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Morphological features of the kidneys in 2-4-month-old Wistar rats

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Abstract. The relevance of the proposed study is related to the wide distribution of Wistar rats in veterinary and biomedical research, while the anatomy and microanatomy of their kidneys at 2-4 months of age are not sufficiently investigated. This study aimed to determine the characteristics

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of the anatomical and microscopic structure of the kidneys in Wistar rats of the specified age. Anatomical dissection, macroscopic examination of the kidneys and histological analysis of their structural elements were performed for the implementation of the aim of the study. The kidneys of both male and female Wistar rats of 2, 3, and 4 months of age exhibited the typical structure of the organ, including its dark red colour, bean-shaped form, fibrous connective tissue capsule, and division into cortical and medullary regions. It has been established that the cortical and medullary areas of the kidney have characteristic structural features (such as medullary rays, kidney pyramids, and kidney columns). Within the kidneys, the number of mesangial cells within the renal corpuscles was variable, as were the diameters of the glomerular capillaries; those corpuscles that contained fewer mesangial cells had more dilated capillaries and more blood within their corpuscles. In the proximal convoluted tubules, the nuclei of epithelial cells were often shifted to the luminal surface; the lumen of these tubules often contained proteinaceous masses. The distal convoluted tubules had a more elongated shape, the nuclei of the epithelial cells were often located in the centre of the cells, and the proteinaceous masses accumulated in the lumen did not cause narrowing of the distal tubule lumen. All the collecting duct system tubules consisted of simple cuboid epithelium cells; their cytoplasm was light, and the nuclei were predominantly central. The results obtained can be used in practical experiments in the morphological studies and applied in such disciplines as comparative anatomy, histology, embryology, and veterinary medicine

Keywords: renal corpuscles; mesangiocytes; proximal convoluted tubules; distal convoluted tubules; collecting ducts; cortex; medulla

Introduction

The relevance of the study presented in this study is associated with the fact that Wistar rats are some of the most common types of laboratory animals that are utilised in biological, medical, and veterinary research. In order to understand the results of the experiments that are performed upon these animals, it is first necessary to understand the anatomy and histology of their organs. First and foremost, the kidneys are one of the key organs responsible for maintaining homeostasis and eliminating metabolic waste products. Despite the widespread use of Wistar rats in research, information on the structure of their kidneys is insufficiently systematised and has not provided a comprehensive understanding of the structure of the nephron and its components. Based on the above, a study of the anatomy and microscopic features of the kidneys of Wistar rats was carried out in order to ensure the appropriate use of this model in future experimental studies. According to A. Domínguez-Oliva *et al.* (2023), animal models are extensively utilised in contemporary biological and medical research to explore the course of pathological processes, evaluate the impact of diverse factors on organisms, and verify the efficacy of therapeutic and prophylactic strategies at the preclinical phase. P. Krubaa & P.S. Yogitha (2024) indicated that the rat is a prominent animal among laboratory animals that is a valuable model due to the possibility of strict control over the genetic and environmental parameters, the relatively large size of the body, ease of invasive manipulations, and a high level of reproducibility of results. In addition, according to S. Patel *et al.* (2024), Wistar rats are one of the most widespread experimental animals in the field of pharmacology,

toxicology, physiology, and biology; they are also a convenient model for obtaining reference values of haematological and biochemical parameters required for the accurate assessment of experimental changes.

The kidney is one of the key organs in all vertebrates, a paired organ that performs the functions of blood filtration and the excretion of metabolic end products, and regulates the water-salt balance and homeostasis in the body. In this regard, the kidneys are one of the target organs in experimental models with the use of toxic agents, metabolic, vascular, and other factors. Much attention has been paid in modern research to studying functional status, the morphological state of the kidney structures in different conditions of the experiment. In a study of water balance, the levels of urinary excretion of some biomarkers, and kidney histology in the Wistar rat, A.C. Ibezute & O.D. Igiegie (2024) showed the preservation of kidney architecture without pronounced disturbances. In a study on gentamicin-induced nephrotoxicity, A.I. Matouk *et al.* (2023) found that the most vulnerable structures of the kidney were the tubules. According to R. de Miguel *et al.* (2025), who systematised post-mortem morphological changes of kidneys in Wistar Han rats, the distal convoluted tubules and the inner stripe of the outer medulla are among the most sensitive zones.

The international scientific literature has also described morphological alterations in the kidneys of Wistar rats under the influence of various damaging factors. S.A. Kehinde *et al.* (2025) established that polyethene microplastics caused impaired renal function and alterations in renal histoarchitecture. C.G.F. Freire *et al.* (2025) demonstrated that exposure to cigarette smoke was accompanied by pronounced morphological changes in the renal tissue of rats of this strain. L. Fedoniuk *et al.* (2025) analysed the morphofunctional features of nephrons under conditions of cellular dehydration and during periods of adaptation and readaptation, concluding that nephron structural changes under these conditions were substantial and required a prolonged recovery period. Thus, contemporary studies have provided evidence of the high sensitivity of the kidneys in Wistar rats to various experimental factors and confirmed the important role of individual renal structures in the development of morphological responses. At the same time, analysis of the literature demonstrated that most recent studies have focused either on the functional state of the kidneys or on alterations in specific renal structures under experimentally modified physiological conditions. There is a lack of systematic and detailed descriptions in the literature of the anatomical and microscopic structure of the kidneys of Wistar rats as a whole, taking into account the characteristics of the parenchyma, nephrons and collecting duct system in young animals. This applies in particular to a comprehensive description of the renal corpuscles, proximal and distal convoluted tubules, the loop of Henle, and the collecting duct system with an account of their interconnection. Therefore, this study aimed to investigate the anatomical and microscopic features of kidney structures in the young laboratory Wistar rats (2-4 months) with detailed attention to the morphological features of their parenchyma, nephrons and collecting duct system.

