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A comprehensive review of the architecture morphology of the avian kidney: Review

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Abstract

A thorough understanding of the architectural morphology of the renal structure is necessary to gain insights into the renal structure. During kidney development in avian embryos, the pronephros, mesonephros, and metanephros arise in succession, as in mammals and reptiles. The mesonephros function for fish and amphibians, whereas the metanephros function for reptiles, birds, and mammals. Birds have elongated, irregularly shaped kidneys that are bigger than the kidneys in mammals and reptiles. Cranial, middle, and caudal kidney lobes make up each kidney, which are blood vessels that cause these divisions. The avian kidney has a dual vascular supply. The renal arteries provide the afferent arterioles of all glomeruli. In reptilian-type nephrons, the veinous supply terminates in the peritubular capillaries. In mammalian-type nephrons, it terminates at least in the proximal tubules. Birds possess renal portals, which are analogous to those seen in reptiles, amphibians, and fish. These portals facilitate renal portal circulation, wherein the renal portal veins transport blood to the kidney tubules, similar to arteries. Bird kidneys have cortical and medullary lobules. Each kidney lobule has a massive cortex and a cone-shaped medullary tract. The base of the medullary cone forms a single collecting duct where lobule nephrons discharge into surrounding collecting ducts. There is no clear line separating the cortical and medullary parts of the lobules. The cortex has Henle loopless reptilian nephrons and Henle loop-containing mammalian nephrons. Birds have pairs of ureters that are symmetrical, and about 17 principal branches vary in length, and subsidiary branches lead to compact cone-shaped collecting tubule tufts. The study attempts to provide any definitive structural correlations that can be determined for the entire group of birds.

Keywords: avian kidney, reptilian nephrons, mammalian nephrons, medullary cones, renal portals.

1. Avian kidney development

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The kidney originates from the intermediate mesoderm, which is a group of cells that links the somite (dorsal mesoderm) to the lateral plate (1, 2). The mesomere undergoes anterior segmentation in all vertebrates and exhibits more extensive posterior segmentation in lesser vertebrates (1). Each part of the mass is referred to as a nephrotome, and from each part, the functional units of the kidney and the nephrons are formed (3). (4) Found that the intermediate mesoderm was initially detected as a faint ridge of undifferentiated mesoderm between the segmental plate and lateral plate at the 8^{th} somite in chick embryos. The Wolffian duct's epithelial ureteric bud invades the undifferentiated metanephric blastema to become the kidney (2; 5). The ureteric bud becomes collecting tubules and the mesenchyme becomes nephrons (1). (6) Found that the intermediate mesoderm and adjacent mesothelium lining the coelom form a urogenital ridge with a laterally positioned nephrogenic cord that forms kidneys and ureters and a medially positioned gonadal ridge for ovary, testis, and female and male genital tract formation, the intermediate mesoderm also forms the adrenal cortex. The avian embryo undergoes a sequence of three separate excretory organs: the pronephros, mesonephros, and metanephros (2, 5, 6).

1.1. The first stage of kidney development, known as the pronephros

The pronephros serves as a functional kidney in early fish and frog larvae, but its functionality in human embryos is uncertain. In the embryos of birds (1), reptiles (7), and mammals (8, 9, 10), the pronephros is a temporary structure that degenerates while the mesonephros grows just behind it (2, 5, and 6).

1.2. The mesonephros is a developmental structure in vertebrates that functions as an early kidney

The mesonephric tubules originate from the intermediate mesoderm located behind the pronephros. The initial stages of their development may be observed in transverse sections of chicks with 26 to 30 somites, which corresponds to around 55 hours of development (1, 11). Furthermore, in reptiles and birds, the mesonephros serve as the operative excretory organ until the moment of hatching. Following the process of hatching, the metanephric kidney assumes control (1). Additionally, the chicken embryo's mesonephric afferent venous system receives blood supply from two vessels, namely the anterior and posterior mesonephric portal veins (2; 5).

1.3. The metanephros is the final stage of kidney development in vertebrates

In reptiles, birds, and mammals, the mesonephric duct diverticulum behind the mesonephros indicates metanephros formation (1, 6, 12, 13). The ureteric buds lengthened and reached meta-nephrogenic mesenchyme. The ureteric bud instructs metanephrogenic mesenchyme to form nephric renal tubules (1). This mesenchyme instructs the ureteric bud to branch out and form a tree-like collecting duct network. The

