**Slide 1**

When talking about the urinary system and its functions, we spend most of our time talking about the kidneys, the two organs that occupy much of the function and space within the body for the urinary system.

**Slide 2**

The kidney has a number of functions. First is the excretion of toxic, metabolic waste through urine production. The kidneys filter blood plasma, and as a result of filtering blood, the kidneys help eliminate toxic materials, drugs, and hormones from the body. In other areas of the body, we have ways to eliminate, for example, carbon dioxide, such as the respiratory system; or we have ways to eliminate other metabolic wastes in the digestive system, such as the secretion of bile. And in other ways, the sweat off of our skin can also help us eliminate certain products that are made inside. But there are many other metabolic wastes that don’t have another answer as to how the body can eliminate them on a regular basis, and so this is where the kidneys come in.

A second major function of the kidney is the regulation of blood volume and blood pressure. Blood volume and concentration is regulated by the amount of water that is pulled out and/or is put back into the blood, so the kidneys can help us manage our water levels. The urine that we produce from our kidneys is a result of pulling water out of the bloodstream. If our blood volume (in other words the quantity of blood that we have inside of our body) is deemed to be too great in terms of homeostasis, the kidneys have the ability to pull more water out of the blood and put it in the urine and ,thus, help lower blood volume back to acceptable levels. If we find that our blood volume amount (or the water in the blood) is too low, then the kidneys can adjust how much water they pull out of the blood to put in the urine, and they can choose to do less, allowing us to conserve more water in the body. So in this way, the kidneys help us regulate the actual volume of the blood in the body by determining how much urine, and how much water in that urine, there should be. The amount of blood in the body also relates to the pressure that that same amount of blood exerts on the blood vessels as it passes through them. So if blood pressure is also deemed to be higher than homeostatically-desired, the kidneys can be stimulated to pull more water out of the blood and put it in the urine and get it out of the body so that the blood pressure can go down. The less blood there is in the body, the less pressure it will exert on the blood vessel walls. In the same way, if blood pressure is too low, the kidneys can be stimulated to not take as much water out of the blood and put it into the urine so that blood pressure doesn’t drop. So in this case, as volume is conserved, the pressure can also respond and not drop as drastically.

A third important function of the kidney is the regulation of electrolytes and the pH levels within the blood. So back to the first function, this one is a description of getting rid of things that we have made within our bodies (metabolic wastes), finding an effective way to get them out of the body. In this case, electrolytes and the hydrogen ions (that contribute to pH levels), these are not necessarily things that we have made within ourselves; they’re just things that exist within the blood, and the kidneys are asked to help regulate that quantity as well. So this one is separated from the excretion function. Remember that electrolytes are substances that separate, when in water, into ions, and very often they resemble what we consider to be minerals, things such as potassium ions, sodium ions, calcium ions, things like that that have a charge to them when they are suspended in a fluid like water. So we take those in all the time with our food, we use them as we’ve seen in this class, and so sometimes the blood has too much of certain electrolytes, and it’s the kidneys’ job to determine that and help eliminate those excess electrolytes in the urine to keep us in balance. At the same time, we may find ourselves deficient in electrolytes, and the kidneys can be stimulated to not eliminate as much as they usually do, trying to conserve the quantity. In terms of pH, remember that’s a description and a measurement of how acidic or how basic a fluid is, and the acidity of a fluid is determined by the quantity of H+ ions that are freely suspended within it. We are constantly producing H+’s, and one of the concerns of the body is to deal with the blood pH and whose job is that? What if the H+ levels get high? The kidney can help with that by taking H+’s from the blood, distributing them to the urine, and then urinating them out of the body. So the kidneys also help us eliminate and manage our pH levels by managing the H+’s.

**Slide 3**

Now let’s take a look at the gross anatomy of the kidney. The kidney is a retroperitoneal paired organ, meaning that it is posterior to the peritoneum and that there are two of them. The gross anatomy of the kidney is composed of a few noticeable structures. First, the fibrous capsule. Th fibrous capsule is a cover made of fat and collagenous fibers that surrounds and contains the organ itself. It doesn’t serve a function in terms of the urinary system, of forming urine and filtering the blood, but like with many organs, it serves a job of binding and containing the organ and protecting it.