Literature Review

The anatomical and microscopic structure of cat, dog, and large mammal kidneys is well-documented. In these species, the kidneys are generally kidney-shaped or bean-shaped. The parenchyma consists of cortical and medullary sections, creating cone-shaped renal lobules. The apices of the lobules directed into the interior of the kidneys, at their concave surface, lead to the entrance of urine into minor calyces that eventually combine into major calyces

that empty into the renal pelvis. R. Baymuradov (2026) noted that the minor and major calyces, together with the renal pelvis, are the elements that compose the renal sinus. At the microscopic level, the functional unit of the kidney is a nephron, a structure composed of a series of successive parts merging into one another. The nephron carries out all the functions characteristic of the kidney. These functions are the excretion of metabolic products of blood and the regulation of blood volume, blood pressure, blood pH, as well as the levels of electrolytes and metabolic byproducts in the serum. The main function of the nephron is the formation of urine, which is eliminated through the urinary tract. Nephron performs three relatively simple procedures, namely filtration, excretion, and resorption. Filtering is carried out by the renal corpuscle, from where nephrons begin to arise. Here, components of the blood plasma pass through a filter of capillaries into the cavity, and the initial formation of urine takes place. According to the observations of H.R. Jacobson (1981), the renal corpuscle is a capsule, consisting of a double-walled capsule, containing a glomerulus of blood capillaries. The glomerulus receives blood from the afferent arteriole and drains it out through the efferent arteriole. The diameter of the efferent arteriole is smaller than that of the afferent arteriole. As a result, increased hydrostatic pressure is observed in the glomerular capillaries, causing water and soluble substances (blood plasma components) to filter into the cavity of the renal corpuscle capsule. It has been shown by A. Madrazo-Ibarra & P. Vaitla (2023) that only about 1/5 of the plasma volume entering the glomerular capillaries can penetrate the glomerular wall and pass into the capsule space. The filtration of the components of the blood plasma through the wall of the renal corpuscle's capsule is regulated by the renal filtration barrier. This barrier consists of three morphological components. The first of these components is formed by the endothelial cells of the glomerular capillaries. These endothelial cells contain numerous pores referred to as fenestrae. The endothelial cells of the glomerular capillaries are, therefore, referred to as fenestrated endothelial cells. According to the study by N.C. Finch *et al.* (2023), the fenestrae of the fenestrated endothelial cells of the glomerular capillaries are not covered by diaphragms. The diameter of the fenestrae allows for the passage of plasma substances, including proteins.

According to X. Mou *et al.* (2024), the second morphological component of the renal filtration barrier is the basement membrane of the glomerular capillary endothelium. This basement membrane consists of three layers. The layer directly adjacent to the endothelial cells is known as the inner thin lamina, which prevents the passage of molecules owing to its negative charge. In the opinion of K. Ebefors *et al.* (2021), the middle layer of the glomerular capillary endothelial basement membrane consists of bundles of collagen fibres forming a mesh-like structure. This layer limits the size of molecules passing through the basement membrane (it blocks the passage of molecules with a molecular weight greater than 5,800 kDa). D. Chen *et al.* (2024) demonstrated that the third, outer layer of the basement membrane is referred to as the outer thin lamina. This layer restricts the passage of substances through the basement membrane in the same way that the first layer of the basement membrane does. This outer thin lamina is adjacent to the third component of the filtration barrier. The third component of the renal filtration barrier consists of epithelial cells, known as podocytes. These podocytes have long cytoplasmic processes, known as podocyte foot processes, that completely envelop the glomerulus. One of the barriers preventing

the passage of negatively charged molecules, such as serum albumins, through the filtration diaphragm within the pores between podocyte foot processes is the negative charge of the podocyte cell surface, which is covered by a negatively charged glycocalyx. According to the findings of J. Cunanan *et al.* (2025), these foot processes of the podocytes allow for the regulation of the filtration of proteins that exit the lumen of the glomerular capillaries and enter the cavity of the renal corpuscle's capsule. Damage to the filtration diaphragm or to the podocytes themselves results in the filtration of large quantities of proteins into the renal corpuscle capsule cavity, resulting in proteinuria. Podocytes became not only a key component of the kidney's filtration barrier, but they also performed another vital function. Through the control of filtration slit width, the podocytes control the glomerular filtration rate, which represents the amount of filtered blood in all the renal corpuscles. Authors J.F. Bertram *et al.* (2025) state that this parameter has become the most important indicator of the functioning of the kidneys, as a decrease in the normal level of glomerular filtration is generally indicative of the presence of renal failure. The kidney is a complexly organised organ, whose nephron, glomerular filtration barrier and tubular apparatus are responsible for maintaining fluid-electrolyte homeostasis, performing filtration of blood plasma, reabsorption and excretion of waste products. Thus, the interaction of podocytes, mesangial cells, tubular cells, and the collecting system regulates the filtration capacity and the urinary concentration. This is why the morphological evaluation of nephrons in conjunction with renal functional parameters has become the basic tool for interpreting the changes of the water-electrolyte balance, urinary parameters, and the microscopic picture of the kidney in rats under experimental conditions.