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ureter is the ureteric bud's first tube (3; 2). However, (11) observed that massive glomerular tufts fed by big capillaries created future renal lobules in an embryonic avian kidney's metanephros. Solitary glomeruli formed as these tufts divided into intralobular feeding and drainage channels. Using intussusception pruning remodeling and glomerular duplication. In chick trypan blue injection trials, (14) found kidney function on the eleventh day of incubation. (15) documented the physical appearance of a one-day-old chick, which has cranial, middle, and caudal divisions on the dorsal wall of the body cavity. According to (16), chick embryo metanephros at 15 days or older had many nephrons and had finished differentiation. In a quail embryo's metanephros, (17) observed enzyme activity in the collecting duct system being active only after hatching, with associated differences in the diameter of these tubules (18). Most embryonic metanephros enzyme activity comes from the cytosolic isoenzyme (19). Arid-living reptiles and birds have inadequate glomerular development (20). (21) Found that chick embryos' Juxtaglomer cells are smaller and fewer than those of adult chickens from the 19th day till hatching. (5) Reported that the kidney of the chicken embryo was in the metanephros phase at 14 and 20 days of incubation. (22, 23) found the thin Henle's loop limb in mammalian-type nephrons after hatching. A 1-day-old chicken has a 0.1–0.13 mm segment. Mammal-type nephrons are the longest and feature the biggest glomeruli of the three categories at all stages of development. As Chukar develops, the medullary cones and the number of loops of Henle of mammalian-type nephrons in each cone lengthen, according to (24). This means 65% of mammalian-type and 90% of reptilian-type nephrons develop after hatching (23).

2. Anatomy of avian kidney

2.1. Kidney shape and position

Bird kidneys and ureters transfer urine to the cloaca urodeum (25; 26; 27; 28; 29, 30). Other than ostriches and rheas have urinary bladders (31). Kidneys are elongated, irregularly shaped, dark brown, and delicate (28; 29, 30). They are bigger than kidneys in mammals and reptiles (31; 20). Cranial, middle, and caudal kidney lobes make up each kidney (5, 32). The kidney's primary blood vessels cause these divisions (33; 34, 35). (33) and (36) stated that the femoral artery divides the cranial and middle divisions, whereas the sciatic artery divides the middle and caudal divisions. In Passerines, the middle kidney division is united to the caudal one, unlike in domestic fowl (37). However, the caudal division of the two kidneys is fused in the center in the Canary Islands, Bubgerigars, Penguins, and many other species, but not domestic fowl (15). Lumbar and sacral plexus spinal nerves also travel through the kidney (37). Each division of the kidney has several subdivisions visible throughout its surface (20, 38, 39), which are the basis of the kidney lobules, tiny polyhedral regions with slightly protruding centers and surrounding grooves. It is also so close

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to the pelvis that its dorsal surface fits into the middle of the depressions and ridges on the ventral surface of the pelvis (15, 28, 37, 29, 30, 40). (41) Found birds' kidneys below the acetabula in the dorsal body cavity using the X-ray method. They are in synsacrum ventral bone niches. The ventrally bulging cranial division is most visible on the lateral. (42) Indicated that domestic birds' three pairs of renal fossa, which contain the kidney's main segments, lie on either side of the os lumbosacral axis. Each kidney has a cranial extremity just beyond the lung and a caudal extremity at the synsacrum (26). According to (43), the avian kidney is more complicated than the human kidney, which has a peripheral cortex and central medulla. Instead, the avian kidney features a series of elongated cones interspersed with the cortex. Cone apices merge at the papillary duct and join the ureter. In 1989, (44) examined 61 Passeriformes, Psittacifornes, Podicipediformes, Anseriformes, Galliformes, and Columbiformes birds from 14 species. He observed that the kidney's cortex was 77%, the medulla 10%, blood vessels 12%, and the ureter and uretral ducts 1%. 45 observed that Anna's hummingbird's kidney has relatively little medullary tissue (2%), and the kidney's volume is 90% cortical tissue. (46) found no substantial seasonal variations in house sparrow kidney morphology. (47) showed that the alteration of the osseous pelvis affects kidney morphology in domestic birds, such as gallinaceous birds, which have short kidneys, and waterfowl, which have long kidneys. (36) stated that adult chicken kidneys are 6 cm long, 1.5 cm wide, and 1 cm deep; however, breed and age have an effect on the size of the kidney. Chicken kidneys are around 7 cm and have a transverse width of 2 cm, while duck and goose kidneys are long, craniocaudal, and thin towards the cranial end, according to (26) . The duck is about 9 cm long, the largest transverse width across the caudal division is 2.2 cm, and the width across the cranial division is 1.2 cm. Goose is about 11 cm or more, 2.5 cm, and 1.5 cm. However, (48) showed that the two domestic chicken kidneys differed in weight by 10.1 g. In fowls, the weight is 1.750 gm, and the right kidney is 6.6 cm long and 1.2 cm wide, while the left kidney is 6.7 cm long and 1.3 cm wide. In geese, the right and left kidneys weigh 12.12 gm and 2.500 gm, and the right kidney is 10.32 cm long and 1.3 cm wide, while the left kidney is 10.26 cm long and 1.4 cm wide.

