9. THE URINARY SYSTEM

The urinary system comprises of an *excretory* part (the kidneys) and a *collecting* part (the *renal calyces* and *pelvis*, the *ureter* and the *bladder*) which ends up at the *urethra*, by which the urine is expelled during voiding (urination). The main function of the urinary system is to filter the blood, eliminate useless and excessive substances and regulate the water, electrolyte and acid-base equilibrium of the body. The kidneys, however, are more than "filters". They also actively control important functions of the human body, such as blood pressure regulation, erythropoeisis (production of red blood cells by the bone marrow) and Vitamin D activation.
The urinary tract is similar in both males and females, only down to the level of the urethra. In the male the urethra is longer, as it has to travel through the *prostate* and *penis* and is also shared by the genital system, where it conveys semen during ejaculation.

The kidneys

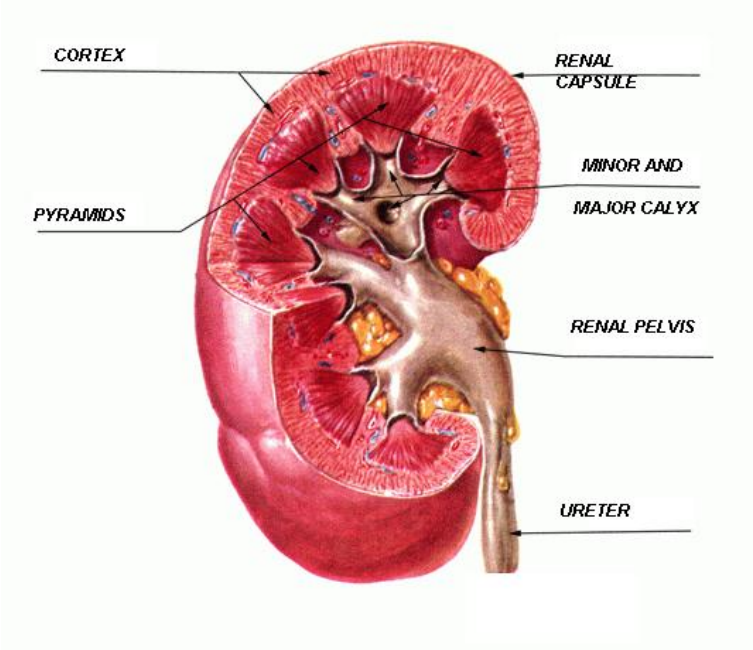
The kidneys are two bean-shaped organs, located on either side of the vertebral column in the abdominal cavity, behind the peritoneum (in the *retroperitoneal space*). They lie at the level of the 12th thoracic to the 3d lumbar vertebrae. The right kidney is situated lower (approx. ½ vertebra) than the left one, because of the position of the liver. The kidneys are approximately 12 cm long, 6-7 cm wide and 2.5-3 cm thick. At their concave, medial surface lies the hilum, the area where the renal pelvis and ureter exits and the renal vessels (artery and vein) enter and exit, respectively. The kidney is embedded in a thick layer of fat (adipose tissue) that surrounds the kidney. The outer part is called the **cortex** and contains capillary tufts and tubules. The inner part is the **medulla**, which comprises of several triangular masses called the **renal pyramids**, separated by the **renal columns**. The pyramids are 8-12 and contain bundles of **papillae**, that project into a membrane depression called the **minor calyx.** Several calyces together (usually 3) form a **major calyx**, that empties in the **renal *pelvis.*** From there, the collected urine will be actively transported (by a mechanism called *peristalsis* i.e. movement by a series of smooth muscle contractions) towards the *ureter* and the bladder.

