

THE KIDNEY: A DESIGNED SYSTEM FOR PLASMA HOMEOSTASIS

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KEYWORDS

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ABSTRACT

The kidney is an excellent biochemical model showing design in nature. Design implies a designer. The development of the kidney follows a very precise pattern and time schedule. The anatomy and physiology of the kidney and the entire urinary system are complex and precise. This is true when regarding the urinary system alone; and also, in studying its relationship to other systems. The urinary system is tied in with the circulatory and nervous systems in very unique fashion. Each part is carefully integrated into the whole system to form a homeostatic control network that operates efficiently in a large number of metabolic states. Each section of the urinary system is specific, yet completely dependent on other sections. Three separate mechanisms are involved in forming the end product, urine. These are filtration, reabsorption, and secretion. Filtration takes place in the glomerulus. Reabsorption and secretion occur in the tubules. The circulatory system of the kidney is unique. The capillaries in the glomerulus are more porous than capillaries elsewhere in the body. The medulla contains a specialized capillary network which forms a countercurrent mechanism along with a hairpin design. This arrangement is not found elsewhere in the body, or in any organisms except mammals and birds. This countercurrent system creates a concentration gradient which enables the production of a concentrated end product while preserving necessary ions for the body. Mechanisms within the kidney enable it to modify its function; yet function is also sensitive to hormone and neurological input. In this way, the kidney is sensitive to needs and changes throughout the entire organism. Biochemical engineers create artificial models to take the place of diseased kidneys. These models require the input of intelligence and design, yet fall short of the precision of the natural model. Therefore, I conclude that the kidney was designed by a superintelligence beyond the scope of nature.

Ah, Sovereign Lord, You have made the heavens and the earth by Your great power and outstretched arm. Nothing is too hard for You. Jer. 32:17

INTRODUCTION

A designed system is an integrated, symmetrical unit which serves some purpose. Design implies a designer; someone who intelligently lays out a plan. Is the kidney the result of design or is it the result of random natural processes? The goal of biology is to ultimately explain all function in physical, mathematical, and chemical terms. We can gain a great deal of understanding by describing the anatomy, physiology, and biochemistry of the kidney; yet, to grasp how this biochemical unit came to be requires that we step outside of science and into the realm of philosophy. As a creationist I believe that the structure and function of the kidney show design, and that this was laid out by a superintelligence beyond the scope of nature. This plasma purification system is incredibly complex and precise. It consists of paired kidneys, the ureters, the bladder, and the urethra, all of which must be tied in precisely and uniquely with the circulatory system, as well as with the lymphatic and nervous systems. All of these units must be complete and functional in order to maintain chemical balance in the body and to purify the blood of toxins, drugs, and other soluble impurities.

The kidney meets these needs in a great variety of different metabolic states. It exhibits symmetry, complexity, integration, and purpose. Therefore, the kidney shows design. If any part of this extensive intricate system was not functional at the same time as all of the other parts, the whole unit could not function. For this reason, creationists believe the kidney was created by a Master Designer.

DEVELOPMENT

The urinary tract arises from three distinct embryonic tissues. The bladder and urethra arise from the uro-rectal endoderm. The kidney begins first as a pronephros, arising about the fourth week of gestation, but it quickly degenerates into a system of ducts utilized by the next stage, the mesonephros. This stage is not known to be functional in the human, although it is functional in some mammals. Some researchers are beginning to associate function with the mesonephros in the human fetus, now, too. The mesonephros develops tubules and glomeruli which degenerate into genital ducts in the male, and vestigial tissue in females. The true kidney begins to develop during the fifth week of gestation, and is functional by the eighth week. This true kidney develops from the metanephros, which consists of two parts: the metanephric diverticulum, or bud, and the metanephric mass, or blastema. The diverticulum gives rise to the ureters, renal pelvis, calyces, and collecting ducts. The blastema forms a cap over the diverticulum and differentiates into the glomerular capsule, the proximal and distal convoluted tubules, and the intervening hairpin loops. All of this is a patent pathway and becomes patent with the collecting tubule where they meet. This system is patent from the collecting tubule to the ureters and becomes patent with the bladder, thus forming a continuous open pathway from the capsule to the external opening of the urethra. While the cells of the filtering receptacle are developing, the aorta is branching into the renal artery, which invades the kidney at the renal pelvis, where it branches and rebranches to form the supply unit— the glomerulus, as well as the specialized system of arterioles, capillaries, and venules necessary for kidney function. The development of the filtering system shows design. A single cell, which holds all the genetic information necessary for the final product, divides again and again until some master control initiates differentiation. Differentiation includes integration with three separate embryonic tissues to form a patent pathway. Three tissues become integrated into one functional unit. Added to this complexity is further integration with the nervous system and the endocrine system for regulation. This initial level of examination gives us a sketch of a remarkable design.