2.2 Vascularization

The avian kidney has a dual vascular supply. The renal arteries provide arterial supply to all glomeruli. The venous supply, on the other hand, terminates in the reptilian-type via the peritubular capillaries. In the case of the proximal tubules, the venous supply comes from the portal system (23, 49, 50). (36) stated that the kidney of domestic fowl receives its arterial blood from the aorta through the renal arteries. Additionally, venous supply from the pelvis, abdominal viscera, and hind limb, and can enter the kidney through the renal portal vein. The efferent venous blood is then drained from the kidney through the renal vein into the caudal vena cava (38).

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2.2.1. The arterial supply

Two anterior renal arteries reach the kidney's cranial lobe. The kidney receives one or more branches from the femoral arteries, which branch off from the aorta near the dorsal kidney boundary between the cranial and middle lobes. The Ishiadicae artery branches through the kidney at the middle-caudal lobe boundary (25). The renal arteries are cranial from the aorta, middle, and caudal from the sciatic or external iliac artery; according to (27), the femoral artery does not supply the kidney's middle and posterior lobes, although the latter two do. (51) studied fowl arterial systems with resin and casts. They noticed that the kidney's cranial renal arteries divide into three or four primary branches from the abdominal aorta. The caudal renal artery originates near the internal iliac artery, whereas the middle renal artery provides the middle division. The dorsal and caudal renal divisions get four or five branches from the caudal renal artery. (36) confirmed that the renal artery originates from the aorta and branches to the adrenals and gonads. These divisions are supplied by three principal branches of the artery going laterally, caudolaterally, and caudally on the cranial division (38). (42) Examined four domestic animals' renal blood vessels with X-rays. He determined that the external Ischiadic artery, or common trunk, supplies the caudal renal arteries. The hind limb blood vessels intersect the kidney at the major segment borders. All four species investigated had blood arteries distributed virtually equally to hind leg bones. (43) tested latex-injected kidneys that deteriorated in HCl. Cocks, hens, turkey-cocks, turkey hens, drakes, ducks, genders, and geese aged 6 months to 1 year provided kidneys with identical renal vessel placements. The cranial renal artery supplies the kidney division straight from the descending aorta. However the middle and caudal renal arteries branch from the ischiatic artery to serve their kidney divisions (37), and (44, 45) found this in fowl. However, in racing pigeons, 38 found that one pair originates from the femoral arteries. The renal arteries branch into the renal parenchyma as interlobar arteries. There are intralobular and intraalobaris arteries. These branches form the glomeruli's afferent arteriole and efferent artery. Blood travels around cortical tubular components via efferent arterioles that connect reptilian-type nephron glomeruli to sinuses (29).

2.2.2. Portal venous supply

Birds possess renal portals, which are analogous to those seen in reptiles, amphibians, and fish. These portals facilitate renal portal circulation, wherein the portal veins transport blood to the kidney tubules reminiscent of arteries (38). In their study, (51) investigated and depicted the renal portal and venous system in the fowl's kidney. This system receives venous supply from the ischiatic vein, the external iliac vein, and the internal iliac vein. These three vessels connect with the middle and caudal renal portal veins, allowing the kidney to receive venous blood from the portal veins (38; 52). Additionally, the cranial renal portal veins course through the cranial lobe and give branches in all directions. They anastomose with the vertebral vein or sinus at two points (38). The intervertebral vein's ramification in the middle and caudal division is also

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anastomose with the vertebral vein at several points. Together, these connections contribute to the formation of the renal circular vein (53).

2. 2. 2. 1. Renal portal vein

The fractional distribution of blood flow in the coccygeomesentric vein was almost always directed toward the liver (38). The external iliac vein portal blood supplies the ipsilateral kidney, liver, and lungs. In addition, portal blood transport to organs varied greatly across people and during his investigation. Most birds' right and left external iliac vein blood was asymmetrically distributed, demonstrating the relevance of local variables in controlling kidney portal blood distribution (37). Local portal vascular vasoconstriction may cause this. In domestic poultry, the cranial and caudal renal portal veins create a venous loop with the internal vertebral venous sinus and caudal mesenteric vein, according to 37. In an anesthetized Pullets Gallus gallous, (49) closed two major shunt channels bypassing the kidney to venous blood from the leg suffuses the peritubular regions before entering the systemic circulation. According to (45) and (38), afferent venous blood enters the kidney via cranial and caudal renal portal veins, whereas efferent blood departs through such veins. However, (36) revealed that the chicken possesses a renal portal system that feeds the kidney and caudal vena cava with venous blood from the legs. (47) found that the thermal pulse system reduced blood movement throughout actuator abstractions of portal or arterial flow, but this supports previous findings that avian renal blood flow remains constant over a wide range of renal arterial perfusion pressure and that the portal system maintains renal blood flow in proportionately high-flow regions. (34) observed that domestic fowl's renal portal blood permeates all kidney parenchyma except the loops of Henle. According to (54), afferent portal blood arteries from the rear limbs provide post-glomerular arterial and venous blood to the avian kidney's cortical areas.