Materials and Methods

The experiments were performed at the educational, scientific, and production Clinical Centre Vetmedservice of the NULES of Ukraine between March and May 2026, after which the harvested kidneys were examined and the results analysed. Eighteen sexually mature Wistar rats of both genders were used in the study: 6 rats aged 2 months (3 males and 3 females), 6 rats aged 3 months (3 males and 3 females) and 6 rats aged 4 months (3 males and 3 females). The animals were kept in standard polycarbonate cages under conditions of standard maintenance of the microclimate (temperature 22°C-24°C, relative humidity 50%-60%, 12-hour light/12-hour dark photoperiod), with standard pelleted feed and drinking water available at any time. All the experimental animals underwent daily observation (monitoring of the general clinical status, behaviour, feed and water intake) throughout the experimental period. At the end of the experiment, the animals were subjected to human euthanasia by the inhalation of CO_2 in the absence of prior gas filling of the exposure chamber at a flow rate of 30%-70% of the chamber volume per minute, followed by the secondary use of physical methods to confirm that the animals were dead, such as decapitation. All procedures and euthanasia were carried out in accordance with the requirements and provisions of the European Convention for the Protection of Vertebrate Animals used for Research and other Scientific Purposes (1986) and the Law of Ukraine No. 3447-IV (2006). Approval for the study was obtained from the Bioethics Commission of the NULES of Ukraine for the use of animals in scientific research (No. 045/2025, dated 26 June 2025). During animal housing and experimental procedures, the scientific and practical recommendations of Y. Kozhemiakin *et al.* (2002) concerning work with laboratory animals were followed.

A post-mortem examination of all rats was performed via complete evisceration. To perform this procedure, the skin was incised from the angle of the mandible to the pubic bone, and the skin was separated from the underlying tissues. The muscles of the anterior abdominal wall were dissected in the median line, and all muscles surrounding the pharynx, larynx, the cervical part of the pharynx, the thyroid gland, and the cervical part of the trachea were dissected to free these organs. The thoracic cavity was opened by a sternal approach. The thoracic cavity was opened via severance of the ribs and costal cartilages along all ribs, and removal of the sternum. After all body cavities were opened, the location of the internal organs was examined and photographed. Subsequently, all internal organs were removed as a single organ complex, beginning with the tongue, followed by the organs of the neck, thoracic cavity, gastrointestinal tract, and pancreas, while transecting the supporting structures of these organs. The location of the spleen, liver, and kidneys was examined, photographed, and the organs of the reproductive system in females (ovaries, oviducts, uterus, vagina, and external genitalia) were also checked. The spleen, liver, and kidneys were removed, whereas in females, the organs of the reproductive system (ovaries, oviducts, uterus, vagina, and external genitalia) were removed together. The external surfaces of the kidneys were inspected and recorded with a focus on size, outline, colour of the surfaces and state of the capsule. A longitudinal incision through the midline was done, and the kidneys were investigated and photographed in the section, with particular attention being paid to the features of the structural organisation of the cortex and medulla, the border between these tissues, the renal papillae, renal calyces and renal pelvis. After the study of the topographical anatomy of the experimental rat kidneys, tissue samples were taken from each kidney, in a manner to encompass all the structures, from the renal cortex to the renal pelvis. Fragments were fixed in a 10% solution of formalin (pH 7.2-7.4) for 7 days and then dehydrated using ethanol (70º, 80º, 95º, and 100º). The pieces were left in each of the ethanol solutions for 24 hours. The fragments were cleared in chloroform and embedded in paraffin at +58°C. Histological sections 6-8 μm thick were obtained using a sledge microtome MBS-2 (Med-Tech, Ukraine) and stained with Carazzi's haematoxylin and eosin. All histological preparations were examined under an MS-100X microscope (Micros, Austria) and photographed using an NDPL-2 (2x) photoadapter and a Canon EOS 550D camera (Canon, Japan).

Results and Discussion

The kidneys are one of the key organs of the urinary system of the rat. The structure of the kidney is associated with the physiological processes of the organ, including the formation of urine. Therefore, an investigation of the macroscopic and microscopic structure of the kidneys of Wistar rats is essential to gain an understanding of the morphological norms characteristic of a particular species and age. Special interest is the study of the kidney of sexually mature rats aged 2-4 months, which are most commonly used in experimental biological, morphological and toxicological research. Accordingly, a comprehensive macro- and microscopic examination of the kidneys of Wistar rats was conducted, taking into account their anatomical structure, histological organisation of the parenchyma, nephrons, tubular apparatus, and collecting system. The study found that in Wistar rats aged 2-4 months, as in other strains of rats and, generally, in mammals, the kidneys are located in the retroperitoneal space (Fig. 1).

Figure 1. Anatomical position of the kidney in a sexually mature Wistar rat (female), 3 months of age
***Note**: macroscopic specimen, kidney indicated by arrow; 1 – small intestine; 2 – caecum; 3 – rectum; 4 – stomach; 5 – spleen; 6 – pancreas*
***Source**: authors' photo*

There were no morphological differences in the kidneys of males and females of this age. At the same time, the kidneys of Wistar laboratory rats aged 2-4 months were dark red in colour (Fig. 2) and bean-shaped, with convex and concave surfaces.

