lining the tubes of the kidney has been shown to be of the

pavement or tessellated variety. (See Plates 1 and 2.) The physiological inferences from this anatomical fact have already been considered.

3. Ciliary motion, although weak and imperfect, has been seen in the kidney of the higher animals.

4. I cannot but consider that the views of Mr. Bowman concerning the connection of the Malpighian body with the uriniferous tube are indubitably correct, inasmuch as I have observed this arrangement so very often, and under circumstances entirely different from those under which his observations were made. His plate, however, showing the connection of the expanded extremity of the uriniferous tube (or the capsule) with the Malpighian tuft, together with the "vas efferens" returning the blood of that tuft into the venous plexus, and which has been so generally copied into the text-books on physiology, is merely a diagram, or "plan," and is so called in his paper. By the processes which have here been recommended, I have been enabled to obtain a similar view from the field of the microscope. (See Plates 10 and 12.)

5. The existence of oval, nucleated cells upon the Malpighian tuft of the higher animals has been clearly demonstrated by certain processes which, it is believed, are original. (See Plates 24, 25, and 26.)

6. Some facts and arguments adduced in this paper have led to the conclusion that the function of the Malpighian tuft is to separate from the blood many of the proximate elements of the urine in combination with water.

7. It is not improbable that any elements of the urine which may have escaped separation from the blood, while they were still in the Malpighian tuft, would pass on into the venous plexus, and, in combination with water, be separated from it by the epithelial cells of the uriniferous tubes.

8. The physiological views of Mr. Bowman, which have been so generally received, are not here adopted, and for reasons previously stated.

9. A mode of readily exhibiting the fibrous matrix of the kidney, and views of this structure in different animals have here been given.

10. The arrangement of the minute vessels as they pass through the substance of the matrix has been shown, and also the effect of its constriction upon the vessels in cases of induration of the kidney.

11. The appearance of the matrix in this disease, and its effect upon the circulation, nutrition, and secretion of the organ. I am aware that the views expressed upon this point are not in accordance with those of some excellent pathologists.

12. The chemical and histological nature of the matrix.

13. With regard to the Plates, several views have been given, which may be regarded as new. They were all drawn from nature, with the exception of Plate 27, which was copied from the very excellent paper of Mr. Bowman in the *Philosophical Transactions.* The plates were drawn from the field of the microscope by Henry A. Daniels and Sicard David, anatomical draughtsmen of this city, whose services were the best that I could command. The greatest care was taken to insure accuracy in every instance. The woodcuts were made by Mr. Jacob Wells, 52 John Street, who is well known as one of the best engravers in this city. The microscopes employed were those of Nachet, of Paris, and of Powell and Lealand, of London.

14. In conclusion, it will be remembered, that the investigation of this subject was undertaken with the view of ascertaining, if possible, the true structure of the kidney, and with the hope of thus, perhaps, settling the disputed points relative to its anatomy. Entering upon this examination without any preconceived theory, it has occupied much of my attention for some years past, and for the last twelve months I have labored upon the subject almost daily, sparing neither time, trouble, nor expense, and carefully guarding against arriving at any conclusion until after long continued and repeated examinations. The facts from which deductions have been drawn have all been obtained by the careful examination of the kidney in many animals, and especially in the frog, turtle, snake, alligator, fish, bird, mouse, rat, squirrel, cat, dog, raccoon, rabbit, hog, sheep, deer, elk, moose, ox, horse, black bear, rhinoceros, monkey, and in man. Among the important and disputed questions

which have been considered, are those of the nature of the epithelium in the uriniferous tubes; of ciliary motion in the kidneys of the mammalia; of nucleated cells upon the Malpighian tuft; of the connection of that tuft with the uriniferous tube; of the function of the Malpighian tuft, and of that of the epithelial cells; of the arrangement of the minute vessels of the kidney; of the fibrous matrix—its nature and condition in health and disease. It now only remains for the better judgment of the Academy to decide whether these long-disputed points can now be regarded as satisfactorily determined.

I take this opportunity of expressing my sincere thanks to the Academy for their kind and patient attention.