LOUIS BOLK INSTITUTE

Physiology

Organphysiology from a Phenomenological Point of View

Christina van Tellingen MD

BOLK'S COMPANIONS FOR THE STUDT OF MEDICINE

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LOUIS BOLK
INSTITUTE

BOLK'S COMPANIONS
FOR THE STUDY OF MEDICINE

Physiology

Organ Physiology from a Phenomenological Point of View

Christina van Tellingen MD

About the Author

Christina van Tellingen MD (1949) has been a general practitioner since 1982. She has educated medical students, physicians, and therapists in the United States, Canada, and Europe. She teaches medical students and physicians at the University of Witten/Herdecke, Germany. She is a member of the Medical Section of the School of Spiritual Science at the Goetheanum, Dornach, Switzerland.

About the Project

The project *Renewal of Medical Education* aims to produce Companions that demonstrate how the insights of current biomedical science can be broadened by using the Goethean phenomenological method. This method innovates current concepts and expands the understanding of biochemical, physiological, psychological, and morphological factors in living organisms and their development in time and space, and in health, illness, and therapy. The project is commissioned by the Kingfisher Foundation, which aspires the development, application, and publication of the Goethean phenomenological research method in the widest sense, to complement and innovate the accepted scientific view and research method.

BOLK'S COMPANIONS FOR THE STUDY OF MEDICINE complement current medical education, specifically disclosing human qualities in the fundamental biomedical sciences of today.

BOLK'S COMPANIONS FOR THE PRACTICE OF MEDICINE contribute to a scientific phenomenological basis for integrative medicine and integral psychiatry.

4. The Kidneys and Urogenital Tract

4.1. Introduction

The kidneys take in large quantities of blood, filter it, and then *reabsorb* most of the ultrafiltrate. A small part of the ultrafiltrate is excreted as waste in the urine. Some substances are actively secreted out of the plasma into the urine. The kidneys secrete hormones and are regulated by hormones.

We will consider the physiological morphology and embryology, blood supply, physiology, regulation, and function of the kidneys and urogenital tract to gain a view of their characteristic place in the organism.

4.2. Physiological Morphology

4.2.1. The Shape of the Kidneys and Urogenital Tract

The kidneys have a characteristic shape, which impresses itself on the surroundings. The caudal surface of the liver carries an imprint of the right kidney, the spleen from the left kidney.

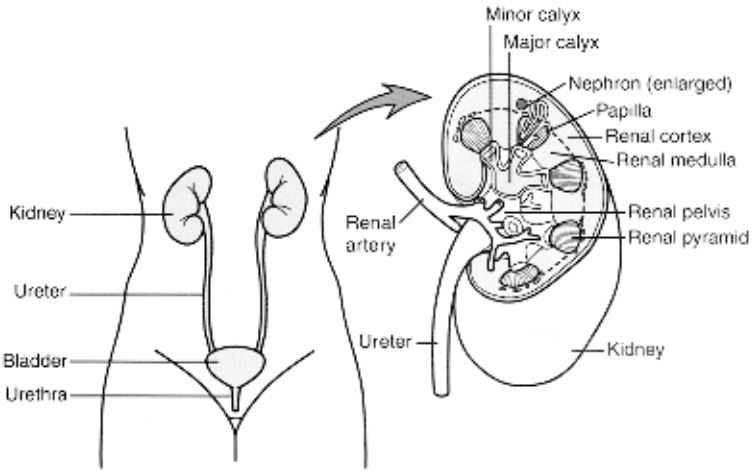

Fig. 4.1. The kidneys and urinary tract (from Guyton 2000)

The kidneys are parenchymatous organs. The

parenchyme is not uniform, but differentiated. Morphologically, two areas may be distinguished on the cut surface of the kidneys: the cortex and the medulla (fig. 4.1.). The outer layer is the cortex. The inner layer of medullar tissue surrounds the renal calyces, where the urine is collected to pass from there to the renal pelvis and then through the ureters to the bladder. From the bladder, unconscious reflexes and conscious relaxation of the bladder neck musculature allow the urine to pass through the urethra and be excreted. The urinary tract is a tube-like organ (fig. 4.1.).

The kidneys are paired and more or less symmetric, and are situated in the upper dorsal abdominal cavity. Liver, pancreas, gallbladder, stomach, and intestines, the prototypical digestive organs of the abdominal cavity, are neither paired nor at all symmetric. They also do not have the differentiation into a cortex and medulla. The adrenal glands, which are situated on top of the kidneys, are also paired organs and have a cortex and a medulla. The other symmetric abdominal organs with a cortex and medulla are the genital organs. The genital organs, like the kidneys, have a differentiated duct structure that allows excretion. Together with the kidneys and adrenals, the genital organs are not situated inside the peritoneum, which surrounds the prototypical digestive organs. The kidneys, adrenals, and genitals lie retroperitoneally, in contradistinction to most of the "typical" abdominal organs.

