6. RENAL PHYSIOLOGY

THE URINARY SYSTEM

Components and function

The urinary system is composed of two kidneys, the functionally filtering apparatus, which connect through two tubular structures called ureters to a urinary bladder, which serve as a reservoir for urine. The bladder, controlled by a sphincter, empties into the urethra to eliminate the urine from the body (Fig. 6-1).

Since the organ of most interest in the urinary system is the kidney we are going to concentrate in its structure and function. The working capacity of these organs far exceeds the need of a normal organism to the extent that an animal can function absolutely normal with only one quarter of the renal capacity and can survive with only one tenth.

The main role of the kidneys is to filter the circulating blood in order to remove from the body waste products acquired through direct ingestion or resulting from catabolism of the organism (Fig. 6-2). The removal of these products is meant to avoid their accumulation to toxic levels.

A second critical role of the kidneys is to regulate and try to maintain within normal levels the extracellular fluid, circulating blood volume and, as a consequence, the blood pressure. This is achieved by regulating the volume of electrolytes and fluid which is excreted in urine and also through the production and release of enzymes by the rennin angiotensin system, leading to the production of vasoactive compounds.

In the process of filtering blood, the kidneys regulate the ionic concentration in circulation by either retaining or excreting, depending on the needs, ions such as Na⁺, K⁺, Cl⁻, Ca²⁺, HCO₃⁻, HPO₄²⁻.

In order to maintain a narrow physiological intercellular fluid pH the kidney controls the excretion of H⁺.

The kidney also has an endocrine role which contributes to several rather important physiological activities. It contributes to the regulation of red blood cell through production or erythropoietin. Regulates diuresis through increased renal blood flow as a result of production of urodilatin and, calcium absorption through conversion of 25-hydroxycholecalciferol to 1,25-dihydroxycholecalciferol, the active form of Vitamin D₃. The kidneys also secrete renin, an enzyme involved in the production of angiotensin II, leading to synthesis and release of aldosterone.
The final role attributed to the kidney is in gluconeogenesis. Tubular cells of the kidney are capable of using amino acids from circulation to make glucose and export it to circulation as the liver does. The main difference appears to be that liver operates more in a circadian rhythm according to food intake, while kidneys produce a continuous supply of glucose.

**Anatomy of the kidney**

Depending on the species the kidney can be composed of a single smooth continuous surface structure as it is the case in humans, pigs, dogs, sheep, cats, (Fig.6-3) or a multi-lobulated structure as it is in the case of cattle (Fig.6-4). In the ventral aspect, the kidney has the renal sinus which has an accumulation of adipose tissue to provide a soft buffer against bumps when the animal makes fast movements (Fig. 6-5).
Several minor calyces converge to form a major calyx and several major calyces join in the smooth kidney to form a cavity called the renal pelvis which then narrows into a single tube called the ureter. The ureter exits the kidney through at the central hilum and empties into the urinary bladder. There are many pyramids in each smooth kidney but in the lobulated kidney there is normally one pyramid in each lobe. In the lobulated kidney there is no renal pelvis. Each pyramid lead to minor and major calyces and these connect directly into the ureter.

Blood supply and innervations of the kidney

Given that the function of the kidney is to filter the blood, this organ receives a disproportionally high supply of blood in comparison to other parts of the organism. For an organ that accounts for only about 0.4 % of the body weight it receives between 20 and 25 % of the cardiac output.

The kidney is irrigated through the renal artery which branches of the abdominal aorta. The renal artery enters through the hilus of the kidney into the renal sinus and divides into several segmental arteries which in turn give rise to the interlobar and arcuate arteries (Fig. 6-8). These travel through the renal column towards the cortex of the kidney and upon reaching the base of the pyramids they follow the base projecting interlobular arteries towards the cortex and these, in turn divide into the afferent arterioles that brings blood to each glomerulus forming the glomerular capillaries within each renal corpuscle. Exiting the renal corpuscle the glomerular capillaries coalesces into the efferent arteriole which, intimately associated with each nephron, form a plexus named peritubular capillaries in close apposition with the proximal and distal convoluted tubules of each nephron. The peritubular capillaries then travel into the medulla where it becomes the vasa recta which are
in close contact with the loop of Henle of the juxtamedullary nephrons. Finally, the vasa recta join and become the interlobular vein leaving the cortex into the arcuate vein. Several arcuate veins form the interlobar vein which travels through the renal column towards the renal vein. This in turn leaves the kidney through the renal sinus and joins general circulation through a connexion to the inferior vena cava.