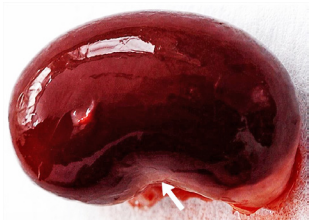

Figure 2. External appearance of the kidney in a sexually mature Wistar rat (male), 2 months of age
***Note**: macroscopic specimen, renal hilum indicated by arrow*
***Source**: authors' photo*

On the concave surface of the kidneys, there is a depression known as the renal hilum. On this part of the kidney, the renal artery enters and the renal vein and ureter exit. In the hilum, there is also adipose tissue and lymph nodes. Externally, the kidneys are covered by a fibrous connective tissue capsule, which in turn is surrounded by a fatty capsule. Ventrally and laterally, the fatty capsule is enclosed by the peritoneum, while dorsally it is covered by the transverse fascia. A cross-section of the kidneys in 2-4-month-old Wistar rats shows that the parenchyma of this organ is composed of two parts: the cortex, located in the peripheral region of the kidney, and the medulla, situated in the central region (Fig. 3).

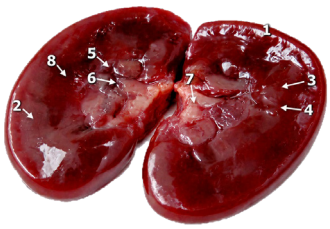

Figure 3. Kidney of a sexually mature Wistar rat (male), 4 months of age, in cross-section
***Note**: macroscopic specimen: 1 – cortex; 2 – medulla; 3 – renal lobule; 4 – renal column; 5 – minor calyx; 6 – major calyx; 7 – renal sinus; 8 – renal pyramids*
***Source**: authors' photo*

The cortex and medulla form cone-shaped renal lobules, each of which gives rise to renal pyramids. The renal columns (Bertin columns), which represent an outgrowth of cortical substance, lie between the pyramids. The cortical substance also includes medullary rays, in each of which are many tubules that pass into a common excretory tube. The upper part of the pyramids is the renal papilla. Slightly above the papillae, there were small cavities (the minor renal calyces) where the urine from the papillae entered. Further down the urinary tract, the minor calyces merged into the major calyces, opening into the renal pelvis. The renal pelvis and the calyces make up the renal sinus. The histological examination of the kidneys of female and male Wistar rats aged 2-4 months revealed no differences in the microscopic structure of the kidneys. On the outer side, the surface of the kidneys is covered with mesothelium, which consists of a single layer of

significantly flattened cells with elongated, spindle- or rod-shaped nuclei and a large amount of cytoplasm (Fig. 4).

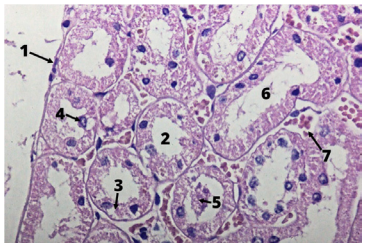

Figure 4. Cortex of the kidney in a sexually mature Wistar rat (female), 2 months of age
***Note**: 1 – renal capsule; 2 – proximal convoluted tubule; 3 – cytoplasmic accumulation of fluid in epithelial cells of the proximal convoluted tubule; 4 – displacement of the nucleus into the lumen of the proximal convoluted tubule; 5 – proteinaceous material in the lumen of the proximal convoluted tubule; 6 – distal convoluted tubule; 7 – blood vessel of the interstitium. Carazzi's haematoxylin and eosin, × 400*
***Source**: authors' photo*

According to W. Kriz & B. Kaissling (2008), two main morphological elements can be distinguished microscopically in the mammalian kidney: the "urinary" and the "vascular" compartments. The morphological and functional unit of the kidney is a nephron, which fulfils all functions of the kidney. Each kidney in rats contains, depending on the breed and age of the animal, 30,000-40,000 nephrons, each of which is divided into the following sequential segments: the renal corpuscle, the proximal convoluted tubule, the loop of Henle (comprising descending and ascending limbs), the distal convoluted tubule, and the collecting duct system. Based on the location of the renal corpuscles and the length of the loop of Henle, nephrons in the kidney are classified into cortical and juxtamedullary types. Renal corpuscles of both cortical and juxtamedullary nephrons are found in the renal cortex substance, but the corpuscles of cortical nephrons are located in the superficial layer of the cortex, while renal corpuscles of the juxtamedullary nephrons are located adjacent to the medulla (Fig. 5). Cortical nephrons predominate in the kidney. According to A.M. Hall (2025), juxtamedullary nephrons account for only 15% of the total nephron population.

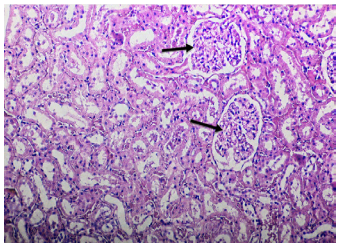

Figure 5. Renal corpuscles of cortical nephrons in the kidney of a sexually mature Wistar rat (female), 2 months of age
***Note**: renal corpuscles of cortical nephrons indicated by arrows. Carazzi's haematoxylin and eosin, x 200*
***Source**: authors' photo*

In cortical nephrons, the loop of Henle extends into the medulla near the corticomedullary junction. In juxtamedullary nephrons, the loop of Henle is located in the deeper regions of the renal medulla. Accordingly, the loop of Henle in cortical nephrons is shorter, whereas in juxtamedullary nephrons it is considerably longer. As noted by S. Bachmann *et al.* (1986) and T. Blanc *et al.* (2021), the longer loop of Henle in juxtamedullary nephrons establishes a hyperosmotic gradient, which facilitates the formation of concentrated urine. Renal corpuscle is the initial part of the filtering of nephrons in Wistar rats' kidneys, 2-4 months of age. In turn, the renal corpuscle is formed by a tuft of blood capillaries (known as the glomerulus of the renal corpuscle), which is surrounded by the capsule of the renal corpuscle (Fig. 6). At the same time, the renal corpuscle is formed from two layers: the outer capsule layer (parietal), which does not take part in filtration processes, and the inner capsule layer (visceral) that covers the glomerulus of renal corpuscle externally. Between these two layers was a cavity known

as the lumen of the renal corpuscle capsule. Primary urine is filtered from the glomerulus in the capsular space, then moves from there into the proximal convoluted tubule.