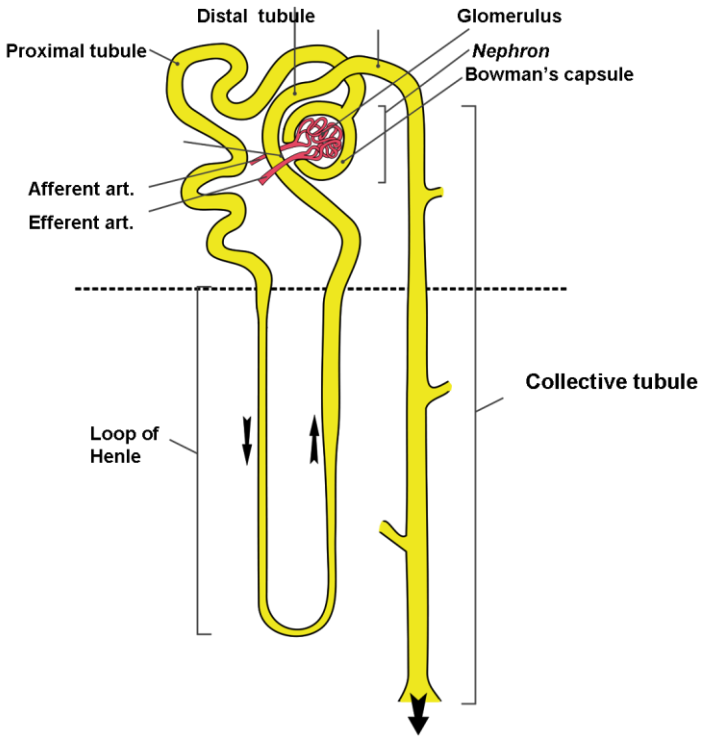
The kidneys are being held in place by a) the abdominal pressure, b) the surrounding fat and fibrous capsule and c) the vessels at the hilum. There are no strong holdings of the kidneys, so that they are allowed to move up and down eg during respiration.

Production of urine

The functional unit of the kidney is the **nephron**, a series of blood vessels and tubules that produce, regulate and expel urine to the papillae. Each kidney has more than 1 million nephrons. The components of the nephron are: 1) **glomerulus** capsule (**Bowman's capsule**), 2) **proximal convoluted tubule**, 3) **loop of Henle**, 4) **distal convoluted tubule** and 5) the **collecting duct**.

The **glomerulus** is a complex of looped, thin vessels (capillaries) embedded in the Bowman's capsule. The capillary endothelium has openings (fenestrations or pores, 50-100 nm in diameter) and is permeable. As blood comes through the glomerulus at high pressure, water, glucose, urea, electrolytes, minerals and other substances ooze into the glomerular space, between the 2 layers of the Bowman's capsule. This is called the **pre-urine** and is being produced in huge amounts (approx. 150 liters/day). As the pre-urine moves down the tubules, most of the water, glucose and electrolytes is reabsorbed, while waste products and unwanted substances are not reabsorbed or even actively secreted in the tubule. The end-result is a liquid that has been regulated for precious substances eg glucose or electrolytes,


CORTEX
RENAL CAPSULE
MINOR AND MAJOR CALYX
PYRAMIDS
RENAL PELVIS
URETER


Distal tubule
Glomerulus
Proximal tubule
Nephron
Bowman's capsule
Afferent art.
Efferent art.
Collective tubule
Loop of Henle

balanced for acid-base and concentrated for saving body water. This is the **urine** that enters the collecting ducts and gets expelled to the renal calyces and pelvis.