ANATOMY

Looking into the anatomical layout of the kidney, even more astounding integration and complexity of design can be seen. The overall shape of the kidney is similar to a lima bean. It is covered with a tough membrane which lines the entire organ, including the sinus. The kidney is divided into three distinct parts. The outer part, called the cortex, is granular in texture due to the great number of renal tubules which comprise its structure. The renal corpuscles are located here, although they are absent from the outermost layer. Under the cortex is the medulla which looks striated to the unaided eye. This striated appearance is due to the many papillar tubules and the loops. There are no renal corpuscles in the medulla. The medulla ends in the renal papillae, which comprise the inner wall and border on the calyces. The papillae are flattened cones with tiny openings, or ducts, into which the collecting ducts empty. The papillae in turn empty into the renal pelvis. The calyces and pelvis, called the hilus, contain all of the major blood vessels, nerves, and fatty tissue. The lima bean shape, with the cortex located on the long side, and the medulla on the narrow side, creates a uniquely shaped structural unit of a wedge with the cortex forming the broad side of the wedge, and the medulla forming the narrow side. This is significant as will be seen later when considering the function of the kidney. Interestingly, the functional units are not long narrow tubes, or spheres, or cubes. They are precisely shaped like wedges, and this shape is very important to the design, because it provides the unique interrelationships between vessels and tubules necessary for the intricate job of concentrating urine.

The paired kidneys in a human weigh approximately one-half pound. In any mammal, both kidneys together weigh slightly less than one half of one percent of the total body weight. Human kidneys contain about three million nephrons, Windhager [25, p. 3]. Each nephron is 3 cm. in length, but if all the nephrons were laid out end to end, the tube would stretch for 50 miles, Prowser and Brown [18, p. 43]. This length is much more than is needed for the job of purifying the blood. There is a very large reserve of nephrons should some of them be damaged during the life of the individual.

The functional unit of the kidney is the nephron. It consists of a supply unit from the circulatory system and a collecting unit from the urinary system. These two structures are intricately intertwined with a highly specialized capillary network in order to form the urinary waste and to maintain the quality and quantity of the body fluids.

The supply system of the nephron begins with the renal artery, which gives rise to the arcuate arteries at the junction of the medulla and cortex. These arched vessels give rise to tiny afferent arterioles. Several glomeruli branch off each afferent arteriole. These glomeruli are specialized tufts of arterial capillaries which redivide many times before anastomosing within the glomerulus to form the efferent arterioles exiting from the renal corpuscle. After leaving the glomerulus, the efferent vessels again divide into a capillary network. Weiss, [24, p 820] has likened this to the portal system of the liver and calls it an arterial portal system. Some differences exist, however,

since the portal system of the liver begins with a vein which breaks up into a capillary bed and finally reforms a vein; whereas, the arterial system of the glomerulus is an arteriole which breaks up into a capillary bed, then reunites into an arteriole before again forming another capillary bed. The afferent arterioles contain smooth muscle and are thicker than the efferent vessels. Adrenergic nerve fibers are located within one third of the efferent vessels and somewhat fewer in the afferent vessels, Brenner and Rector [3, p. 19]. This is an important component of the pressure control system which will be discussed later. These neural components are also important features in the structure and function of the juxtaglomerular apparatus, although renal circulation changes very little with or without nerve stimulation. Autoregulation is important in the kidney and is very efficient.