The clear differentiation of tissue into a cortex and a medulla that we see in kidneys, adrenal tissue, and ovaries and testes, is a characteristic feature of the brain. The brain and the organs of the head and nervous system are paired and/or display symmetry like the kidneys, adrenals, and genitals. In the heart and lung, both organs of the rhythmically active middle area of the body, we find a reminiscence of symmetry, but no differentiation of tissues into a cortex and a medulla. The phenomenon of symmetry is decreasingly present from cranial to caudal. Yet, we find paired, symmetric organs such as the kidneys and genitals in the abdominal region. This may raise questions as to how kidneys, adrenals, and genital organs got there (see section 4.2.3.).

➔ *The kidneys and adrenals (and genital organs) are more similar to the nervous system of the head in their shape than to the other abdominal*

organs. They are retroperitoneal, paired, symmetric organs and display a cortex and medulla in their parenchyme. The firm outer shape of the kidneys impresses itself on neighboring abdominal organs.

4.2.2. The Inner Structure of the Kidneys

The kidneys have a rather complicated and intricate inner structure (fig. 4.1. and 4.3.). The renal functional units, more than a million nephrons, are located partly in the cortex, partly in the medulla. The nephrons have four structural and functional parts. The *glomerulus* is the place where the filtration occurs to form the ultrafiltrate (180 L/day). The other three parts, the *proximal tubule*, *Henle's loop*, and the *distal tubule with collecting ducts*, mainly serve the reabsorption of constituents from the ultrafiltrate. The secretion of compounds from the plasma directly into the urine takes place in the tubules. Urinary output is approximately 1.5 L/day.

The Renal Cortex

The cortex is the place where the glomeruli are located. Glomeruli consist of a tuft of capillaries inside the bowl- or vessel-shaped end of the urinary tubules: Bowman's capsule. The filtration barrier between blood vessels and urinary tubules has three constituents:

- the capillary membrane with fenestrae (=holes, windows), similar to the sinusoidal pores or fenestrae in the liver
- the basement membrane with large spaces
- the podocytes of Bowman's capsule with large slits between them.

The filtration barrier allows the passage of small compounds, which includes water and electrolytes, and somewhat larger compounds such as glucose and urea. The negative charge of the proteins in the capillary membrane, the basement membrane, and the podocytes of Bowman's capsule repels compounds which are themselves also charged negatively. It prevents many proteins from passing the filtration barrier, even when they are small enough. The filtration barrier in the kidneys filters 100x more water and solutes than usual capillary membranes.

The juxtaglomerular apparatus is also situated in the cortex. It consists of:

- mesangial cells, which provide structural support, secrete extracellular matrix, and may act as phagocytes. The phagocytes indicate that the kidneys also have an interface with the world outside the organism
- granular cells, which produce renin, prostaglandins, and cytokines
- the macula densa, which registers changes in the NaCl concentration in the distal tubule.

The juxtaglomerular apparatus plays a major role in the auto-regulation of the blood flow to the kidneys (see also section 4.5.).

In the glomeruli an intricate passive filtration system has developed, as compared with the basic diffusion capability of the lungs. The juxtaglomerular apparatus in the cortex regulates blood flow to the kidneys.

The Medulla

Proximal tubules, Henle's loops, and distal tubules with collecting ducts are chiefly situated in the medulla.

The epithelium lining the renal tubules has specialized membrane proteins on the urinary side and/or the blood side that allow active transport of specific compounds in specific areas (see also section 4.4.). In the proximal tubules, $^2/_3$ of the filtered sodium and water is reabsorbed. In Henle's loop, the urine is concentrated and another $^1/_4$ of sodium and $^1/_6$ of water is reabsorbed. In the distal tubules and collecting ducts, the fine-tuning of the consistency of the urine and of the plasma is achieved. Secretion of substances from the plasma into the urine occurs in the proximal and distal tubules. These processes result in an inner structure of the medulla in which the fluid osmolality changes from the area close to the cortex to the area close to the renal calyces. The osmolality in the medulla increases fourfold from the cortex side (300 mOsm/L H_2O) towards the calyx (1200 mOsm/L H_2O) (see section 4.4.3).

In the highly specialized cells of the tubular system in the medulla of the kidneys, selective reabsorption takes place. This is more developed and has a reverse direction of the substrate stream as compared to the absorption in the intestines. A physiological differentiation of the medulla in the form of a fourfold increase in fluid osmolality is present.