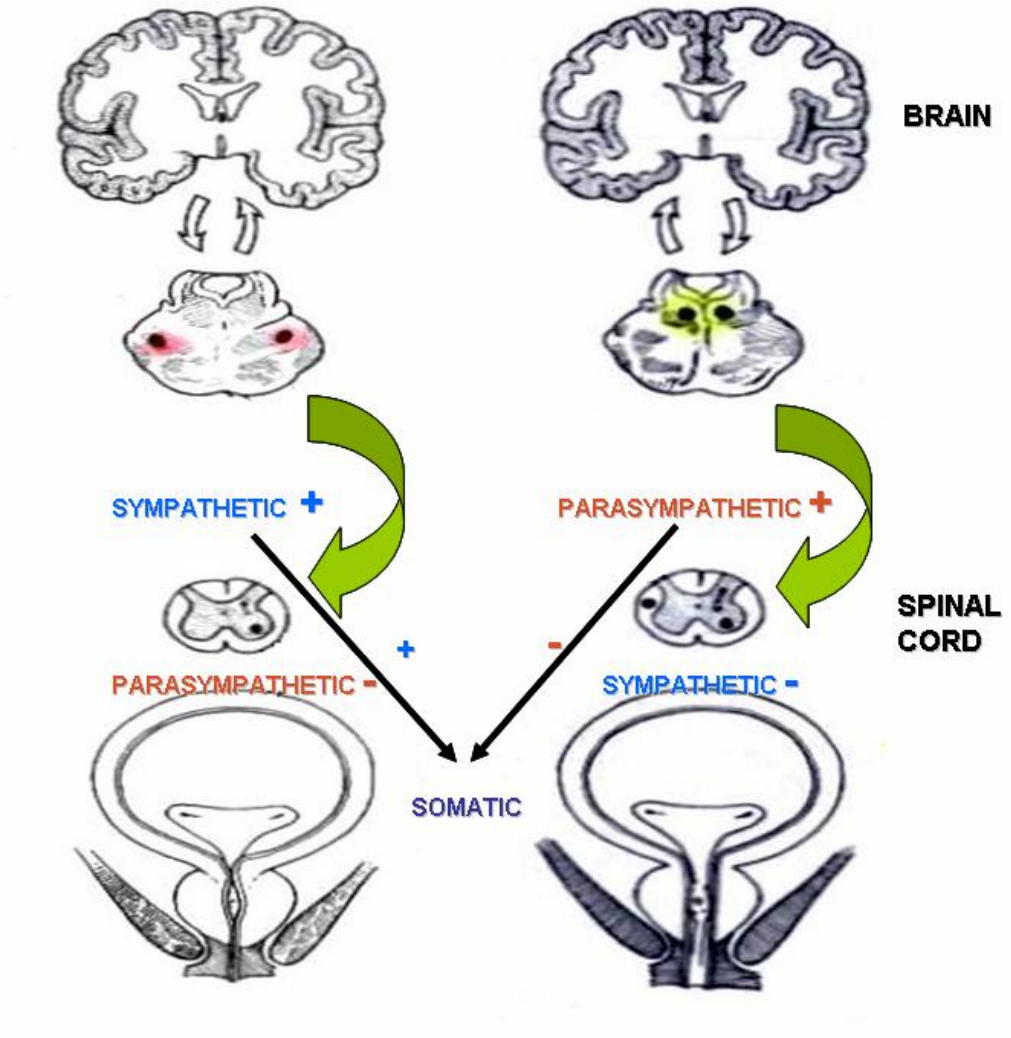
The ureter

The ureters are narrow, muscular tubes that convey urine to the urinary bladder by peristaltic waves. They are about 25 cm long and lie at the posterior abdominal wall and in the pelvis. They present 3 "natural" narrowings: 1) at the **ureteropelvic junction**, 2) as they cross **over the iliac vessels** at the entrance of the pelvis and 3) at the **ureterovesical junction**. Due to the peristaltic movements, the urine *flow is unidirectional* i.e. from the kidney towards the bladder only, even when we are lying in bed or stand upside down! The ureterovesical junction is also very important as it possesses a **double valve mechanism** that prevents back-flow of the urine that is in the bladder back to the ureter and the kidney. Children that are born with a defect in this valve mechanism may suffer from infections and renal damage due to **vesicoureteral reflux (VUR).**