2.2.2. 2. Renal portal valve

(38) showed that a valve or constriction partially blocks the portal vein-efferent vein anastomosis. He thought the valve allowed additional blood to flow directly to the heart when leg flow exceeded kidney needs. Although (27) showed that the renal portal valve regulates blood flow either to the kidney or to the heart, this suggests that the valve remains open to reduce the kidney's load when blood flow is high after norepinephrine and that its contraction supplies adequate blood to the kidney from the cocceygeomesentric vein when blood flow is low. (55) found that the chicken renal venous portal circulation nourishes only the peritubular capillaries and not the glomeruli. The renal portal and renal artery circulation have variable blood flow. (26) said that the renal portal valve is a conical or cylindrical valve inside the common iliac vein, peripheral to the caudal renal vein opening. The valve diverts portal blood away from kidney tissues and into the caudal vena cava

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when open, indicating that it can close either by contracting its circular smooth muscle fiber under anatomic nerves or by swelling its special epithelial cells at the valve apex. (56) found that the avian kidney's renal portal circulation has a unique smooth muscle valve that directs blood flow from the posterior extremities to the central circulation or kidney. The valve, extensively innervated with cholinergic and adrenergic neurons, relaxed as the iliac vein constricted after transnural nerve stimulation (38, 29, 57). Thus, the vein contracts largely adrenergically like most vascular smooth muscle, whereas the valve contracts and relaxes via cholinergic neurons. The valve might be a thin membrane or a broad funnel with one or several openings at the apex, depending on species and kind.

2.2. 2. 3. Renal portal shunts

(58) noted that radiographs of the domestic chicken's renal portal system using renal vein injections might show several patterns:

1. From the renal portal vein to the renal vein and subsequently to the open vena cava. Most people use this path.

2. Through the caudal renal portal vein and coccygeomesentric vein to the liver. The coccygeomesentric vein connects the renal and hepatic portal systems, diverting blood flow from the liver to the renal portal vein and back again.

3: Cranial renal portal vein, vertebral venous sinus.

(56) and (59) recommended shuffling blood straight to the central circulation, where the valve is open or relaxed, during sympathetic discharge in high fight or flight. The caudal vena cava absorbs all kidney and tail drainage and most hind leg blood that enters the renal portal system. Reptiles and birds have direct shunts from the renal portal system to the caudal vena cava, thus not all of this blood flows via the capillary beds over the kidney tubules. When the shunt valves are open, blood flows faster to the heart from the renal peritubular capillaries or caudal vena cava (37).

2. 2. 2. 4. Efferent venous drainage

From the capillary network of the legs to the interlobular veins, the renal portal system transports afferent venous blood through the sinuses, where it is mixed with post-glomerular arterial blood and drained by the intralobular efferent veins. (58) stated that blood ingoing the cranial and caudal portal circulations empties into the interior vertebral intravenous sinuses and returns to the right side of the heart. However, (50) found that venous drainage from the interlobular to the intralobular vein occurred via a venous capillary network between tubular segments. The external iliac veins provide many alternatives for pockets of venous blood returning from the legs:

1. The sympathetic nervous system opens the renal portal valve, allowing blood to flow from the kidney into the vena cava, iliac vein, and right side of the heart.

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2. If parasympathetic stimulation partially closes the valve and valve resistance is in elevation, blood can pass into the portal circulation via the portal veins, which function in parallel with the iliac vein and vena cava (52, 53, 58).

3. Histology of the avian kidney

3.1. Lobule

Each kidney division has several lobules, which are irregularly polyhedral and densely packed (25; 36). (51) categorized chicken kidney lobules as Japanese fan-shaped and fig-shaped. The former type has the intralobular vein parallel to the kidney surface in the cortical lobules and gives off the central vein at intervals, while the latter type has the central vein enter the lobule directly from the interlobular or intralobular vein. (25) said that the cut stumps of three or more lobules' collecting tubules produce cone-shaped tufts of tubules encircled by connective tissue, which may constitute the medullary base of one renal lobe. A cone-shaped tuft resembles the mammalian medullary pyramid. (60) and (61) describe the avian kidney lobule as a medullary cone and the cortex. The number of kidney lobules differs significantly between classes. However, (62) reported that the avian renal division has several unclear lobules. A kidney lobe drains into a single ureter branch. Each lobule is pear-shaped, with cortical tissue broader and medullary tissue tapering. Interlobular veins are squeezed between lobules in greater cortical regions around cone-shaped medullary tracts. Each bird's kidney lobule has a massive cortex and a cone-shaped medullary tract (63). The medullary region forms a distinct collecting duct where lobule nephrons discharge into surrounding collecting ducts. Although the cortical and medullary sections of the lobules are difficult to distinguish, the cortex contains reptilian-type nephrons without loops of Henle and mammalian-type nephrons with loops (64). However, (7) showed that the avian cortical lobules radiate from the central point across the kidney's surface and deep to these outer units, containing small nephrons without Henle loops and larger, more complex ones with loops. However, (50) observed the kidney's lobule in the subcapsular and middle cortex, delineated by the renal portal system's interlobular veins.