The second structure we talk about is the renal cortex. The renal cortex is the outer functional layer of the inside of the kidney. It contains nephrons, which are units that actually do the filtering of the blood, and when we go microscopically in a little bit, we’ll focus on those. The cortex also has extensions of itself that go deeper, further into the kidney called renal columns.

The third thing to mention about the kidney is the inner, functional layer of the kidney, referred to as the renal medulla. All of the triangular wedges that you see on the picture are collectively referred to as the layer of the kidney called the renal medulla; but when you are referring to one of those triangular-shaped wedges, on its own, we describe that structure as a renal pyramid. So on this picture we see 6 renal pyramids, and collectively, we refer to them as making up the tissue layer of the kidney known as the renal medulla.

At the tip of each of those pyramids you notice a small funnel-like structure called a minor calyx. Its job is to gather and collect the urine that’s being formed in and around each pyramid and direct it to a central source. So each pyramid has a funnel at its tip collecting the urine that’s being made in that area; that’s called a minor calyx. Sometimes, two or more neighboring minor calyces may fuse rather quickly to form an even larger funnel or tube; at that point, that new structure (even though it is brief) is called a major calyx. The renal pelvis is an enlarged chamber that comes about from all of the calyces fusing together and merging to form this large chamber called the renal pelvis. So ultimately, all of the urine formed within the pyramids and the cortex (all of the functional part) is being funneled into this common space called the renal pelvis. The renal pelvis then exits the kidney and narrows to become a tube called a ureter that will deliver the urine down the body (inferiorly) to have it stored in the urinary bladder.

The renal hilum is the folded-in, or concave, area of the kidney. It’s a little bit difficult to point to or to hold; it’s not a physical structure but a reference to a region of the kidney. We bring it up, because it’s the only part of the kidney where you see any tubes entering or exiting. You see the renal artery, renal vein, and the pelvis (those 3 tube-like structures) are all coming in or exiting in that bowed-in or concave part of the kidney. So sometimes we want to talk about that region, and we need a name for it, and that’s what the renal hilum refers to. You see the renal artery there in red on the picture. The renal artery is responsible for bringing blood to the kidney, not only to nourish the tissue of the kidney like with any other organ, but it’s also going to be passing through the kidney and being filtered and cleaned of metabolic wastes and excess electrolytes. The renal vein, shown in blue on this picture, represents the outflow of that blood as it leaves the kidney; that blood has delivered its oxygen and glucose to the kidney, but it’s also seen a lot of its waste material removed, so as it exits the kidney, the blood will have a lot less waste and fewer electrolytes in it to return to the body.

**Slide 4**

Now we turn our attention to the microscopic anatomy of the kidneys. Now we zoom in to the region where the cortex and medulla are, particularly where they come close to each other, and look at what we would find on a microscopic level deep in those tissues. What we will find is a functional unit of the kidneys called a nephron. There are about 1.2 million nephrons in each kidney. Each one is capable of filtering some of the blood and producing urine from it. When considering the entire nephron, we say that it consists of two areas: the renal corpuscle and the renal tubules.

The renal corpuscle is the beginning of the nephron, and it’s located in the cortex tissue of the kidney. Some of the features of it include an afferent arteriole, which is a larger blood vessel that is trying to bring blood needing to be filtered to the nephron; so blood is flowing toward a nephron in the afferent arteriole. A second part of the renal corpuscle is found at the end of the afferent arteriole where the blood then flows through a nest or a network of capillaries called the glomerulus. These capillaries have holes in them and allow some of the material in the blood that’s small enough to leak out of those holes and exit the bloodstream for the time being. Anything in the bloodstream that didn’t leave through those holes in those glomerular capillaries would then flow out of the glomerulus in a slightly smaller blood vessel called the efferent arteriole (‘e’ for ‘exit’). So one more time, the flow of blood through the corpuscle: blood needing to be filtered coming to the nephron in the afferent arteriole, that blood would then flow through a maze or network of capillaries that are leaky called the glomerulus (where some of the stuff in the blood that’s small enough will leak out), and any blood that’s remaining will exit through that maze or network of the glomerulus using the efferent arteriole. The last part of the renal corpuscle is the part of the nephron that allows you to do something with that material that leaked out of the glomerulus. This is called the glomerular capsule. It’s a series/collection of cells that cup and wrap around the glomerulus, containing and holding whatever it is that was able to leak out of those leaky capillaries of the glomerulus.