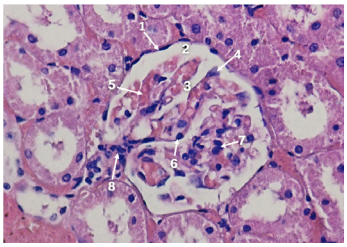

Figure 6. Renal corpuscle of a sexually mature Wistar rat (male), 4 months of age
***Note**: 1 – cells of the parietal layer of the renal corpuscle capsule; 2 – capsular space of the renal corpuscle; 3 – space between the loops of the glomerular capillary tuft; 4 – podocyte; 5 – blood-filled glomerular capillary; 6 – endothelial cell of the glomerular capillary; 7 – small number of intraglomerular mesangial cells; 8 – extraglomerular mesangial cells. Carazzi's haematoxylin and eosin, ×400*
***Source**: authors' photo*

The parietal layer of the renal corpuscle is composed of a single layer of epithelial cells of simple squamous epithelium. The visceral layer of the renal corpuscle capsule is formed by the podocytes – epithelial cells positioned externally on the glomerulus's basement membrane. There are intercellular slits between the long (pedicle processes) processes of the podocytes, which surround the entire glomerulus and are about 8 nm in diameter. It is through these pores that the blood components pass and are filtered into the renal corpuscle capsule space. Filtration diaphragms, situated in the interstices between podocyte projections, control this filtering level. Diaphragms are composed of multiple proteins embedded on the surface of the foot processes of podocytes. These diaphragms allow a filtrate of proteins of about 30 kDa molecular mass to pass, but given the negative charge of both the basement membrane of a glomerular capillary and the surface of podocytes covered by glycocalyx, there is an additional mechanism to resist the movement of negatively charged molecules (e.g. serum albumin). Therefore, the composition of blood filtrate that enters the capsular space of the renal corpuscle (primary urine) includes all substances found in blood plasma, excluding plasma proteins (Yoshimura & Nishinakamura, 2019; Cunanan *et al.*, 2025).

In the renal glomeruli of laboratory rats, Wistar (2-4 months of age), blood capillaries whose walls comprise endothelial cells with a typical microscopic structure are the structural foundation (Fig. 6). These cells rest on a thick basement membrane. Overall, the renal filtration barrier located within the renal corpuscle is composed of three components: the endothelium of the glomerular capillaries, the basement membrane of the glomerular capillary endothelium, and the filtration slits of the podocytes. Within the glomeruli, between the blood capillaries, lies the interstitial component of the glomerulus – the mesangium – which consists of the mesangial extracellular matrix and cells (intraglomerular mesangiocytes), which surround the blood capillaries in each glomerulus (Fig. 6). These cells cover approximately 30% of the capillary surface externally and perform three main functions: providing structural support to the glomerulus, phagocytosis, and regulation of filtration processes within the renal corpuscle. According to K. Ebefors *et al.* (2021), regulation in the renal corpuscle is also indirectly provided by the contractile properties of intraglomerular mesangial cells, which affect blood flow in the glomerular capillaries. The number of mesangial cells in laboratory rats, Wistar (2-4 months of age), was different for individual glomeruli of the same kidney. This was closely related to other morphological changes in renal corpuscles. In the renal corpuscles with a smaller number of intraglomerular mesangi-

al cells (Fig. 6), capillaries in the glomerulus were much more dilated than in those that had a higher number of intraglomerular mesangial cells (Fig. 7) and were also fuller of blood.

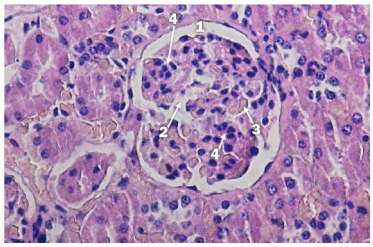

Figure 7. Renal corpuscle of a sexually mature Wistar rat (male), 4 months of age
***Note**: 1 – capsular space of the renal corpuscle; 2 – space between loops of the glomerular capillary tuft; 3 – small amount of blood within a glomerular capillary; 4 – high number of intraglomerular mesangial cells. Carazzi's haematoxylin and eosin, × 400*
***Source**: authors' photo*

Further, in the renal corpuscles with a lower number of mesangial cells, there was a larger interval between the loops of the capillary tuft in the glomerulus. This reflected a different intensity of glomerular filtration in each of the renal corpuscles. In the renal corpuscles of laboratory rats, Wistar (2-4 months of age), in addition to intraglomerular mesangial cells, there were also found extraglomerular mesangial cells, which formed part of the juxtaglomerular apparatus. In a single nephron in laboratory rats, Wistar (2-4 months of age), the proximal convoluted tubule began in the outer parietal layer of the renal corpuscle capsule and continued directly into the renal corpuscle capsule (Fig. 8).