3.2. Renal cortex

The cortex is composed of the broad cortical sections of the lobules, which are formed of cortical and medullary nephrons, save for the loops of Henle in the latter (38; 63). Birds combine their neighboring lobes, especially their cortical sections, to form a single kidney mass, whereas cetaceans require connective tissue to hold them together. The cortical tissue between the glomeruli and interlobular veins is usually proximal convoluted tubules. Distal convoluted tubules connect the glomeruli to the intralobular veins (36). However, (65) observed that Senegal dove kidneys contained few medullary cones and a lot of cortex per cone. This showed that the kidney possesses few mammalian-type nephrons and little countercurrent multiplication, unlike the zebra finch. Due to their excellent mobility, all doves are likely prevalent in deserts because they can graze in xeric

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environments. (65) discussed that the avian kidney has cortical and medullary parts, although the boundaries are less clear than in most mammalian kidneys. The avian kidney has a mixed cortex and medulla. The mammalian kidney cortex has tubular organization, whereas the avian kidney cortex does not. The mammalian renal cortex may only include cortical segments with the proximal and distal tubules of individual nephrons, save for tiny superficial ones. Like the snake kidney, the avian renal cortex has entire simple nephrons without Henle loops that discharge into collecting ducts at right angles. Because they resemble reptile nephrons. (60) noted that birds had a distinct renal cortex-medulla boundary compared to mammals. This is because Henle and collecting duct loops drain reptile and mammalian nephrons. (66) and 46 indicated that the reptilian type with no Henle loops is in the cortex, whereas mammals with long or intermediate loops are in the medulla. (44) examined fourteen passerine and non-passerine bird species from six orders. Wet and marsh birds had greater cortex (78%–80%) and less medulla (6%–9%) than dry birds, which had 72% cortex and 14% medulla. The Australian honeyeater, a member of the Meliphagidae family, has both nectarivorous and insectivorous species. The nectarivorous species has a 75%–85% cortex, and the insectivorous species has a 73%–80% cortex. While the medulla accounts for 4–9% of renal capacity in carnivorous animals (73%–80%).

3.3. Renal medulla

The avian kidney's medullary portion has several little tapered cones twisted in a thin layer of connective tissue that is connected with the ureter's outer layer. The medullary units in sparrow were more compact than those in the Budgerigar's kidney. The Savannah sparrows had concentric rings of thick limbs that surrounded circular collecting ducts and a larger vascular core. Because there is proportionately more medullary tissue in short passages, the unit association is altered. Connective tissue sheaths separate many continuous groups of units until the ureter. (67) noted that the avian renal medulla, particularly the loop of Henle, looks to closely resemble the mammalian kidney's countercurrent multiplier. The avian renal medulla is cone-shaped because Henle loops diminish at medullary cone apexes (28, 68). (65) observed that the Zebra finch had three times more medullary cones per kidney than the Senegal dove; however, these values changed with focusing ability. The singing honeyeater had roughly half the cone abundance of the zebra finch, but their ratios were similar. In Anna's Hummingbird, (69) found tiny medullary cones with few Henle loops and collecting ducts, called the vasa recta, that were made up of a complicated network of capillaries that branch off and connect.

3.4. Nephron

Lobules contain millions of nephrons that power the kidneys. They include the glomerulus, a capillary knot, loops of Henle, renal tubule, and peritubular capillaries (27; 31). Short reptilian-type nephrons near the brain lack Henle