➔ *The inner kidney parenchymatous structure has become more differentiated as compared to the liver. The differentiation is anatomical as well as actively physiological.*

4.2.3. Embryology

Pronephros

The kidneys are formed from intermediate mesoderm, which is dorsally situated, next to the developing nervous system. The first beginnings of the kidneys appear early in the 4th week of embryological development in the *cervical* region. The so-called pronephros obliterates after a few days, before it is ever functional as an excretory organ (fig. 4.2.).

Mesonephros

The next kidney system, the mesonephros, is formed in the area of the *thoracic* vertebrae. It includes glomeruli and excretory ducts, and may function for a brief period. The excretory ducts develop from

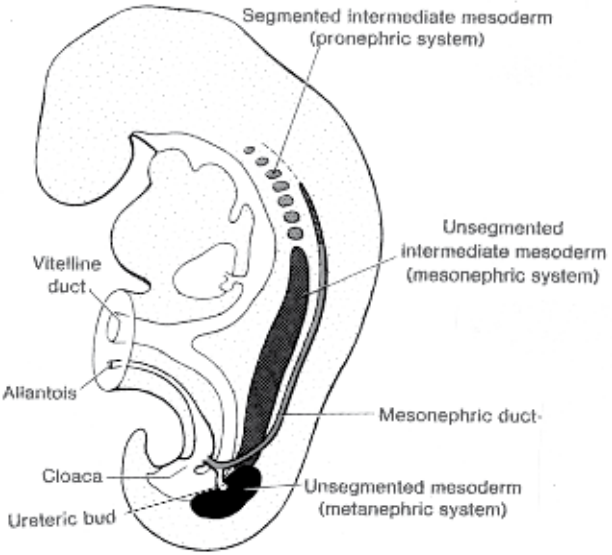

Fig. 4.2. Development of the kidneys in a 5 week old embryo (from Sadler 1995)

outgrowths of the intraembryonic coelom, which grow toward the developing glomeruli. The gonads develop directly medially to the mesonephros on either side of the body on the urogenital ridge. During the second month, the mesonephros also obliterates, except for some of its duct system. The Wolffian ducts persist in males to form some of the excretory system of the male genital tract. The Müllerian ducts form main components of the female genital system.

Metanephros

The third embryological kidney system is the metanephros, and it is permanent. It forms in the *lumbosacral* region of the intermediate mesoderm from the 5th week onward. It starts to develop when the ureteric buds, bilateral outgrowths from the mesonephric ducts, grow towards the metanephrogenic mesoderm, forming the renal pelvis, the calyces, and the collecting tubules. The ureteric buds *induce* the formation of the glomerulus, specifically Bowman's capsule, in the metanephrogenic mesoderm. The bowl- or vessel-shaped Bowman's capsule and a tuft of capillaries together develop into the glomerulus. The metanephros, or definitive kidney, becomes functional at the end of the first trimester.

This phylo- and ontogenetical "descent" of the urogenital tract is followed by an embryological "ascent", in which the kidneys move cranially from a low lumbosacral (pelvic) location to their final location, high up and dorsal in the abdominal cavity at the level of the lower thoracic vertebrae. Their retroperitoneal position indicates that they are not part of the "typical" abdominal organs.

The kidney and genital systems are originally (also phylogenetically) formed much more cranially than their final location in humans. A descent takes place, followed by a partial ascent of the kidneys. The ureteric buds actively induce the formation of glomeruli.

➔ *The cervical onto- and phylogenetic origin of the kidneys, adrenals, and genital systems close to the nervous system goes hand in hand with their similarity to the brain in structure and symmetry.*

4.3. Renal Blood Supply

The renal artery from the aorta supplies the kidneys with oxygen saturated blood. The blood flows through afferent arterioles to the glomeruli, and from there through efferent arterioles to the rest of the nephrons (fig. 4.3.). From there it collects in the venous system. Renal blood flow is 1100 ml/min, or 22% of cardiac output. The kidneys constitute only 0.4% of total body weight.

Renal blood flow is normally constant in spite of differences in arterial pressure between 90 and 180 mm Hg. This is the result of autoregulation by the juxtaglomerular apparatus and a pressure-sensitive, myogenic mechanism in the afferent arterioles. Different hormonal substances influence renal blood flow, such as epinephrine and angiotensin II.