A.M. Hall (2025) and M.P. Hoenig *et al.* (2025) stated that usually such tubules have a rounded shape. They are formed by a relatively thick basement membrane on which a single layer of cuboidal epithelial cells is arranged. On the luminal side, these cells possess a striated border, which increases the absorptive surface area in this segment of the nephron. About 60%-70% of the salts and water in the primary urine are reabsorbed in the proximal convoluted tubule, together with all of the organic substances, in particular amino acids. For this reason, the cytoplasm of the epithelial cells of the tubules often looks foamy and vacuolated with large vacuoles, due to the abundant fluid in them. This is evidence of the intense activity of the process of reabsorption in this part of the nephron of Wistar rats aged 2-4 months. Due to the extensive absorption of substances by the epithelial cells of the proximal convoluted tubule, other morphological changes seen in the cells in Wistar rats aged 2-4 months post-natal age range include the shift of the nuclei of epithelial cells towards the lumen of the tubules and the appearance in the lumen of proteinaceous material, which in part occludes the lumen in a number of segments of the proximal convoluted tubule. Analysis of the morphology of the cortical substance of the kidney in sexually mature female Wistar rats aged 3 months showed clearly recognisable convoluted tubules and a descending limb of the loop of Henle that had maintained its structure, indicating a normal organisation of the nephron at this stage of postnatal development (Fig. 9).

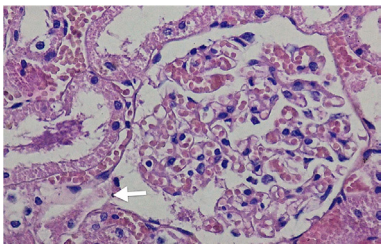

Figure 8. Renal corpuscle of a sexually mature Wistar rat (male), 4 months of age
***Note**: the origin of the proximal convoluted tubule from the outer layer of the renal corpuscle capsule is indicated by an arrow. Carazzi's haematoxylin and eosin, × 400*
***Source**: authors' photo*

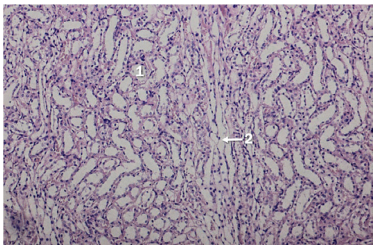

Figure 9. Renal cortex of a sexually mature Wistar rat (male), 3 months of age
***Note**: 1 – convoluted tubules; 2 – descending limb of the loop of Henle. Carazzi's haematoxylin and eosin, x 100*
***Source**: authors' photo*

The loop of Henle continues from the proximal convoluted tubule and is subdivided into descending and ascending parts. In Wistar rats 2-4 months of age of laboratory origin, the descending limb of the loop of Henle was seen on stained slides with haematoxylin and eosin as a slightly serpentine tubule whose wall consisted of a distinctly flattened simple squamous epithelium, lying on a fairly thin basement membrane, and resembling straight renal vessels. Its epithelial cells had elongated nuclei, very similar to those in the endothelium of blood vessels. However, the descending segment of the Henle loop was easily distinguished from straight renal vessels by the absence of blood cells in its lumen (Fig. 10).

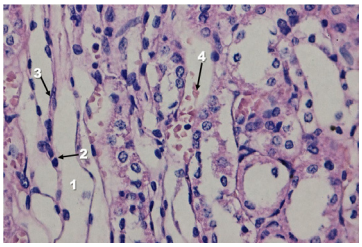

Figure 10. Descending limb of the loop of Henle in the kidney of a sexually mature Wistar rat (female), 3 months of age
***Note**: 1 – lumen of the descending limb of the loop of Henle; 2 – epithelium of the descending limb of the loop of Henle; 3 – basement membrane of the epithelium of the descending limb of the loop of Henle; 4 – erythrocytes in the lumen of a blood vessel. Carazzi's haematoxylin and eosin, ×400*
***Source**: authors' photo*

The ascending limb of the Henle loop, like the descending limb, was lined with simple squamous epithelium and was clearly distinguishable from blood vessels (Fig. 11). On histological sections, its lumen was most often narrow and sometimes moderately dilated, and did not contain any blood cells. The epithelial cells had elongated and clearly stained nuclei, arranged parallel to the surface of the basement membrane and were flat with a thin layer of cytoplasm. The wall of the loop of Henle appeared thin and uniform. There was no marked cellular infiltration. In contrast to the vessels, there were no blood cells in its lumen, and the cells in the wall had an orderly arrangement. In these aspects, these elements facilitate the differentiation between the loop of Henle and the capillaries or smaller vessels of the renal medulla.

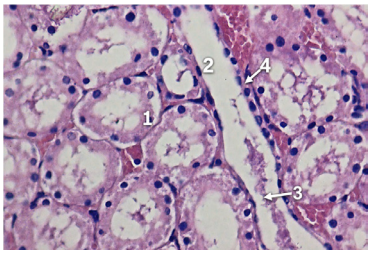

Figure 11. Ascending limb of the loop of Henle in the kidney of a sexually mature Wistar rat (male), 3 months of age
***Note**: 1 – convoluted tubules; 2 – lumen of the loop of Henle; 3 – proteinaceous material in the lumen of the loop of Henle; 4 – epithelial cells of the ascending limb of the loop of Henle. Carazzi's haematoxylin and eosin, × 400*
***Source**: authors' photo*

A.-A. Marcoux *et al.* (2022) noted that, in the loop of Henle of the nephron, 25% of the ions and 20% of the water in the renal corpuscle are reabsorbed. The loop of Henle subsequently transitions into the distal convoluted tubule. In Wistar rats aged 2-4 months, the distal convoluted tubules are clearly differentiated from the proximal convoluted tubules –

alongside which they reside within the renal cortex – owing to their distinct morphological characteristics. Compared to the round proximal convoluted tubules, the distal convoluted tubules seemed more elongated, oval, and of irregular shape. The nuclei of the epithelial cells of the distal convoluted tubules were large, round, and centrally located within the cytoplasm. Nuclear displacement of epithelial cells, characteristic of the proximal convoluted tubules, was not observed. Proteinaceous material was also present in the lumen of the distal convoluted tubules; however, unlike in the proximal convoluted tubules, it did not lead to luminal obstruction. The cytoplasm of the epithelial cells of the distal convoluted tubules, similarly to that of the proximal convoluted tubules, had a foamy appearance and formed a striated border on the luminal surface. However, unlike in the proximal convoluted tubules, the cytoplasm of the epithelial cells of the distal convoluted tubules formed basal infoldings, which increase the surface area of this part of the cell membrane for the placement of ion pumps and transporters. As in the proximal convoluted tubules, the distal convoluted tubules were lined by a single layer of cuboidal epithelial cells resting on a relatively thick basement membrane.