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loops. Henle loop-equipped, longer mammalian-type nephrons are deeper in the medullary cone (38, 63, 64, 66, 70). (71) found that the desert quail kidney's reptilian-type nephrons are made up of basic tubules that are folded four times. As you move ventrally, the middle of each radial group of cylinders gets more complicated. Proximal and distal tubules and intermediate segments resemble Henle loops as nephrons get increasingly convoluted (39; 63). Highly convoluted proximal tubules, loops of Henle with thick and thin limbs, and distal convoluted tubules characterise mammalian-type nephrons. It drains into collecting ducts at right angles and is never found on the kidney (45). The kidney's cortex contains primarily small reptilian-type nephrons without a nephronal loop parallel to collecting ducts, according to (72). Reptilian-type nephrons are simple and vary in size from surface to cortex. Only 15–30% of nephrons are mammalian-type, according to (73) and (28). A parallel Henle's loop, collecting duct, and vasa recta are present. (74) discovered three morphologically distinct nephrons. The intermediate and juxtamedullary nephrons have Henle loops like mammals (39; 63). The most frequent kind, cortical nephrons, feature a short, thin intermediate tubule between the proximal and distal tubules. However, (75) observed three kinds of nephrons in both kidneys of both chicken breeds: Like reptile nephrons, cortical ones have a tiny glomerulus and are located in the cortex. Mammalian medullary nephrons have a big glomerulus and are partially in the medulla. Similar to 30, the intermediate nephrons were between reptile and mammalian varieties in structure. (60) identified loopless nephrons in 90% of Gambel's quail (Lopharynx gambelii) and 68% of European starlings (Sturnus vulgaris) (43). Crowned sparrows contain 10% mammalian-type nephrons, while desert house sparrows have 18%, according to (60).

3.4.1. Renal corpuscles

Renal corpuscles in all species ranged in size, with peripheral cortical examples measuring 30 µm and juxtamedullary ones measuring 40 µm. Bowman's capsule encased the renal corpuscle's primary glomerulus. A densely packed central core of mesangial cells, capillary loops, and a fenestrated endothelium wall make up the glomerulus. It is separated from the glomerular slit membrane podocytes by the three-layered glomerular basal lamina and pedicles. The glomerular slit membrane podocytes wrap around the capillaries and split into trabiculae, secondary processes, and pedicles (43). Avian glomeruli have fewer capillary loops and less vascularity than mammalian ones (25). Chickens have 840000 glomeruli in both kidneys; ducks have 1989000; geese have 1659000; and pigeons have 274000–535000 (27). However, 36 found 30000 glomeruli in tiny passerines and 200000 in hens. (60) discovered that the House sparrow kidney contains 35700 glomeruli per kidney, whereas the White-Crhas moreed sparrow kidney has 53000 glomeruli per kidney. (75) found more glomeruli in White Leghorn chickens than Rhode Island Red chickens. It is near the vascular pole of its parent glomerulus and at the start of the distal convoluted tubule in Rhode Island and White Leghorn chickens. The position, form, and kind of Macula densa matched 36. In research on domestic chicken kidneys, (34) found that male

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glomeruli measure 0.15 µm in circumference and females 0.19–0.26 µm. According to (69), Anna's hummingbird's kidney glomerular tufts have a single, unbranched capillary that spirals or folds back on itself only once or twice. The afferent arteriole-level anti-diuretic hormone (ADH), Arginine Vasotocin, controls avian glomerular intermittence. The same elements may govern ultrafiltration in birds' and mammals' glomeruli. Ultrastructural investigations suggest that both groups have similar filtration barriers (76). The glomerular capsules of any bird species vary greatly in size. This variety reflects the considerable nephron morphological variability. Small reptilian-type nephrons have a capsule diameter of 28–35 πm, similar to the proximal tubule diameter, but giant mammalian-type nephrons in the same kidney can have a capsule diameter of 90–120 πm (71). Avian kidneys have considerably more distinct glomerular capillaries than reptile or mammal kidneys. A reptile's or mammal's glomerular tuft seems to be a single, unbranched capillary looped around the renal capsule (76). (77) examined Callipepla Gambels and Gallus gallus glomerular capillaries. Looped nephrons have more convoluted glomerular capillaries than loopless ones. Nephrons that didn't have loops had glomerular capillaries that were folded and not much mesangial tissue, but nephrons that did have loops had capillaries that were structured in a way that surrounded mesangial cells. Avian glomerular capillaries are simpler than those of mammals, with a single loosely organized capillary or two loops in a loop containing fewer nephrons. Avian erythrocytes may not be able to tank-tread through a tight interweaving network of capillaries due to their nucleus or because their blood is more viscous than mammals'. In contrast, (21) discuss chicken juxtaglomerular cells. These cells are in the tunica medium, vascular pole, and mesangial area of the glomerular afferent arterioles. Three types of juxtaglomerular cells were provisionally defined according to their distinct placements for simplicity of description: Arteriolar type (A) is on glomerular arteriole walls. The paravascular pole has V-type vascular poles. M type exists in the mesangial area. The three Juxta glomerular cell types have identical ultrastructural granules.

