>> I'm told it's November 25th, 2015 and this is lecture 26, a brand new topic, brand new unit, one that naturally you carry around 24/7, the urinary system. When you think of pathways to excretion, you might think of the urinary system, but let's not forget the respiratory system eliminates CO2 and water, so there are other ways for products to escape your body, but the kidneys, of course, get our attention on a regular basis. So, we're going to focus on the anatomy, the microscopic, as well as, the gross anatomy. And let's get right down into it. The workhorses of this system, naturally, are the kidneys themselves, and you have two of those. I'm sure you know. They're located bilateral to the abdominal aorta, but they're not in the abdominal cavity they're actually behind it in a space you know is called the retroperitoneal space. So, there are about waist height bilaterally retroperitoneum. They're fairly heavy. So, the question would occur, why don't they just fall? What holds them in place? They're anchored or attached by renal fascia and they're pretty well padded by, surrounded by, and supported by adipose, adipose in this location which is called perirenal fat. Obviously, the amount of this fat is a function of your own body weight and so if you're anorexic, you have low body fat, naturally this would be in short supply as well. And that would allow the kidney to indeed fall, something called ptosis, especially as a result of vibration or any movement of the body. In fact, you may know that off-road motor vehicle operators wear something around their waist not to support their back, but actually to support their kidneys. They're called kidney belts, because off-road vibrations can actually shake the kidneys loose in especially a slender individual. So, here's the kind of ghosted impression of the kidneys and I'm sure you're quite aware of their location. This shows it better against the vena cava and aorta and the yellow demarks the peritoneum. So, surgery for the kidneys does not involve an anterior incision, but a posterior incision because these are accessible through the back much more easily than they are from the front. Having said that we have two kidneys, there are unusual abnormalities, this is called a "horseshoe" kidney, essentially a single kidney which didn't separate and this is just an anatomical curiosity, but interesting nonetheless. So, let's diagram a kidney. Let's slice a kidney vertically in a frontal section and realize that we're talking about an organ that's maybe 4-and-a-half inches from top to bottom. On the surface of the kidney, in lab for instance, you'll be able to peel apart or peel away a surface membrane which is called the renal capsule. It's the external most covering which is continuous with the same covering which surrounds the ureter. It's made of dense irregular connective tissue and basically encapsulates the kidney, hence the name "renal capsule." When you section a kidney, it doesn't take a microscope to see that actually this organ is C-shaped and there is a definite demarcation between the surface anatomy and the deep anatomy and so these words are used once again. What's the word for "bark" or the "surface", it's the? Cortex which is the outer layer and deep to that is the core, c-o-r-e which, as you know, is a word called "medulla." So, in this exaggerated drawing, we can see the cortex, maybe the first quarter-of-an-inch and then deep to that much thicker is the medulla. The medulla is actually segmented or divided into parts or lobes which are pyramidal in three-dimensions. That means they're like the pyramids. They're

tetrahedral and for that reason those segments are called the renal pyramids described at least in two-dimensions as a triangular zone within the medulla. So, these are the renal pyramids which occupy most of the medulla. We'll talk about their composition in a minute, but now we're just giving you some names and references before we get detailed. Notice that the pyramids taper into a kind of nipple of nozzle which literally is dripping urine 24/7. The name of that nipple is called the "renal papilla." We've used that word more than once, and that drips urine into a series of spaces really that begin with the so-called "minor calyces." The word "calyx", c-y-a-l-y-x is singular and it refers to a cup, c-u-p. So, the minor calyces precede and drain into the major calyces. Essentially, these don't make urine; they just collect urine from the microscopic elements of the kidney which we've yet to mention. So, in this interior view, we can see the minor calyces draining into the major calyces and maybe this is better, once again, the cortex distinct from the medulla; the medulla is organized into these so-called pyramids that drip urine into the minor calyx, then into a major calyx, and finally into a larger basin simply called the "renal pelvis" which protrudes from the kidney and ultimately tapers down into what you know to be the ureter. So, your book has an excellent illustration and this one that you have in front of you is not bad, especially if you color it up with some colored pencils. So, to repeat, the medulla is demarked into pyramids or triangular sections within the medulla, then that tapers down into a nipple which drips urine first into the minor then major then renal pelvis, all of which carry urine ultimately out into the ureter. So, this is the gross anatomy which is easy to see and you'll have a chance to look at naturally in the lab. Are there blood vessels in and out of the kidney? Of course. And you know the one that goes in is, well an artery and that would be the renal artery, and notice that it divides pretty quickly as it enters the