The distal convoluted tubules continued into the collecting duct system. In Wistar rats aged 24 months, the different segments of the collecting duct system (connecting tubules, cortical collecting ducts, outer medullary collecting ducts, inner medullary collecting ducts, and Bellini's ducts formed by the fusion of inner medullary collecting ducts) exhibited a uniform microscopic structure in the histological preparations examined. None of these sections was a straight tube; instead, they were sinuous, and some of the connecting tubules were arched in shape. From the morphological point of view, all the sections of the collecting duct system were formed by a single layer of cubic epithelial cells on a basement membrane (Fig. 12). These cells had a light-staining nucleus of an average size, usually in the middle of the cell, and lightly stained cytoplasm.

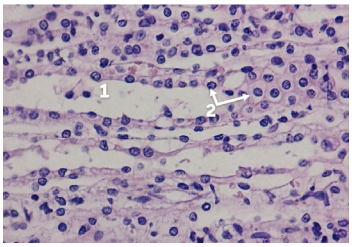

Figure 12. Renal medulla in a sexually mature Wistar rat (male), 2 months of age
***Note**: 1 – lumen of the inner medullary collecting duct; 2 – epithelium of the inner medullary collecting duct. Carazzi's haematoxylin and eosin, ×400*
***Source**: authors' photo*

The wall of the renal pelvis in Wistar rats aged 2-4 months was lined with stratified epithelium (Fig. 13) on the side of the renal pelvis lumen. Three cellular layers could be seen in the stratified epithelium. The base layer consisted of a polymorph population of cells of different sizes and shapes, with a small amount of cytoplasm in a thin band and an oval, round, and elongated shape of nuclei, and some degree of chromatin condensation was revealed. This polymorphism reflects the processes of cell division. In the intermediate layer, the cells seemed to be more homogenous. They were more or less the same size and round or oval in shape, with a greater amount of cytoplasm and an oval or round nucleus with less condensed chromatin. The cells of the superficial layer, in direct contact with the cavity of the renal pelvis, were flattened cells, usually elongated along the general surface of the epithelium, with elongated and oval nuclei.

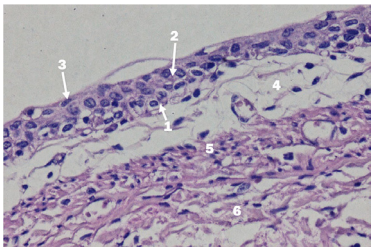

Figure 13. Wall of the renal pelvis in a sexually mature Wistar rat (male), 3 months of age
***Note**: 1 – cells of the basal layer of the epithelium; 2 – cells of the intermediate epithelial layer; 3 – cells of the superficial epithelial layer; 4 – loose fibrous connective tissue; 5 – smooth muscle cells; 6 – loose fibrous connective tissue. Carazzi's haematoxylin and eosin, ×400*
***Source**: authors' photo*

Beneath the surface epithelium, there was a layer of loose fibrous connective tissue composed of sparsely distributed fibroblasts and bundles of collagen fibres. Blood vessels were also observed within this layer of the renal pelvis wall. Below this layer lay a layer of smooth muscle cells, beneath which there was again a layer of loose fibrous connective tissue. One of the structural components of the renal corpuscle is the mesangium – the glomerular interstitium, consisting of an extracellular matrix and cells known as mesangial cells (mesangiocytes). All mesangiocytes are divided, according to their location and function, into intraglomerular and extraglomerular forms. According to B. He *et al.* (2021), the intraglomerular mesangial cells surround glomerular capillaries, and cover about 30% of their external surface, being responsible for three major functions: structural support of the glomerulus, maintenance of filtration processes, and participation in phagocytosis. Intraglomerular mesangiocytes produce an extracellular mesangial matrix, composed of type IV collagen, perlecan, fibronectin, and laminin. They also phagocytose immune complexes and cell debris in the glomerulus, such as fragments of the basement membrane or fragments of mesangiocytes that have undergone apoptosis. Intraglomerular mesangiocytes also have contractile properties, being able to contract the glomerular basement membrane and reduce the glomerular surface, decreasing the filtration rate of the renal corpuscle. K. Ebefors *et al.* (2022) reported that, through their processes extending into the lumen of the glomerular capillaries, these cells may also participate in the regulation of serum glucose levels.

M.P. Hoenig *et al.* (2025) reported that extraglomerular mesangiocytes are located outside the glomeruli in the region of the vascular poles of the renal corpuscles. They are classified as part of the juxtaglomerular apparatus. Urine from the primary formation of each renal corpuscle passes into the renal tubules for further modification. Every renal tubule consists of separate sections, which are differentiated both in structure and function. The proximal convoluted tubule emerges directly from the renal corpuscle and is situated in the cortex. It is lined with simple cuboidal epithelium, the adjacent cells of which are connected by large lateral interdigitating contacts. Consequently, in the microscope, it is difficult to define the boundaries between neighbouring epithelial cells of the proximal convoluted tubule. In this tubule, about 2/3 of salts and water, as well as all organic substances (mainly glucose and amino acids), are reabsorbed.