Urinary stones (calculi) are solid concretions that form by precipitation of organic and / or inorganic salts. Causes for stone formation are numerous: dehydration, poor diet or excess consumption of certain foods, infection, urine stasis, endocrine complications etc. Stones usuallu are formed in the calyces or the renal pelvis. Occasionally, stones may pass in the ureter and obstruct the lumen, causing **colic**, a severe pain in the back (lumbar region) or the lower abdomen. *Stones usually get stuck at the narrowings of the ureter (see above).*

The urinary bladder

The bladder is a hollow, balloon-like organ that serves as a reservoir for urine. The wall of the bladder is comprised of muscle bundles (**detrusor muscle**) that are interwoven in a special way. The inner lining of the bladder is mucosa and it creates *folds* (**trabeculations**) as it covers the muscle bundles. The bladder has a *base* and a *dome*. The dome lifts up in the abdomen as the bladder fills with urine. The ureters enter the bladder from behind in an *oblique* route through the bladder muscle and their openings (**ureteral orifice**) form the two upper corners of a triangle (**trigone**), the lower corner lying at the **bladder outlet**, at the beginning of the **urethra**. Note that the trigone is *smooth*, with no trabeculations.
The bladder has a unique function: it can accommodate large amount of liquid (urine) without pressure increase. This function is called *compliance* and allows us to tolerate a near-full bladder without extreme pressure or pain. A normal bladder volume for an adult would be approx. 300-350 ml of urine. However, when the bladder is affected by a disease of the muscle wall or nerve trauma eg at the spinal cord, compliance is lost and we feel ***urgency*** to void, even with little urine amounts.
Nervous control of urination (voiding) is achieved by both **sympathetic** and **parasympathetic** innervation (the autonomic nervous system). The two systems must coordinate well for normal voiding. The bladder function has two parts: filling with urine **(storage phase)** and emptying the urine **(voiding phase).** During the *storage phase*, the bladder must accommodate as much urine as possible, without increase in pressure or leak of urine! Hence, the sympathetic system (L1-L2) relaxes the detrusor muscle by *inhibiting* the parasympathetic system (which contracts the muscle). Moreover, through stimulation of *somatic fibers* it ensures that the **sphincter** at the urethra will remain closed (**sphincter contraction**). On the other hand, during the *voiding phase* things happen in exactly the opposite manner: the sympathetic system (S1-S3) is stimulated and leads to *contraction* of the bladder muscle while the sphincter is relaxed (open) through inhibition of the somatic neurons.