3. 4. 2. Proximal convoluted tubule

At its exit from the corpuscle, the proximal tubule is linked directly to the glomerulus' urine pole (43). 45 found that nectarivorous birds' kidney proximal tubules were as long as two-thirds of the descending limb of Henle. It was discovered by (72) that the reptilian type, called nephrons, has a small lumen like the early mammalian tubule. The epithelial lining is made up of low columnar cells or tall cells with brush borders and eosinophilic cytoplasm. A sudden change from the straight proximal tubule to the slender descending limb occurs (49, 78). However, 43 found a central nucleus in the cytoplasm and a cuboidal epithelium in the proximal tubule. There were narrow and large intercellular gaps between cell membranes and a 2 m-thick microvillus brush border that boosted the luminal surface area. 36 also noted that the epithelium of the proximal tubule appears as a column in the longitudinal

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section but as a somewhat pyramidal form with truncated ends in the transverse section. (66) observed that one dry zone species had a bigger brush border volume and surface in the cortex's proximal tubule, which may increase water absorption. According to (72) and (43), the New Holland honeyeater has more proximal tubules than the white-fronted honeyeater. Mammals absorb 70% of all ions in the proximal tubule, but birds absorb just 50–60% of glomerular-filtered sodium and potassium. (77) showed that the Savanna sparrow had more proximal tubules than other species but fewer distal tubules. (37), on the other hand, found that birds have ureters, keep their plasma urate levels high, and get rid of most of their urate waste through renal proximal tubular secretion and urate transport across the brush border membrane, just like people do. Proximal convoluted tubules with microvillus borders are easy to discern in avian and mammalian cross-sections. The sections were examined for open and closed-lumen tubules (71). Proximal tubules were simple to distinguish since their brush boundaries were significantly PAS-positive, according to (74). However, the distal tubules were Alcian blue, and PAS revealed negative findings except at the end, surrounding the central veins, where few cells showed slightly positive responses.

3.4.3. Loops of Henle

In the avian kidney, loops of Henle have varying lengths and turn back at various levels along the medullary cone, with the majority of them turning back close to the cortical medullary boundary (79). Moreover, the turn of Henle's loop was restricted to the thick limb in all birds examined (80). However, the mean length of the loop of Henle for the mammalian-type nephrons in the kidneys of *desert quails* ranged from 0.7 to 3.7 µm (71). (25) said that the proximal tubule connected to the much narrower segment that came after it. This narrow part of medullary nephrons is the same as the ciliated intermediate part of reptilian-type nephrons and the thin part of Henle's loop in mammals. Also, the intermediate segment in the cortical nephrons joins the distal convoluted tubule (29). Between 10 and 30% of the nephrons in a white leghorn chick's kidney contain simple Henle loops arranged in bundles called medullary cones; the remaining nephrons lack Henle loops but display considerable heterogeneity in overall length and glomerular size (54).

3.4.4 Thin descending limb

The short, thin descending limb of Henle's loop in the avian kidney thickens before the arch. (67) studied Gambel's quail, (43) honeyeaters. The narrow descending limb of Henle climbed swiftly from the proximal tubule into the medulla. It possessed a basal nucleus and a cuboidal epithelium. The apex of each cell had small microvilli and intercellular gaps up to 750 πm, with neighboring cells having wider spacing. In Desert Quail (49) reported that upper descending thin limb epithelial cells feature many microvilli and shallow, tight connections. Low-descending thin limb cells are flat and have few interdigitations. In Inows, (77) found large intercellular gaps in thin Henle

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limbs but not thick ones. (45) found that the number of thin limbs of Henle decreasing towards the apices of medullary cones was faster than the decrease in thick limbs and had little correlation with cone length. (45) reported that Anna's hummingbird's kidney differs from other nectarivorous and aquatic birds. This is because looped nephrons lack the narrow descending limb of the loop of Henle. In contrast, birds' looped nephrons have a thin loop of Henle descending limb between the pars recta of the proximal tubule and the thick one at the loop's apex. The thin limb cells are ultrastructurally distinct from the proximal tubule cells in nectar-eating and water-living birds' kidneys (43).

3. 4. 5 The thick ascending limb

The thick segment is located in the center of the descending limb and extends across the arch and the whole ascending limb (49). The thick ascending limb of Henle is composed of a cuboidal epithelium that exhibits different ultrastructural characteristics along its length. In the proximal portion, the cytoplasm contains a central nucleus, while in the distal portion, the cytoplasm is similar but contains numerous elongated mitochondria (36, 43).