Outside of the corpuscle, in the cortex, the efferent arteries in nephrons near the capsule divide into an extensive capillary bed, the peritubular network, with no specific direction of flow. These are very thin-walled fenestrated vessels. This unique system provides an oxygen-rich blood flow with high pressure to the renal corpuscle, and an oxygen-rich but low pressure blood flow around the proximal and distal tubules, a necessary arrangement for active transport. In the corpuscles near the medulla, the efferent vessels give rise to two capillary systems. One is the peritubular network, and the other is a parallel network known as the *vasa recta*. The volume and rate of blood flow to the medulla is less than that which supplies the cortex. The oxygen tension is less, also; so the medullary cells derive much of their nutrition from glycolysis. One to two percent of the urinary blood flows through the *vasa recta*. Blood flows into the *vasa recta* without being exposed to the peritubular environment, and no solutes are contributed to the juxtanephron network. The flow is counter to the flow of the tubular solution; flowing down past the ascending loop, then up the descending loop where anastomosis with the intermediate branches of the arcuate vein occurs, ending finally with the interlobular vein. As these capillaries descend, they give off parallel branches which anastomose with the ascending vessel, forming a countercurrent pattern which is maintained among all the loops. In order to do this, adjoining nephrons share a *vasa recta*, and the loops are mirror images. The kidney capillaries have a structure that is different from capillaries elsewhere in the body. If the capillaries in the muscles, for instance, were like the capillaries in the kidneys, our muscles would be engorged with fluid and would not work properly. Imagine, too, how thick and heavy they would be. The pores in muscle capillaries occur between endothelial cells overlying a collagen-glycoprotein basement membrane; whereas, in the kidney, there are two porous layers separated by a basement membrane, which also appears to be fenestrated. The unique wedge shape of the kidney units creates a high pressure center in the glomerulus where it is needed to drive the filter system, and a low pressure system around the tubules where it enhances reabsorption. The point of the wedge is in the medulla where the osmotic gradient is the greatest. The double flow system in the medulla coupled with specific cell design creates a mechanism for concentrating urine found only in mammals and birds.

The collecting system of the nephron is composed of a glomerular capsule, a proximal convoluted tubule, a hairpin loop, and a distal convoluted tubule. The capsule is a cap of specialized cells surrounding the glomerulus. Together, this cap and the capillary tuft, or glomerulus, form the renal corpuscle. The distal convoluted tubule opens into the collecting duct. These two structures have similar function and are discussed together, although the collecting duct arises from a different embryonic tissue than does the distal tubule. The proximal convoluted tubule is a long twisted duct leading from the renal corpuscle. It winds around the cortex until it dips toward the medulla and gives rise to the hairpin loop. Some loops are short, remaining in the cortex for their entire length, while others are long and dip to various depths into the medulla. The number of nephrons with long loops and the length of the loops is correlated with the ability to concentrate urine. The greater the proportion of long loops, the greater the ability to concentrate urine. The distal convoluted tubule arises abruptly from the loop. Distal convoluted tubules are shorter and less convoluted than the proximal, and wind around the cortex near the corpuscle until they empty into the collecting duct. A specialized group of cells, called the juxta-glomerular apparatus lies between the distal tubule and the neck of the glomerulus. These cells secrete a hormone, renin, which aids in the control of the blood pressure leading into and exiting from the corpuscle.

FUNCTION

The really incredible story is a description of the kidney at work. Studying the delicate organ has not been easy. There are three distinct processes involved in urine formation: glomerular filtration, tubular reabsorption, and tubular secretion. Much of the knowledge of kidney function has come from indirect means and the study of pathological changes. Investigators injected traceable agents into rabbits or other experimental animals and studied the results. Micropuncture techniques gave proof that the glomeruli were ultrafilters. By micropuncture, scientists showed tubular reabsorption and also where in the tubules it takes place. The use of inulin and phenol red indicators aided in proving tubular secretion. Tissue cultures of embryonic and mature kidney fragments also aided in the gathering of knowledge of kidney function. Recent advancement in biochemical and histochemical research has added much to the knowledge of kidney function. The study of changes in plasma composition in relation to changes in kidney cellular morphology also gave insight into kidney function. This research is carried out by intelligent knowledgeable scientists using complex scientific instruments. The research is carefully designed so that the results can be studied in an organized fashion. Can we acknowledge our own intelligent efforts without acknowledging the Superintelligence which designed the system in the first place?

It must be remembered, too, that cells are made up of proteins and lipoproteins. Sometimes we think of cells as

solid structures, like boxes or cubes. It helps clarify how the kidney works if we remember it is a network of molecules which in turn are composed of chemicals. These chemicals fit together and work together to form the united whole. This interdependence changes as we move through the nephron; so each part has a unique structure and function. Even though all of these cells originated from one cell, the master program provides immense differentiation within this organ enabling integration of function in a precise and efficient manner.