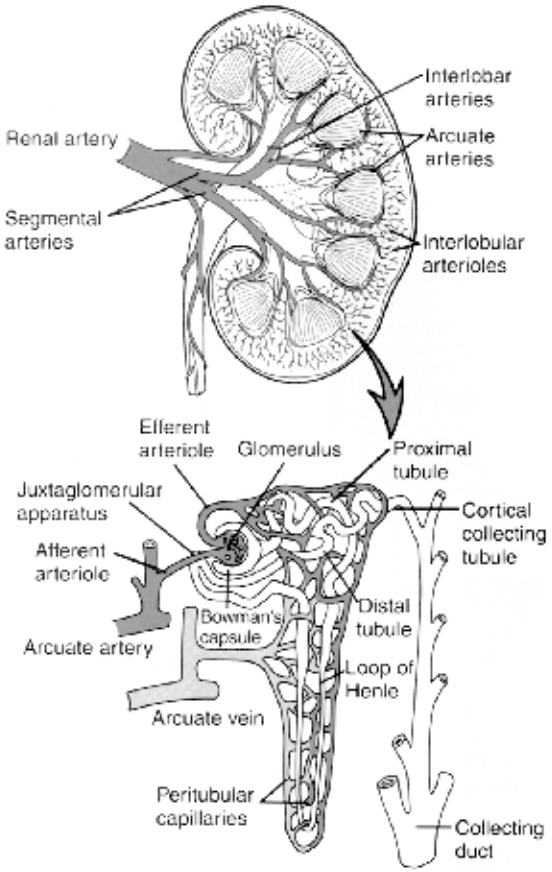

Fig. 4.3. The blood supply of the kidneys (from Guyton 2000)

➔ *The kidneys have the second greatest perfusion of blood in the body after the liver. They have a specialized arterial system, which forms afferent and efferent arterioles to and from the glomeruli. In contradistinction to the lungs and liver, blood supply to the kidneys is saturated with oxygen. Blood flow is regulated by autoregulation as well as by hormonal influences.*

4.4. Physiology of the Kidneys

Each tubular segment has various subsegments that differ anatomically and/or functionally from one another. The effect is that tubular fluid composition varies at different locations in the nephron. The resorption of every substance is linked in some way to the activity of the sodium-potassium ATPase system (see section 4.4.2.). The activity of active resorption consumes much ATP, which is supplied from metabolic energy. Therefore tubular activity requires a large supply of oxygen, which is provided by the blood in the efferent arterioles.

4.4.1. The Glomerulus

The blood is filtered in the glomerulus. The glomerular filtration rate follows renal blood flow, and is 20% of renal plasma flow or approximately 180 L/day. Most of this is obviously reabsorbed, since urine output averages 1.5 L/day. Resorption takes place in the tubular system. Ultrafiltration in the glomerulus happens under the influence of Starling forces, namely hydrostatic and oncotic pressure differences between the blood and the lumen of Bowman's capsule. Ultrafiltration is principally a *passive* process and does not take much energy. The oxygen from the oxygen-saturated blood in the afferent arterioles does not get used up and is available for physiological processes in the medulla.

Glomerular filtration is a passive process.

4.4.2. The Proximal Tubule

Resorption

- Sodium, bicarbonate, chloride, and water:
  In the proximal tubule, Henle's loop, and the distal tubule, 99.5% of Na^+ is resorbed, mainly through the action of sodium-potassium ATPase, an enzyme in the basolateral membrane of tubular cells. This is an *active* transport mechanism, which is accompanied

by the *passive* movement of other compounds such as $HCO3^-$, Cl^-, and water. Sodium and water are the two substances that are resorbed most abundantly in the tubular system. Almost all of the sodium is resorbed *actively*, all of the water is resorbed *passively*. The hormone angiotensin II stimulates Na^+ resorption, dopamine release from the local dopaminergic nerves inhibits Na^+ resorption in the proximal tubules.

- Albumin:
  The ultrafiltrate contains 7 grams of albumin/day (out of 50,000 g/day that pass through the glomeruli), which is *actively* reabsorbed in the proximal tubule, almost none is excreted with the urine.
- Glucose:
  Glucose is normally completely reabsorbed in the proximal tubule. An *active* transporter brings it into the cell, it leaves the cell passively to enter the blood again.
- Lactate and inorganic phosphate:
  Lactate and inorganic phosphate are also *actively* resorbed in the proximal tubules. Most of these resorption mechanisms are co-transport systems with Na+.

Secretion

Organic end products of metabolism and exogenous organic compounds, such as drugs and pollutants that were not filtered, are selectively secreted from the plasma into the urine in the proximal tubule. This is an *active* process.

In the proximal tubules the active resorption of sodium allows many other substrates to be resorbed in co-transport systems or to diffuse passively. Sodium resorption is actively regulated through hormones here. There is some active secretion.