The main innervation of the kidney is sympathetic derived from celiac ganglion. They connect mainly with small arteries and afferent arterioles, the juxtaglomerular apparatus and the tubules. The main purpose of sympathetic stimulation is to cause vasoconstriction of these vessels, thus reducing the formation of filtrate and urine when the animal is under severe stress. Under mild sympathetic stimulation the change in filtrate volume is negligible.

**Nephron, the functional filtering unit of the kidney**

The nephron is the functional unit of the kidney. There are two types of nephrons, cortical and juxtaglomerular nephrons (Fig. 6-9). In domestic animals approximately 25 % of the nephrons are juxtaglomerular and the majority are cortical. Each nephron consists of a renal corpuscle, which is located in the cortex of the kidney, and a tubular component, which, in juxtaglomerular nephrons, extends deep into the medulla of the kidney, towards the tip of the renal pyramid. In the cortical nephrons most of the tubular component resides in the cortex of the kidney. The renal capsule is made by the glomerulus surrounded by the Bowman’s capsule. The tubular component starts with the proximal convoluted tubule followed by the loop of Henle which in turn can be divided in three sections with self explanatory names. These are: the thin descending limb, (descending towards the medulla) the thin ascending limb and the thick ascending limbs (ascending towards the cortex). Once in the cortex the loop of Henle becomes the distal convoluted tubule which travels through the entrance of the renal capsule in very close contact with both, the afferent and efferent arterioles. Then this becomes the collecting duct which, as it travels through the medulla towards the tip of the renal pyramid, it receives the content of many nephrons and increasing in diameter (Fig. 6-10). At this point the collecting duct becomes the papillary duct which then empties in the renal papilla and this into a minor calyx.

The histology of the contents of the Bowman’s capsule is of special functional importance. The outside of the renal corpuscle is the Bowman’s capsule or capsula glomeruli. This structure is like a spherical funnel with the mouth in what is also known as the vascular pole, where the afferent arteriole enters and the efferent arteriole leaves the renal corpuscle. The exit of the funnel connects with the proximal convoluted tubule. The external wall of the Bowman’s capsule serves as a retention wall to guide the filtrate towards the
tubular end. Then we find a urinary space or capsular space which collects the filtrate. The internal wall of the Bowman’s capsule is made of very specialized cells called podocytes. These cells are made of finger-like projections which lay on top of a glomerular basement membrane which in turn covers the outside of the glomerular capillaries. The podocytes make a thick cellular layer leaving filtration slits in between fingers. These slits permit the passage of filtrate from the glomerular capillaries towards the capsular space (Fig. 6-7).

The glomerular capillaries constitute the vascular component of the renal corpuscle. At the entrance we find the afferent capillary which then divides into multiple vessels making a plexus which then join at the exit of the capsule to form the efferent capillary. The capillaries in the glomerulus are all fenestrated, that is, they have multiple perforations which permit the passage of all of the molecules which will make the filtrate. Each capillary vessel is covered by the basement membrane before being covered by the podocytes.

**Filtration barrier.** All products and materials that form the filtrate have to cross a filtration barrier. This functional structure is composed of the fenestrated endothelial cells of the capillary vessels, the basement membrane and the filtrations slits created by the podocytes covering all the vessels and forming the internal wall of the Bowman’s capsule (Fig. 6-11).

The other structure of functional importance in the nephron is the Juxtaglomerular apparatus (JGA) (Fig. 6-12).
The JGA is a collection of cells located at the entrance of the renal corpuscle and inside the distal convoluted tubule. The cells of the JGA physically connect the distal convoluted tubule and the afferent and efferent arterioles. The juxtaglomerular or granular cells which are located in direct contact with the arterioles are capable of sensing the intra-renal pressure to determine if they need to release the enzyme renin. The role of renin is to increase systemic blood pressure through the renin-angiotensin system. The other type of cells in the JGA, those making the macula densa, are located in the distal convoluted tubule and are capable of sensing the sodium chloride concentration of the filtrate. If the concentration of NaCl is higher than normal the cells in the macula densa send paracrine signals to the afferent arteriole to reduce the glomerular filtration rate. In this manner the loop of Henle has more time to reabsorb Na+ from the filtrate. The exact mechanisms of these signals will be discussed later.