The kidneys perform an incredible function. In one day's time, they filter the equivalence of sixty times the total plasma, Berne and Levy [1, p. 752]. This system receives 20-25 percent of the blood flow of the body, Berne and Levy [1, p. 825], more than is supplied to other organs, and almost all of this blood passes through the glomeruli. The glomerular filtration rate in a 150 pound person is 180 L/day; whereas the filtration rate across other capillaries is 3 L/day, Vander and Luciano, [23, p. 428]. Plasma filtration takes place within the renal corpuscle. This structure is comprised of the glomerulus and its capsule. The cells of the capillaries and the basement membrane of the capsule are very porous. The cells of the capillary side of the cap have a completely different structure from those of the outside. The inside layer is visceral epithelium of the renal tissues and endothelium of the glomerular capillaries. In between the capillary cells and the capsule cells is a complex basement membrane. It continues around the capillary tuft and fuses with the afferent and efferent vessels as they leave the renal corpuscle. The cell body of the endothelial cells protrudes into the lumen of the capillary. The visceral epithelial cells are called podocytes, and have large central bodies with elongated primary foot processes which are largely suspended in the urinary space. Secondary foot processes are firmly adhered to the glomerular basement membrane. These epithelial cells fit together like loosely arranged puzzle pieces. The spaces between the cells form pores measuring about 40 by 140 micrometers, Berne and Levi [1, p 752]. This podocyte structure is unique to the kidney and makes its special filtering characteristics possible. Blood enters the nephron through the afferent vessel. In the renal corpuscle, 20% of the liquid constituents of the blood are filtered out. The filtrate from the glomerulus is captured within the capsular space because the outer layer of cells in the cap, the parietal epithelial layer, is composed entirely of impermeable squamous epithelium. The mesangial cells are the fourth type of cell. They are located around the stalk formed by the afferent and efferent vessels. These cells are sensitive to angiotensin II and ADH, hormones which cause the cells to constrict. This is thought to reduce the filtration area, thereby regulating filtration.

The glomerular filter works by a pressure gradient caused by the heart beat and depends on the available area within the glomerulus. Five features of the filtering system favor high filtration. These are: the large renal blood flow, the complex shape of the podocytes, the presence of large endothelial pores, the contractile efferent arterioles which help maintain high glomerular pressure, and the high hydrostatic pressure relationship within the glomerulus. Blood pressure in the glomerulus averages 55 mg Hg. This is higher than in other capillaries of the body. The fluid within the glomerular capsule averages 15 mg Hg. Protein is present in the plasma but absent in the capsule. The osmotic pressure of the protein is 30 mg Hg. The pressure of protein and the fluid pressure of the capsule counter the blood pressure to the glomerulus. This creates a net pressure of 10 mg Hg which forces an essentially protein-free filtrate into the capsule and down the proximal tubule, Vander and Luciano. [23, p. 427]. The capillaries of the glomerulus are about 100 times more porous than other capillaries in the body. The glomerulus appears to work like a mechanical microfilter, although recent studies have shown that protein can be actively reabsorbed by the endothelial cells. Fluid travels through the endothelial pores, basement membrane, and the epithelial slit diaphragms to become an ultrafiltrate trapped by the parietal epithelium. There is a coordinated interaction among all of these distinct cells, and all must be properly structured and functional for the whole procedure to take place. Water, ions, amino acids, glucose, and other small soluble particles pass through the glomerular filter. Only the blood solids and the large protein molecules escape filtration. In the first step of kidney function, 20 percent of the total volume is removed, seemingly with very little discrimination, and no consideration of body needs! This creates a serious problem. A 170 pound person contains 40 L of water, and 3.5 L of plasma. The glomeruli filter 125 ml of plasma per minute which puts 160 L of water per day into the renal tubules. This filtrate contains 1 kg of sodium chloride, 500 Gm of sodium bicarbonate, 250 Gm of glucose, 100 Gm of free amino acids, and many other essential ions in smaller concentrations, Pitts, [17, p. 15]. The quantities filtered exceed the body stores; yet the quantities excreted are infinitesimally small. This means that tremendous amounts are reabsorbed.