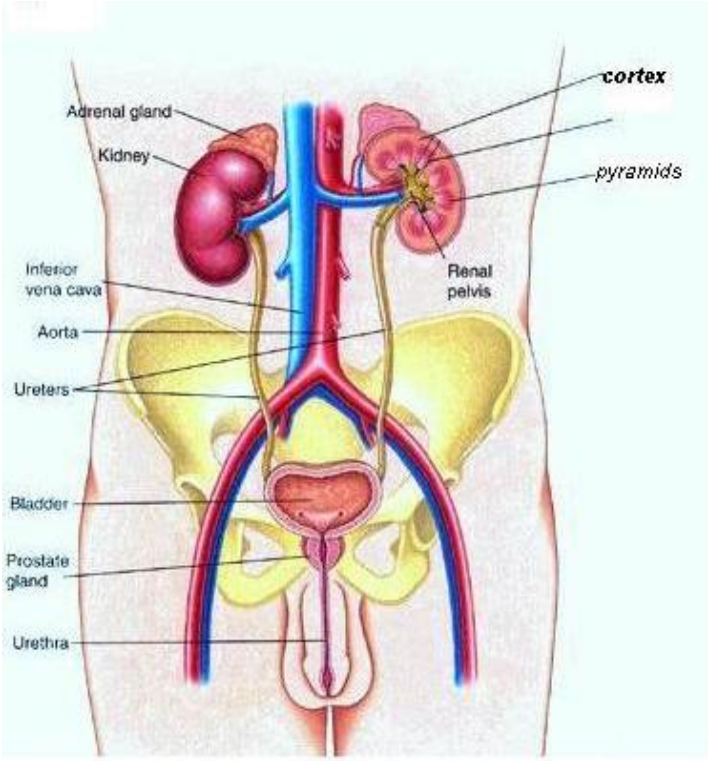

BRAIN
SYMPATHETIC +
PARASYMPATHETIC +
SPINAL CORD
+
-
PARASYMPATHETIC -
SYMPATHETIC -
SOMATIC

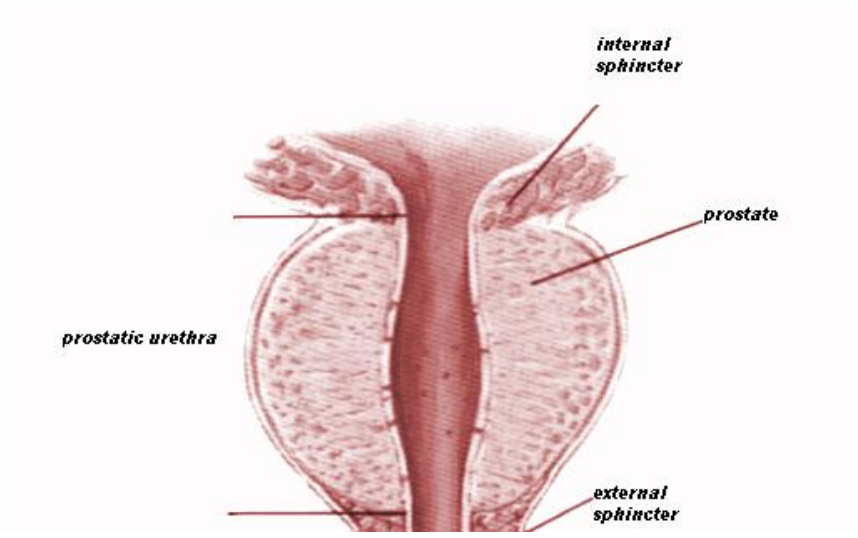
A simple way to understand and remember the nervous control of urination is to think of the “fight-or-flight” principle that goes with the sympathetic stimulation. If a person is about to fight he would surely not have time to urinate! The stress makes you forget that your bladder is full, because the sympathetic system inhibits the detrusor contraction and ensures that no urine will leak through your sphincter!! In a “relaxed” situation the opposite occurs.

The urethra

The urethra is a thin tube, lined by mucosa that conveys the urine out of the bladder. The **sphincter** mechanism of the urethra is responsible for holding the urine and consists of two elements: the smooth muscle sphincter (**internal sphincter**) and the striated, voluntary muscle (**external sphincter**). The female urethra is short (4-5cm) while the male urethra is longer and more complex as it is serving the reproductive system too.
The male urethra has 3 parts: 1) the prostatic, 2) the membranous and 3) the penile part, that travels at the lower surface of the penis. The **prostatic** urethra has a midline bulk, the **verumontanum**, where the openings of the two ejaculatory ducts are. The **membranous** part is the thin portion of the tube as it passes through the external sphincter of the urethra (the urogenital diaphragm). Finally, the anterior, **penile** part of the urethra up to the **external meatus** (the urethral opening) “hides” inside the penile shaft, protected by a spongy tissue that continues up to the **glans** (head of the penis). [See also:The reproductive System].

Urinary tract infections (UTIs) occur when microbes enter the urinary system, most likely through the urethra (ascending infection). In the female the first “station” will be the bladder (**cystitis**) and if the infected urine refluxes up to the kidneys it may become a **pyelonephritis**, a severe infection. In males the prostate is a common “stop” for the germs and **prostatitis** may develop. The shorter urethra explains the higher frequency of infections in females. Abundant liquid consumption and frequent voiding may prevent UTIs.


cortex
Adrenal gland
Kidney
pyramids
Inferior vena cava
Renal pelvis
Aorta
Ureters
Bladder
Prostate gland
Urethra


internal sphincter
prostate
prostatic urethra
external sphincter