The process by which the material comes through the walls of the glomerular capillaries is called filtration, and the material that makes it through and is captured by the capsule (represented by the black arrows on this picture) is called glomerular filtrate.

Slide 5

The second part of the nephron is composed of a region called the renal tubules. These tubules further process that glomerular filtrate that came out of the capsule, and try to convert it slowly and efficiently into the substance you and I call urine. The renal tubules are located in both the cortex and medulla. So these long, extensive tiny tubes aren’t found just in the cortex like the corpuscle is; they’re found in both the cortex and the medulla.

The first part of the renal tubules is called the proximal convoluted tubule. This extends off of the glomerular capsule and looks like a big, twisted, curving tube. It’s made of simple cuboidal epithelial tissue and has microvilli facing in toward the filtrate as it flows through it. What happens here to the filtrate is primarily called tubular reabsorption. As the filtrate (as you follow the black arrows through the PCT) flows through this twisted tubule at the beginning of the renal tubules, we find that the body is trying to take back, or tubularly reabsorb, material that leaked out back at the glomerulus. It’s a time to effectively return things to the body that shouldn’t have left or left in too great of quantities.

The second segment is called the nephron loop. The nephron loop starts as a straightening of the tubule and makes a U-turn as it dips very deeply into the medulla in the pyramids. There are two limbs to the nephron loop. As the filtrate goes down the beginning of the nephron loop, that’s referred to as the descending limb, and as it turns the corner and goes back up the farther side of the loop, that’s called the ascending limb. As you look at the picture, you notice that the nephron loop has a thick segment to it and a thin segment. The thin segment tends to occupy the actual U-turn itself. The thick segment at the beginning and end that constitutes the majority of the descending and ascending limbs is made of simple cuboidal epithelial tissue. The thin segment of the loop is made of simple squamous epithelial tissue. The difference in cell types found in the limbs of the nephron loop is a result of their function. The cuboidal cells in the thick segment participate heavily in active transport and need a lot of mitochondria to produce ATP. The squamous cells in the thin segment are not as metabolically-active, but they allow for movement of water; they are highly permeable to water.

Once the tube has returned to the cortex, it becomes twisted again, though maybe not quite as much as it was at the beginning. At this point the term ‘nephron loop’ is over, and the continuation of this tube is called the distal convoluted tubule (DCT). The DCT is made of cuboidal epithelial tissue and does not have the microvilli that you see so prominently in the PCT. This represents the end of the nephron as it approaches a final large tube called the collecting duct. All nephrons contribute and dump the material they have processed into a neighborhood collecting duct. In this picture there are other nephrons that would be attaching to this collecting duct with their DCT’s as you see the multiple arrows pointing down coming from different tubes.

Finally, to explain (though you don’t see it on this picture) how the body is able to take back material, there would also be what are called peritubular capillaries that surround all of this nephron and its renal tubules, and they arise from the efferent arteriole. So the efferent arteriole isn’t the end of the blood story; it will curve around and branch into many capillaries that will tightly hug the renal tubules of the PCT, nephron loop, and DCT, and that will allow the blood to interact very intimately with the filtrate flowing slowly through these tubules to try to impact it, to try to change it, take things back, add additional things as needed.

SLIDE 6

The formation of urine is a 4-step process. Now that we’ve completed the anatomy discussion, we’re going to use that information to be able to talk about how we convert blood material into, ultimately, urine. The first step in this process is filtration (the glomerular filtration process). Glomerular filtrate is the term for the fluid that has been filtered from the blood plasma in the glomerulus and passes throughout the nephron. Fluid passes from the glomerulus, the capillaries in that nest, into the glomerular capsule via a barrier called the filtration membrane. The filtration membrane represents the physical barrier or difference between the fluid that is found in the blood stream and fluid that is outside of the bloodstream. The filtration membrane is made of three particular structures: the fenestrated endothelium of the capillary (the capillary with the holes in it), a shared basement membrane, and filtration slits formed by the cells in the glomerular capsule wall.