Reabsorption takes place in the tubules, with about eighty-five percent occurring in the proximal tubules into which the filtrate passes after leaving the glomerulus. Solutes from the renal filtrate can pass through the proximal tubule cell membrane by osmosis, or by slipping through the junctions between the cells. Most reabsorption, however, takes place selectively by an active transport system through the cells. In contrast to the bulk flow present within the glomeruli, the flow is restricted in the tubules because no pores are present. In fact, the cells adhere to each other with tight interdigitated junctions, which form extensive processes and greatly enlarge the surface membrane on the basal side of the cells. This basolateral folding is most prominent in the first segment of the tubule and decreases in the latter segments. These junctions are sensitive to osmotic pressure changes within the cells and the intercellular spaces. These pressure changes affect transport through the intercellular junctions. The luminal side of the proximal tubule cells consists of a dense brush border, or microvilli. Proximal tubule cells contain many mitochondria, located on the basal side. These cells also contain large vacuoles and lysosomes. Several cytomembranes, some containing ribosomes, and others being smooth walled, are present, as are numerous microtubules. The proximal tubule is divided into a highly convoluted segment and a straight segment. The cells

of the first part of the convoluted segment, called S_1 , are taller, more interdigitated, and have a more dense, tall brush border than the cells of the latter part of the convoluted segment and beginning of the straight segment, called S_2 . Mitochondria are larger and more dense and vacuoles are more numerous in the S_1 segment. The bulk of the straight segment is called S_3 . The brush border of this segment is tall and thick, but it has the fewest mitochondria. In the straight segment, the Golgi apparatus is more extensive, and the smooth-surfaced reticulum is more pronounced. The distance between microvilli increases with increased tubular flow. It is thought that this increases reabsorption, Windhager, [25, p. 71]. Even though the proximal convoluted tubule is one structure, yet it is subdivided and each section functions in a specific manner. The cells are complex and contain an enormous amount of specialized organelles. Mitochondria provide energy for the cells. Those cells having a large number of mitochondria have a high metabolic rate and many carrier proteins. These are the sites of intensive active transport. The Golgi apparatus is involved with preparing substances for secretion. Each area of the tubule has a specific design for a specific purpose.

Reabsorption mechanisms are passive or active. Passive reabsorption occurs if the substance flows out of the tubules by a concentration gradient or an electrochemical gradient. No energy is expended in passive transport, although energy is expended in establishing the necessary gradients in the first place. Active reabsorption mechanisms are complex and energy is required. Na^+ , K^+ -ATPase is present in the basolateral cell surface and activates a transcellular transport of sodium. This is highest in the first part of the tubule and decreases in the latter segments. The passive transport of water is established by the osmotic gradient created by the active transport of sodium. Urea does not permeate as readily as water, so it is at a higher concentration in the tubules, but when the concentration is high, it will passively return to the plasma. Urea is most concentrated in the collecting tubules. Here urea diffuses from the collecting tubule into the hairpin loop, thus creating a urea cycle. It is thought that retaining urea in the system in this manner creates a greater osmotic gradient than would be attainable otherwise. About half of the urea filtered is excreted. Chloride diffuses passively from the proximal tubules by the electrical gradient created by sodium. The solution in the capillaries surrounding the convoluted tubules is iso-osmotic with that in the tubules; yet the cells themselves may be hyperosmolar. This creates different electrical and ionic gradients, which enable selective retrieval of necessary ions. The carriers are specialized lipoproteins in the cell membranes to which the ions to be transported are attached. There are several carrier mechanisms. Some are specific for certain substances, whereas others carry several different substances. Sodium and glucose, for example, use the same carrier. However, glucose is carried at a fixed rate per unit of time. When more than this fixed amount is present in the filtrate, glucose is excreted in the urine. The body mechanisms that regulate glucose metabolism insure that under normal conditions the renal threshold of glucose will not be exceeded; so all the glucose in the filtrate is reabsorbed. However, in abnormal sugar metabolism, there is more glucose in the plasma than the kidneys are capable of reabsorbing; so the excess will be excreted in the urine. Small amounts of protein filtered are reabsorbed in the proximal tubules. They are broken down into amino acids and utilized by the cells or released from within lysosomes into the tubule lumen. The permeability of the cells in the nephron to water varies along the nephron. Most of the water is reabsorbed in the proximal tubules. In humans this amounts to about 85 percent with another 5-10 percent being reabsorbed in the distal tubules. The amount reabsorbed there is regulated by antidiuretic hormone, ADH, and depends of the level of hydration. If an animal is suffering from water deprivation, the kidneys, by the action of ADH, can excrete all of the necessary substances and still maintain body homeostasis with a urine output of one pint per day, LeGrau, [10, p. 140].