4.4.3. Henle's Loop

The Countercurrent Mechanism

Henle's loop may span the whole depth of the medulla. Here the urine is concentrated by an ingenious countercurrent mechanism (fig. 4.4.). This may concentrate the urine from the normal plasma osmolality of 300 mOsm/L in the area close to the cortex, fourfold to 1200 mOsm/L in the medullar area close to the calyces. This is coupled with the fact that the ascending limb of Henle's loop is impermeable to water, and sodium and potassium can be further *actively* resorbed, along with *passive* diffusion of other solutes such as calcium and magnesium. This may effectively decrease the concentration of the filtrate to 100 mOsm/L. *The intricate structure of Henle's loop allows for regulation of the concentration of the urine.*

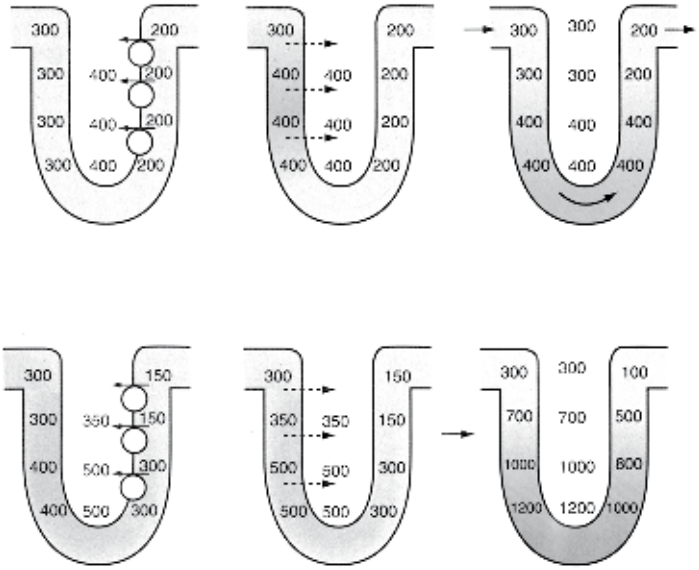

Fig. 4.4. The principle mechanisms of the countercurrent multiplier system in Henle's loop (from Guyton 2000)

Urea

The concentrating ability of the urinary system is highly enhanced by the presence of urea in the ultrafiltrate. Urea contributes about 40% of the osmolality of the medulla (fig. 4.5.). Urea is *passively* reabsorbed, mostly in the collecting ducts. The thick ascending limb of Henle's loop and the distal tubule are impermeable to urea, whilst the collecting ducts are quite permeable for urea and the thin descending and ascending limb sections are somewhat permeable to it. The subsequent high concentration of urea in the medulla allows for its recirculation and high urea concentrations in the urine. Consequently,

individuals on a high-protein diet have a greater ability to concentrate their urine.

The concentrating ability in Henle's loop is achieved by differentiated permeability to various substances, especially water and urea. The osmolality of the medulla, and consequently the concentrating ability of the kidneys, is dependent on the concentrations of sodium and urea.

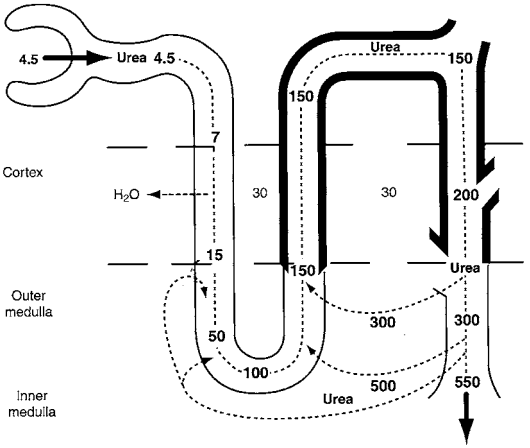

Fig. 4.5. Urea recirculation contributes to the osmolality of the medulla and the urea concentration in the urine (from Guyton 2000)

4.4.4. Distal Tubules and Collecting Ducts

Hormonal Regulation

The resorptive capacity is more limited in the distal and collection ducts, but a fine-tuning of the urine concentration and composition can be achieved here with the help of hormonal regulation, which is specifically *active* in this area. Different hormones regulate sodium reabsorption, including adrenal aldosterone and atrial natriuretic peptide from the heart. Hypothalamic antidiuretic hormone (ADH) is the major factor in regulating water resorption in the distal tubules and collecting ducts. The concentrating capacity of Henle's loop is indirectly influenced by the action of ADH on the distal tubules and collecting ducts, since it determines the amount of water resorption into the medullary interstitium. Sodium and water resorption mechanisms regulate the extracellular volume of the organism. Quantitatively, the selective reabsorption of substances is the major activity of the kidneys that uses up most of the oxygen in the efferent arterioles.

Hormonal regulation in the distal tubules and collecting ducts achieves fine-tuning of the consistency of the urine and blood plasma.