The fenestrated endothelium is honeycomb-shaped with large filtration pores like a colander. Particles in the blood are pushed out through those fenestrations by an increase in blood pressure. The increase in blood pressure is due to a dramatic decrease in vessel size as the blood reaches an afferent arteriole. As the blood comes to one of these nephrons and finds itself flowing through the afferent arteriole, the decrease in vessel size for that blood makes the pressure in that blood rise a fair amount. When it reaches the glomerulus, it finds itself in even smaller vessels (capillaries), and that’s the point: as the blood flows under high pressure through the glomerulus, it is easy to expect that the material in the blood could be pushed and forced through those holes of the capillary wall into the glomerular capsule. This restriction of size causes pressure to build up and moves particles through the filtration membrane. This is similar to putting your thumb over a garden hose to spray water. As we increase pressure, the force of that fluid gets greater and greater.

At this stage, the things that CAN get filtered out through those holes include water, electrolytes, glucose, fatty acids, amino acids, nitrogenous wastes, and vitamins. Those are all things that are small enough to be pushed and forced through those holes. Not all of those things do leak out into the capsule, just some of them do. Blood cells and plasma proteins generally are too large to ever pass through those holes in the walls, so we shouldn’t see blood components liked the formed elements or the cell-like material and proteins showing up in the filtrate unless something is wrong.

The glomerular filtration rate is the amount of filtrate formed in one minute of time by both kidneys. Healthcare providers can use someone’s glomerular filtration rate to help determine if their kidneys are working properly. About 99% of the filtrate that does form at this stage is going to be reabsorbed back into the blood, as we will see in just a little while. So even though we end up filtering a tremendous amount of blood, it only ends up amounting to about 1 to 2 liters of urine per day, because our body chooses to take back most of what leaks out.

Slide 7

Here are some microscopic views of the glomerulus

Slide 8

Here is a picture showing the filtration membrane. If we start on the left side of the picture, you see a large red blood cell on the left, and everything in that pinkish area is blood that is currently in the capillary of the glomerulus. You can see how the wall of that vessel has gaps in it (fenestrations) through which material can pass, and the artist has drawn it to show that the red blood cell is much too large to get through. Then we have this region to the right called the basement membrane, which is a thicker area that slows the material as it flows through. Finally, to the right farther still, we have the podocytes of the glomerular capsule that are tightly wrapped around these capillaries, and the material trying to leak out of the blood has to not only pass through those holes in the capillary wall and the material of the basement membrane, but it also has to find its way between the foot processes of the podocytes. So it’s sort of a three-level filtration process. The things that can actually get through all three levels include water, electrolytes, glucose, amino acids, fatty acids, vitamins, and nitrogenous wastes.

Slide 9

After the fluid leaves the glomerulus and enters the tubules, it’s still considered filtrate, not urine. The next process that happens in urine formation is tubular reabsorption. We talked about this when discussing the PCT. Tubular reabsorption, in general, is the ability of the blood to have a second chance to see the filtrate and take back material that it needs. Very often we lose too much stuff at the glomerulus during the filtration process, and we want to have a chance to return materials that were lost in too great of quantities from the bloodstream. When this happens, it’s called tubular reabsorption. The PCT does the majority of the reabsorption of the filtrate, so we get stuff back in this earliest phase of the renal tubules. The nephron loop and the DCT are more involved with reabsorbing water, whereas the PCT is involved with reabsorbing quite a variety of material in addition to water. The process of tubular reabsorption utilizes both passive and active processes. Sodium, as is often the case, is the key to the movement of everything else. It sets up a concentration gradient: as sodium returns back to the bloodstream, it tends to drag or draw other things with it. Chlorine, being negatively-charged, tends to follow the sodium ions (positively-charged) due to oppositely-charged ions being attracted to each other. Also, normally all of the glucose that has passed through the capillary holes during filtration, is brought back into the bloodstream. Nitrogenous wastes, which are things we’ve made in our bodies and are anxious to get rid of, are partially reabsorbed; sometimes we actually need to take back nitrogenous wastes, but under normal conditions these wastes remain in the filtrate and are not significantly reabsorbed. Most of the water is reabsorbed here as well; it follows sodium through the process of osmosis. So while water does get absorbed in the nephron loop and DCT, that’s primarily what those areas are concerned with when it comes the reabsorption; the PCT also reabsorbs water (in fact quite a bit of it) but reabsorbs other materials as well.