M. Alamilla-Sanchez *et al.* (2025) described that the basic function of the loop of Henle is to increase the salinity of the interstitium and ensure the concentration of different components of the plasma. D. Pearce *et al.* (2022) reported that the loop of Henle is lined with cells whose cytoplasm contains many mitochondria to provide the energy required for the reabsorption of calcium, sodium and chloride.

After that, the distal convoluted tubule passes through into the collecting duct system, through which water is exchanged along with electrolytes – sodium, potassium and hydrogen ions. M. Alamilla-Sanchez *et al.* (2025) also reported that reabsorption of electrolytes is regulated by aldosterone and antidiuretic hormone. Accordingly, the kidneys of Wistar rats aged 2-4 months were morphologically typical of other mammalian species, with neither macro- nor microscopic structure revealing significant sex-related differences at this age. Their morphological organisation was characterised by a clear distinction between cortical and medullary parts, with both types of nephrons present – cortical and juxtamedullary – in all rats. Renal corpuscles, the tubular system and the collecting system had a characteristic architecture. Their specific features of microscopic structure allowed functional differentiation of all segments of the nephron, providing for filtration, reabsorption, and final processing of urine.

Conclusions

Anatomical and histological examination of the kidneys of sexually mature Wistar rats aged 2-4 months showed that the macroscopical structure of this organ was typical, identical in males and females and compliant with general species-specific organisational features of mammalian kidneys. They demonstrated their typical retroperitoneal position, bean-shaped form, dark-red colour and a clear boundary of the hilum as well as cortex and medulla, pyramids, calyces and renal pelvis, which is evidence of full maturation of organ morphological organisation. At the microscopic level, the kidneys of laboratory rats of the studied age had a typical for other mammalian species morphological organisation with a clearly distinguished cortex and juxtamedulla, and with a number of structural elements including renal corpuscles, proximal and distal convoluted tubules, loops of Henle, collecting duct system and renal pelvis. The amount of mesangiocytes of intraglomerular capillaries differed in different glomeruli in the same kidney, and the smaller amount of mesangiocytes was accompanied by more dilated capillary loops, a higher blood content in the glomerulus and a wider space between the capillary loops due to lower glomerular filtration intensity. In the proximal convoluted tubules, the functional organisation of epithelium was revealed as evidenced by foamy epithelium cytoplasm with big vacuoles in many cells, displaced towards the tubular lumen, nucleus of the epithelium, and proteinaceous mass with partial obliteration of the tubular lumen observed in a few tubules. The distal convoluted tubules differed in an elongated shape of tubules with a central position of the nuclei of epithelial cells, no lumen obliteration, although with a large quantity of proteinaceous mass in the lumen. All segments of the collecting duct system were represented with simple cuboidal epithelium with pale cytoplasm and the nuclei centrally located in most of the cells. The renal pelvis was characterised by a well-developed wall in the form of a three-layered epitheliumconnective tissue-muscle wall. Further study is recommended in which quantitative estimation of morphometric characteristics of separate nephron elements is carried out, as well as the determination of the correlation between morphological and functional characteristics under physiological conditions and experimentally induced pathological states.

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Conflict of Interest

None.

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Морфологічні особливості нирок у 2-4-місячних щурів лінії Wistar

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Анотація. Актуальність дослідження зумовлена тим, що щури лінії Wistar широко використовуються у ветеринарних і біомедичних дослідженнях, однак анатомічна та мікроскопічна будова їх нирок у віці 2-4 місяців описана недостатньо. Метою роботи було вивчення особливостей анатомічної і мікроскопічної будови нирок у щурів лінії Wistar зазначеного віку. Для досягнення поставленої мети застосовано анатомічний розтин, макроскопічне дослідження нирок та гістологічний аналіз їх структурних компонентів. Встановлено, що нирки самок і самців щурів лінії Wistar у 2, 3 і 4 місяці мали типову для

цього органу будову – темно-червоний колір, бобоподібну форму, капсулу з волокнистої сполучної тканини та чітке розмежування на кіркову і мозкову речовину. З'ясовано, що кіркова і мозкова речовина формували характерні структурні елементи нирки, зокрема медулярні промені, піраміди та ниркові стовпи. Під час гістологічного дослідження було встановлено, що в різних ниркових тільцях кількість клітин мезангіуму неоднакова, а при меншій кількості внутрішньоклубочкових мезангіоцитів капіляри клубочка були більш розширеними і містили більше крові. Виявлено, що у проксимальних звивистих канальцях ядра епітеліоцитів нерідко зміщені у бік просвіту, а в самому просвіті містилася білкова речовина. Дистальні звивисті канальці мали більш витягнуту форму, їх ядра розташовані центрально, а білкова речовина в просвіті не спричиняла його закупорки. Усі відділи системи збірних канальців вистелені одношаровим кубічним епітелієм зі світлою цитоплазмою та переважно центрально розташованими ядрами. Отримані результати мають практичне значення для проведення експериментальних морфологічних досліджень, а також для порівняльної анатомії, гістології та ветеринарної медицини

Ключові слова: ниркові тільця; мезангіоцити; проксимальні звивисті канальці; дистальні звивисті канальці; збірні канальці; кіркова речовина; мозкова речовина