3. 4. 5. Distal convoluted tubule

In mammals, all nephrons have loops of Henle, and the distal tubule originates in the thick ascending limb of the medulla. In birds, the tube begins at the maculodensa. Avian Juxta medullary nephrons have a distal tubule that runs from the parent glomerulus to the lobular center and then the central vein, where it forms many convolutions before returning to the lobular periphery as the intra-lobular collecting tubule. However, (49) suggested that the reptilian-type bird's distal tubule may have comparable functional heterogeneity and the early segment may resemble the thick limb of mammalian-type nephrons. Reptilian-type and mammalian-type nephrons in the Coturnix quail and other birds have histologically similar distal convoluted tubules (80).The distal tubule always proceeded to the glomerulus hilus, where it had direct contact with the vascular pole, according to (50). Epithelial cells looked different on the side of the distal tubule linked to the vascular pole. The taller, narrower cells had densely packed nuclei and lighter cytoplasm than the surrounding cells (38). A central nucleus lies in the cytoplasm of the distal tubule's cuboidal epithelium. The lining epithelium cells lack a brush border, apical mucopolysaccharides granules, and a short basolateral membrane-infolding apical membrane, unlike the proximal and collecting tubules. A narrow cortical intermediate tubule proximal to the macula densa (39) indicates the commencement of the distal tubule of the cortical nephrons in birds, according to (74). Two cell types were seen at this site: maculodensa cells and nearby distal tubule main cells, which resembled cortical intermediate tubule cells. The maculodensa were shorter and more tightly packed than the major cells and in close contact with the parent glomerulus, Juxta glomerular cells of the afferent arteriole, or both.

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3.4.6. Collecting tubule

The avian kidney's cortical collecting tubule has a cuboidal epithelium with main and intercalated cells, according to 43. Species have comparable cell type ratios. According to (45), the major cells are 11-12 µm tall and contain several mucopolysaccharides granules. The apical cells are flattened and have a few microvilli, while the intercalated cells are spherical and lack microvilli, measuring 8-9 µm in height. Small mucin-producing collecting tubules are easily identified. They join perilobular collecting ducts that enter medullary tracts (78). However, (74) found a progressive transition from the distal tubule to the intralobular collecting tubule. Light microscopy revealed the transition zone by adding slightly PAS-positive cells to distal tubule profiles near the major vein.

3.4.7 Collecting duct

The distal tubules of loopless nephron pairs combine to form the collecting duct tree. These first collecting ducts get signals from loopless nephrons, join together to form secondary collecting ducts, and then join together to form tertiary collecting ducts. They receive signals from transition nephron distal tubules. Thus, all nephron types' fluid mixes in the medullary cone, and all cones act as parallel units (45, 81) discovered that the number of collecting ducts was highest at the base of the cones and rapidly decreased towards the tip of the medullary cones, with 75% of them gone at the midway point. But (74) discovered that the largest perilobular duct joined with many others to make the medullary ducts. These then joined with many others to make the very large lower ducts that connected to the ureter branches. All medullary duct cells were tall, columnar, and mucin-secreting. The nuclei were bigger and more leptochromatic than cuboidal ones. However, (43) described the collecting ducts as a proximal segment and a distal papillary duct. The proximal segment had a columnar epithelium with light and dark cells and a basal nucleus, with the luminal surface covered with a few short microvilli. The papillary duct had a columnar epithelium and basal nucleus, epically situated mucopolysaccharides vesicles, which stained positive for A. According to (76), the collecting ducts are clustered near the base of the inner medulla and ultimately merge into one. (43) found that the New Holland honeyeater's medulla had 54.1% more collecting channels than other species.

4. Ureter

Pairs of ureters are symmetrical. Each has a renal section that passes along the kidney, with the cranial portion nearer the ventral than the dorsal side and the pelvic part from the kidney to the cloaca. About 17 principal branches vary in length, and subsidiary branches lead to compact cone-shaped collecting tubule tufts (3, 26, 37). In Starling, (74) found that at the base of the lobule, the perilobular ducts fuse extensively to form the medullary collecting ducts, which feed the primary branches of the ureter. The largest ducts had a pseudo-

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stratified columnar epithelium. Alcian blue, Toluidine blue, and PAS-positive responses stain the mucoid components of the avian kidney, which secretes a lot of mucus from the collecting duct system and ureter. Chicken ureters are 5cm long and 2 mm wide. The ureter and male or left female genital duct share peritoneum folds (26). The cranial, middle, and caudal renal arteries feed ureters by an anastomosing network of ureteric branches (26). (80) also found that small kidneys have short ureteral branches with main stems grouped in each kidney division, but big kidneys, whose lobules are generally distant, have lengthy, unclustered branches. In general, the histology ureter has a tall pseudostratified columnar epithelium with strong much-secretive activity along all lines. (62) and (82) found that there are two types of visible cells: columnar, extending throughout the epithelium and having large oval vesicular nuclei at or just below the midpoint, and cuboidal, with round nuclei near the base and no PAS-positive, which is su Inner longitudinal muscle and outer circular smooth muscle make up the thick muscular layer. The cloaca is divided into three parts: the coprodeum, which receives the rectum, the urodaeum, which receives the ureters and genital ducts, and the proctodeum. (83) found that in ducks, the ostium cloacale ureteris opened on a well-developed papilla in the dorsal region of the urodeum. Except for the rheas and ostrich, birds lack a urinary bladder, which explains the separate storage of urine and feces and confirms the earlier observation that the ostrich's urine is liquid, which explains its bladder and urination (84).

Conflict of interest

The authors declare that they have no conflict of interest.

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