The hairpin loop originates abruptly at the end of a short straight segment of the convoluted tubule. It consists of a thick descending limb, a thin descending limb, a thin ascending limb, and a thick ascending limb. The thick descending limb is similar to the last straight segment of the proximal tubule. The thin segments are found only in long loops which dip down into the medulla. Short loops remain in the cortex or dip slightly into the medulla, whereas long loops dip to varying degrees into the medulla. The number of loops is successively lessened from the medulla-cortex border to the papillae, which establishes the wedge formation. The loop has a very narrow lumen with nearly impermeable squamous cells as a border. The cells in the descending thin loops have a low permeability to sodium and chloride, a moderate permeability to urea, and a high permeability to water. No evidence for active transport has been found. The ascending thin segment is very impermeable to water, but highly permeable to sodium and chloride, and moderately permeable to urea. The thick ascending limb is the diluting limb. Sodium and chloride are reabsorbed both actively and passively and trapped within the medullary interstitium while water remains trapped within the tubule to be carried into the distal tubule located in the cortex. By enzyme action, these cells are sensitive to dietary load of protein, salt, and water. They are also sensitive to ADH levels which can be modified by diet, disease, or hormone addition. The end portion of the ascending thick limb passes very close to the junction of the afferent and efferent vessels of the glomerulus. Here, the cells become specialized *macula densa* cells. The basal portion of these cells extend between the arterioles. These cells manufacture renin in response to changes in blood pressure, salt load, tubular feedback, or nerve stimulation.

It is the hairpin relationship of the loop with its accompanying capillary bed which accounts for the countercurrent mechanism. Unique arterioles known as the *vasa recta* travel downward along the ascending loop and the venous drainage travels upward along the descending loop, creating a mechanism for the transport of ions from the ascending limb to the descending limb, which in turn draws water out of the collecting tubules, thus concentrating the urine. In order to work efficiently, the hairpin arrangement and a continuous flow of solute are essential. An

osmotic gradient is established from the cortex to the medulla. The solute filtered through the glomerulus is returned to the proximal tubules in such a way that the concentration of individual ions is changed; yet the solution has the same osmolality as the plasma. This holds true for the distal tubules as well. Because of the countercurrent mechanism surrounding the loop, the osmolality increases toward and into the medulla. The design of the capillary bed in the medulla slows down blood flow and helps maintain the gradient. It is based on the active reabsorption of sodium from the ascending limb. Sodium reenters the descending limb or is added to the plasma. Water is drawn out of the collecting tubule, causing the urine to become more concentrated. The presence of urea, a noncharged solute, aids in establishing an osmolar balance while preserving ions for the body. Urea and sodium cycles are established in the loop, which cause the urine to have a high concentration of urea rather than sodium.

In the distal tubule the cells change abruptly to taller cells with extensive basolateral surfaces and no brush border. As the distal tubule runs in close proximity to the renal corpuscle of its origin, the cells of the wall become narrow with nuclei that are close together. This has given rise to the name *macula densa*. ATP-ase is present and sodium and chloride are transported against a strong electro-chemical gradient. These cells respond readily to ADH levels. The distal tubule empties into the collecting duct. The water reabsorption in these cells can range from almost none to very much, depending on the level of ADH. Dilute urine can be formed if ADH is not present, and the permeability of the cells in the collecting duct to water is low. If ADH is present, the permeability to water is increased. Further water reabsorption takes place as the filtrate passes through the hypertonic environment of the medulla.

Secretion is the process of removing substances from the cellular interstitium or the capillaries and adding it to the urinary solution, or in other words, transport of solutes in the opposite direction from reabsorption. It occurs in the proximal and distal tubules. Various organic acids and bases, hydrogen and potassium ions, and complex chemicals such as penicillin are regulated in this manner. The distal tubule and collecting duct are the sites for most potassium and hydrogen secretion. The secretion of hydrogen ion is an important regulatory device in humans, since acid-containing foods are prevalent in the diet. Removing hydrogen in this way helps prevent acidosis. Sodium and potassium transport are closely related because the electric potential of the tubules depends on sodium reabsorption. Under conditions of low dietary sodium, the potential for potassium secretion are increased as the amount of sodium is reabsorbed. The same holds true for the secretion of hydrogen. In this manner, homeostasis much more efficiently maintained in a diverse number of metabolic states.