4.4.5. Acid-Base Balance

The kidneys also play a major role in maintaining the acid-base balance in extracellular fluids. The acid-base balance is maintained with the help of extensive buffer systems. The most important buffer is the CO_2/HCO_3^- (bicarbonate)-system.

Plasma buffer systems react immediately, for instance to a lowering of the pH, but do not have the ability to get rid of excess hydrogen ions. The *lungs* can excrete CO_2 to influence a return of the pH to normal. The respiratory response is just a bit slower than the immediate response of the buffer systems, and only partial, since it cannot return the pH to normal when the cause of the acid-base imbalance lies outside the respiratory tract (effectiveness is 50-75%). The *kidneys* respond most slowly, over days by supplying extra buffering capacity to the plasma and excreting H^+ ions, but are 100% effective. Thus the kidney system is by far the most powerful regulator of the pH of the blood in chronic acid-base imbalances.

HCO_3^- formation in the kidneys is stimulated by the enzyme *carbonic anhydrase*, and occurs when there is excess CO_2 in the circulating blood (fig. 4.6.). With the excretion of an H^+ ion to the urine, an HCO_3^- ion is added to the plasma, increasing its buffering capacity. The H^+ is added to ammonia and excreted as $NH4^+$ in the urine (the ammonia buffer system). This is the most important route for excreting excess acid. An increase in plasma H^+ stimulates the renal metabolism of glutamine to release NH_3.

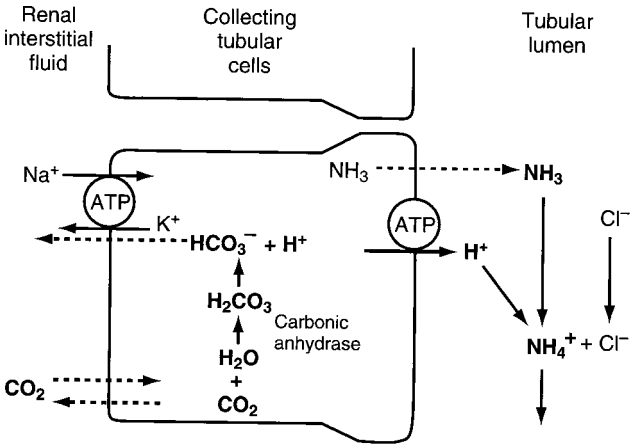

Fig. 4.6. The buffering of hydrogen ions by the bicarbonate buffer system in the collecting duct cell and ammonia io the urine. For each hydrogen ion in the urine a bicarbonate molecule enters the plasma (from Guyton 2000)

The pH of the blood is maintained primarily by the activity of the kidneys, with the help of the release of ammonia from amino acid breakdown and, through the same process and at the same time, HCO_3^- is added to the plasma for extra buffering capacity. The regulation of the pH of the blood is strongly dependent on the production of ammonia.

➔ *Kidney physiology consists of both active and passive processes. These regulate the extracellular volume of the organism and the pH of the blood. Kidney physiology is closely connected to the metabolism of proteins and amino acids.*

4.5. Regulatory Activity in the Kidneys and Adrenals

4.5.1. Regulation of Kidney Activity

Autoregulation in the Kidneys and Sympathetic Control

Renal blood flow is not normally regulated by arterial blood pressure but through the *activity* of various local and systemic hormones. Yet an acute increase in blood pressure of 30-50 mm Hg will increase sodium excretion 2-3 times by means of the phenomena of *pressure diuresis* and *pressure natriuresis*. These two processes are key to the kidneys' regulatory function in regard to body fluid volume and arterial pressure. This basic regulatory mechanism, which is also present in some of the lowest of vertebrates, is expanded in the human organism to include hormonal control for greater precision.

The *juxtaglomerular apparatus* plays a major role in basic regulation of kidney activity. It *perceives* kidney functioning through the macula densa, which registers changes in the NaCl concentration in the distal tubule, and effects *auto-regulation* of the blood flow to the kidneys through the hormones produced in its granular cells: renin, prostaglandins, and cytokines.

The blood vessels in the kidneys have a rich innervation by sympathetic autonomic nerve fibers. They only play a role in regulating kidney activity for a brief period following severe,

acute disturbances such as ischemia of the brain or severe hemorrhage. The sympathetic nerves in the kidneys secrete dopamine as well as norepinephrine. Norepinephrine release from sympathetic nerves stimulates NaCl and water reabsorption; dopamine from dopaminergic nerves has the opposite effect and inhibits NaCl and water resorption.