The third process that is part of urine formation is called tubular secretion. In a way, it is the opposite process of tubular reabsorption. As the blood that’s been filtered in the peritubular capillaries passes very closely by the tubules, not only can it take material back that the body needs, but it can also add additional material to the filtrate in the tubules if it needs to. That direction of the movement of substances, from the blood into the filtrate, is called tubular secretion. Tubular secretion extracts chemicals from the blood and secretes them into the filtrate in the renal tubules. It’s sort of an insurance policy of sorts that anything that’s rather toxic that didn’t make it out of the blood in the filtration process can be removed through tubular secretion. This process occurs throughout all segments of the nephron. For example, H+ are removed to help maintain pH control. Additionally, nitrogenous wastes, potassium ions, and some drugs can also be secreted along this route.

The final step of urine formation is water conservation. This occurs primarily in the collecting duct. Remember, multiple nephrons empty what they have made into a collecting duct. Once the filtrate has entered the collecting duct, it’s pretty much considered urine. As the collecting duct passes through the renal medulla, water can still be reabsorbed to concentrate the urine up to 4 times what it was before. So this is a last chance to get back any water we think we need. It’s slightly different than the tubular reabsorption of water that happened earlier.

Slide 10

Now let’s follow the path of this urine that’s formed on its way for storage and elimination from the body. Urine leaves the kidneys by way of the ureters. The walls of the tubes are made of three layers.

1. The mucosa is the inner layer. It is made of transitional epithelium (recall back to histology and that transitional epithelium is really good at stretching, which is essential in the urinary system to accommodate the fluctuations in urine output) that begins at the minor calyces and extends through the bladder.

2. The middle layer is a muscle layer referred to as the muscularis. There are actually 2 layers of smooth muscle within the muscularis, and as the tube nears the urinary bladder, it becomes 3. The muscularis works in peristaltic wave to move urine, almost like a milking action.

3. The adventitia is the outer layer. It is made of connective tissue that binds to the surrounding tissues.

As mentioned, the ureters function to transport urine from the kidney to the bladder. A valve formed from a flap of mucosa is found at the opening into the bladder which keeps urine from back flowing into the ureters.

Slide 11

The urinary bladder is a large muscular sac. Like the ureters, it has three layers.

1. The mucosa continues into the urinary bladder and is still made of transitional epithelium. There are also rugae that allow the bladder to stretch, similar to those found in the stomach.

2. The muscle layer is referred to as the detrusor muscle and is composed of 3 layers of smooth muscle.

3. There are two different segments of connective tissue that covers the urinary bladder. Adventitia covers the majority of the bladder and parietal peritoneum is found on the superior/curved portion of the bladder.

Internally, there is a region called the Trigone. It is triangular-shaped and is formed by the entrance of both ureters and the exit to the urethra. This is a common site for UTIs (urinary tract infections).

The urinary bladder functions as a place to store urine until it can be eliminated from the body. The elimination of urine is called the Micturition Reflex (urination reflex).

Slide 12

The steps of the Micturition reflex (urination reflex) are simplified in the diagram.

1. Filling of the bladder excites stretch receptors which sends a message to the spinal cord.

2. The spinal cord responds and sends out a signal via parasympathetic nerve fibers.

3. The signal excites the detrusor muscles to contract.

4. The signal also stimulates the internal urethral sphincter to relax.

At this point one of two paths can be followed. The pons regulates voluntary control of the elimination of urine. It will give the go ahead signal or not.

If timely, the pons stops regulating signals which allows the external urethral sphincter to relax and urine to leave the body. If it is not timely, the external sphincter will not relax. When toddlers are potty training, this is the reflex control that they are developing.

Of course, there are situations when it may be necessary for the body to eliminate urine and it will override the voluntary control.

Slide 13

As you may have surmised from the previous slide, the urethra is a tube that conveys urine from the urinary bladder out of the body. There are two sphincters, the external and internal, that allow for control of the passage of urine. The external urethra orifice is the opening to the external environment. The external opening is slightly different in females and males, which we’ll see when we do the reproductive unit. In females, the external urethral orifice is found between the vaginal opening and the clitoris. Also, in males, the urethra is used in both the urinary and reproductive systems. In females, at least in human females, this tube is used solely by the urinary system.