REGULATION OF FUNCTION

The regulatory mechanism of the kidney is incredible. Blood flow through the kidney and the glomerular filter is autoregulatory. At the vascular pole of the renal corpuscle, where the afferent and efferent vessels emerge, the specialized *macula densa* cells of the distal tubule and a unique extraglomerular mesangium are in very close approximation. Renin, a powerful hormone is formed in the *macula densa*. The excretion of renin is controlled by sodium levels in the blood, blood pressure, and the stimulation of sympathetic nerves. Renin affects the entire body by causing vasoconstriction, aldosterone release, and ADH release from the pituitary. Aldosterone enhances distal tubular reabsorption of sodium, and ADH increases the permeability of the collecting duct to water and stimulates thirst. All of this creates a coordinated response to increase extracellular volume and elevate blood pressure. The peritubular network is also a stabilizing arrangement for pressure within the glomerulus. Both the afferent and the efferent vessels moderate pressure and flow within the glomerulus by exerting opposite effects of the glomerular pressure. An increase in resistance of the afferent vessel reduces pressure to the glomerulus while an increase in pressure of the efferent vessel increases pressure. The end result is that the pressure tends to be stable regardless of changes in central blood pressure. The pressure in the efferent vessel is also a regulatory mechanism on the flow and pressure within the peritubular vessels. Increasing efferent pressure decreases peritubular pressure and enhances reabsorption.

Integration of function is also an important regulatory mechanism. Each segment of the individual nephron is integrated with the other segments. Each tubule segment responds differently from every other segment to the fluid composition within them. Changes in fluid volume and composition affect the operation of other segments. The slow steady flow of fluid to the collecting duct enables the final small adjustments in urine concentration. Regional integration exists because the nephron is folded back upon itself. This enables coupling between segments not in direct contact with each other. In this way, the excretion of water and solutes are controlled independently of each other. This creates a steady state excretion of solutes despite large differences in water retention.

CONCLUSION

The kidney is indeed an incredible structure showing tremendous integration and complexity. From a very superficial examination to a detailed analysis, this design and complexity can be seen. Biologists who study this organ use highly sophisticated equipment and technology. Intelligence is necessary in order to use this equipment and technology, and to interpret findings. There are still areas of dispute in understanding and interpreting kidney function. The study of this organ continues and, as our knowledge increases, modifications in interpretation are

made. Even though we are coming closer to being able to describe the organ in chemical terms, we still need to grapple with the question of how it came about in the first place. So far no one has been able to make an artificial kidney which is as efficient in function and use of space as the natural kidney.

Replacement of kidney function is an important medical consideration. People with failing kidneys must be provided with a system of plasma purification or life cannot be sustained. At the present time two methods are available to perform this service. The most prevalent one is peritoneal dialysis. The patient can be treated at home with a maximum of ambulation. This method consists of establishing two fistulas in the abdominal wall. One is used to introduce a special solution which uses the intestinal and mesenteric vessels to effect an exchange of solutes. The second provides drainage of waste solution. The peritoneal vessels are extensive and well adapted for absorption; but a limiting factor is their design. The dynamics of the kidney vessels is lacking. Autoregulation is not present either, so the patient must be monitored by his physician so that changes can be made as needed. The patient must be able to tolerate and utilize the extra fluids introduced into the abdomen. Occasionally, the fistulae will rupture, creating leakage and herniation which necessitate further intervention. The second method is hemodialysis, which must be performed with special equipment in a medical facility. Of necessity, the patient must be recumbent for this procedure. Both peritoneal dialysis and hemodialysis are inefficient and expensive. Fluid introduced into the body must be warmed to body temperature. Individual differences in metabolism must be considered. Problems can arise in creating abnormal extracellular fluid composition which must be corrected according to each patient's needs. Other problems involve the introduction of foreign substances from an external source into the closed system of the body, because both methods involve penetrating the body with needles and tubes. Changes in the structure of the blood vessels involved in the procedures create problems with absorption and exchange of solutes. Both of these methods utilize a simple filtration mechanism with solute exchange proceeding along a concentration gradient. Both require massive amounts of equipment or special solutions. Both of these methods have involved a great deal of super intelligence by human bio-engineers using extravagant intelligence-directed methods and equipment. Both of these methods involve design by human engineers who have been trying to perfect their design for several decades. No one has come up with a unit which compares with the natural kidney; yet scientists are justifiably proud of the advances they have made. How much greater is the design of the biological unit? How much more likely to have been created by the Master Designer?

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