Hormonal and Enzymatic Control in the Kidneys

- The renin-angiotensin system:
  An especially powerful mechanism is the renin-angiotensin system (fig. 4.7.). A fall in arterial pressure causes the release of renin from the juxtaglomerular cells. Renin is an enzyme that acts on a liver produced substance, angiotensinogen, and splits off the

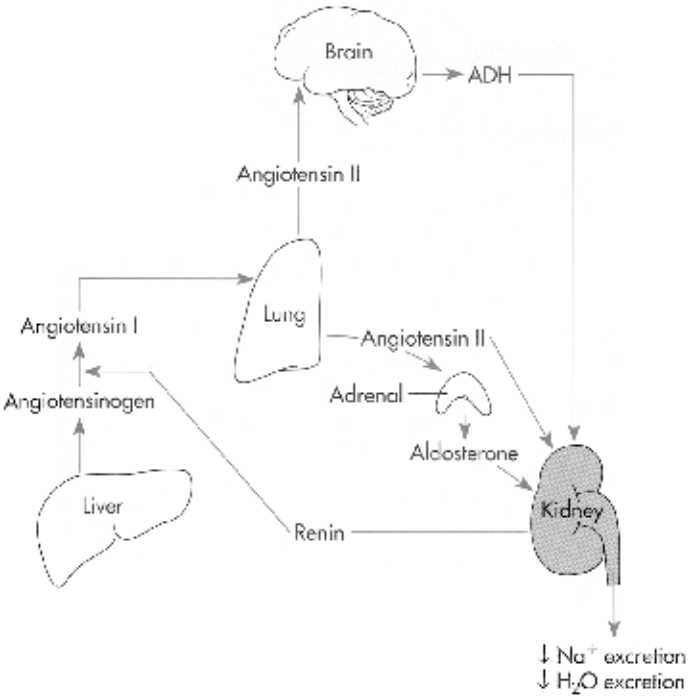

Fig. 4.7. The renin-angiotensin-aldosterone system (from Berne 1998)

decapeptide angiotensin I. In the endothelium of mainly the lung capillaries, angiotensin I is converted to the octapeptide angiotensin II by the angiotensin converting enzyme (ACE) that is present there. Angiotensin II acts on the proximal tubules, increasing the resorption of salt and water, as well as having a direct powerful vasoconstrictive effect on the arterioles. Both mechanisms act to increase arterial pressure back to normal. Conversely, an increase in sodium intake in the diet will lower the level of renin secretion and thus of angiotensin II, which will effect a decrease of the sodium and water reabsorption and a subsequent increased sodium loss through the urine.

- Aldosterone:
  Angiotensin II also stimulates the release of aldosterone from the glomerulosa cells of the adrenal cortex (fig. 4.7.). Aldosterone is a powerful stimulator of NaCl reabsorption in the thick ascending limb of Henle's loop, the distal tubules, and the collecting ducts.
- Atrial natriuretic peptide (ANP):
  Atrial natriuretic hormone is secreted by the cardiac atria. A rise in blood pressure and an increase in effective circulating volume stimulate its secretion by stretching the atrium. It enhances the excretion of NaCl and water in the collecting ducts, and thus has an opposite effect from angiotensin II and aldosterone.
- Antidiuretic hormone (ADH):
  Antidiuretic hormone is the only major hormone that directly influences the amount of water that is excreted by the kidneys. It is produced in neuroendocrine cells in the hypothalamus, and a stimulus from osmoreceptors in the hypothalamus effects their release by the posterior pituitary. The osmoreceptors act in response to an increase in the osmolality of the plasma or a decrease in effective circulating volume.
- Carbonic anhydrase:
  The passive buffer system for maintaining the acid/base balance is activated by the enzyme carbonic anhydrase (fig. 4.6.).
- Erythropoietin:
  Erythropoietin stimulates red blood cell formation. The kidneys produce 90% of circulating erythropoietin, the other 10% comes mainly from the liver. Hypoxia is the principal factor stimulating erythropoietin production. When the kidneys are dysfunctional or absent, patients will be anemic.

Regulation of volume control by the kidneys is basically internal and is fine-tuned by hormones that arise in the kidneys and adrenals, or come from outside, like angiotensin II, ADH, and ANP. The pH is regulated by the local enzyme carbonic anhydrase. Erythropoietin stimulates erythropoiesis.

4.5.2. Adrenal Hormones

In the adrenal cortex, the corticosteroids are produced, including the mineralocorticosteroids, cortisone, and sex hormones. In the adrenal medulla, epinephrine is produced. These hormones have a regulating function, not only with regard to the kidneys and genital tract, but also for many vegetative functions in the body such as are influenced by the vegetative nervous system. The adrenal hormones cortisone and epinephrine help us deal with stress. Embryologically, the cells of the adrenal medulla originate in neural crest cells. Hormones from the pituitary gland of the central nervous system (ACTH and the gonadotropic hormones) stimulate cortisone and sex hormone production in the adrenal cortex.

The adrenal hormones regulate the functions of organs in the abdomen that are morphologically related to the adrenal gland (section 4.2.1.), such as kidneys and genitals. They also influence vegetative nervous system functions in the whole organism, and are regulated in part by hormones from the pituitary gland in the central nervous system.

➔ *Regulation of kidney activity is both internal and through hormones, which come from outside. The kidneys also produce hormones that affect related activities and erythropoiesis. The adrenal hormones regulate the activity of the kidneys and genitals and are related to nervous system functions.*

4.6. Kidney Function in the Organism

The function of the kidneys is to *actively* contribute to homeostasis in the organism by regulating the effective circulating volume and its osmolality as well as the pH of the extracellular fluids. The kidneys have an *active* auto-regulation system in the tubulo-glomerular feedback system to effectuate this, as well as an extensive hormonal control system that fine-tunes the volume and osmolality of the plasma, and an extensive buffer production system to regulate the plasma pH.

➔ *Kidney function in the organism is characteristically active, and is influenced through hormones partly from inside, partly from outside the kidney system.*

4.7. Conclusion

- Morphology:
  The kidneys have their *own strong form*. Their differentiated inner structure (cortex and medulla), as well as their pairedness and symmetry, reminds us of the structure of the brain. This becomes understandable from their phylo- and ontogenetic origin in the cervical region.
- Blood supply:
  Blood supply to the kidneys is *abundant and saturated with oxygen* to support their activity of reabsorption in the tubular part of the nephrons. The kidneys have a *unique arterial supply* in the afferent and efferent arterioles of the glomerulus.
- Physiology:
  Glomerular filtration is a *passive* process. The *active* tubular reabsorption processes are centered around sodium, water, and urea. Protein metabolism plays an important role in kidney physiology.
- Regulation:
  A broad scale of *active* regulating mechanisms is available to effect kidney activity. Plasma volume control is effectuated through regulation of sodium and water

	Lung + Respiratory Tract	Liver + Intestinal Tract	Kidneys + Urogenital Tract	Heart
Morphology	Shape from without, tubular organ, **membranous structure**	Mostly shaped from without, uniform parenchyme, tubular organs	Own active form, differentiated parenchyme with cortex and medulla, tubular parts specialized	
Blood supply	50% of *weight* is blood, largely O_2 unsaturated, capillary blood in thin film	Largest *flow*, special *venous portal system*, 1/4 is O_2 saturated, 3/4 has low O_2 saturation, capillary blood in thin layer	Second largest flow, *unique arterial system*, high O_2 saturation, capillaries in tufts	
Physiology	Passive diffusion	**Great activity in metabolic cycles**	Both active and passive processes	
Regulation	Mainly from without, via the central nervous system	Both through local hormones and local autonomic plexuses, some via central nervous system	Both local and external hormones and buffering processes, kidneys secrete regulatory hormones for functions in organism	
Function	Passively supplying	Passively supplying, maintaining, and storing	**Actively regulating the internal milieu of the organism**	
Characteristic	Membrane-like tubular structure, *diffusion of gases* (O_2 and CO_2) and water	Physiologically active in metabolic cycles, diffusion and *absorption of fluid nutrients* in tubular part	Active regulatory function in the organism, diffusion and *resorption of blood constituents* in tubular parts	

reabsorption by the combined action of brain, liver, lung, and heart with the kidneys. Acid-base balance in plasma is regulated through enzymatic activity.

- Function:
  Kidney function is characteristically *active in regulating* volume, osmolality and pH of the extracellular fluid. Hormones fine-tune the regulatory activity of the kidneys.

➔ *The kidneys are active in their morphology, physiology, and function. Morphology and physiology are supportive of kidney function. Most characteristic of the kidneys is their active, hormone regulated function. The tubular functions are highly specialized as compared to the functions of the respiratory tubular-shaped areas and the tubular shaped intestines. The kidney parenchyme is differentiated as compared to the homogenous liver parenchyme. The capillaries in the kidneys form tufts.*

Physiology

Organphysiology from a Phenomenological Point of View

Can physiology give more insight into the living human organism than the mere facts reveal at first? Is the level of activity the same for all organs? Are the vital qualities at work in organs unique for organisms and limited to biological activity? Can we find a scientific basis to research the coherence between organ systems?

By enhancing the current scientific method with phenomenological points of view we can find meaning in the facts and understand them as an expression of life itself. The phenomenological method makes the relation between organs visible and comprehensible. It approaches scientific facts from the point of view of their coherence and can give totally new insights this way.

What emerges is a grasp of the interrelations between biological processes, consciousness, and nature.