interior. Coming out of the kidney is the larger renal vein which hooks up, you know, with the inferior vena cava. So, these are vascular concerns that you've already been exposed to. The ureter then is that exiting singular tube which carries urine down to the bladder and we'll get to that again before we finish today. Is there a nerve supply? The answer is yes. And so, the kidney is innervated by sympathetic and parasympathetic fibers. It's dual motor innervated. The sympathetic fibers tend to constrict the vessels, the arteries or arterioles of the kidney and therefore they tend to reduce blood supply to the kidney and therefore reduce urine output. So, in effect, sympathetic action tends to reduce the production of urine. Parasympathetic arrive here as well, basically branches of the tenth cranial nerve or the vagus nerve and you might assume that if the sympathetic reduce urine formation that parasympathetic would increase urine formation, but that's not actually been proven. In fact, even today the function of the parasympathetic is unknown, because it doesn't seem to do anything. It doesn't change the composition or the volume or the quantity of urine in any way. So, this remains a mystery, but nevertheless, the kidney is innervated by both sympathetic and parasympathetic fibers. So, let's turn from the gross anatomy now to the real important microanatomy which is, of course, by definition microscopic. And we'll divide this discussion into those parts which belong to the vascular system and those parts which are properly part of the kidney itself. So, the working component of any kidney is called a "nephron" and each of your kidneys has at least a million nephrons. I suppose you could say if you've seen one nephron you've seen them all. And here's a token sketch of a nephron which we'd expect you to learn about and be able to diagram at some point. So, what are the tubular components that describe or essentially represent a nephron? Here in yellow we see the nephron begins in a kind of fishbowl enclosure of a ball of capillaries. That enclosure was first described by William Bowman in the mid1800s. And so in his honor, that's sometimes called the "Bowman's capsule." The word eponym we've used before and I just want to reference it; an eponym is a name given to something based on a person, right? So, why is this called Bowman's capsule? Well, because it was discovered by William Bowman. But actually though, we're trying to get rid of eponyms because they don't help us really remember of even understand the structure, so a more modern reference is simply the "glomerular capsule", which then tapers down into a short, twisted tube which assumes the name "proximal convoluted tubule." This tapers down into a slender tube which dives very deep into the kidney, deep into the medulla of the kidney and then makes a U-turn and comes right back out. Obviously, something shaped like a loop and so today's it's simply called the "loop", although it was first discovered by a German anatomist. His name was Friedrich Henle, so you'll hear that term the loop of "Henle." The loop of Henle opens up, that is it returns to the surface of the kidney where it expands and forms yet another tube, twisted and convoluted, hence that name distal convoluted tubule, which then hooks up with other nephrons into a common single so-called collecting duct which runs back down again through the medulla and eventually drips urine into the minor calyx as we've already mentioned. So, you don't have to be an artist to be able to construct this. So, real quick, here's a rendition of Bowman's capsule. This would be the proximal convoluted tubule. That would be the loop. Then it would open up into another distal convoluted tubule which then would empty into a so-called collecting duct which would accept urine from other adjacent nephrons. So, you'll get the hang of this when you diagram a few times. What's important about it though is the vascular connections to these tubular components which, of course, originate from the renal artery which actually enters the kidney and then that quickly breaks up into what are called "interlobar arteries" which we can catch a glimpse with in this illustration here. So, let's start and approach the kidney; the artery going in is called simply the renal artery. Then it divides quickly into many which basically run between the pyramids, hence the name "interlobar arteries." These interlobar arteries tend to join, that is they connect, forming a kind of arch which runs along the border between the renal cortex and the renal medulla and that arch has the name "arcuate artery" which you can see in this and other illustrations. Coming off the arcuate are smaller arteries which extend toward the surface. Those are known as the interlobular arteries and those give off still smaller vessels now small enough to be called arterioles and the ones which approach and eventually enter the glomerulus are called "afferent arterioles." The word "afferent" we've used already. That means going in. So, the afferent arteriole goes into the glomerulus which is surrounded by Bowman's capsule and naturally if there's an arteriole going in there would be an arteriole going out and this is the so-called "efferent arteriole." Which then becomes highly branched and forms a network of capillaries surrounding the nephron and those are called "peritubular capillaries" which eventually unite up with interlobar veins, which hook up to arcuate veins, and then interlobar veins, finally leaving as the renal vein. Now, that's a lot of information which doesn't have any real meaning until you can construct a diagram. So, let's do it. Here's the kidney or at least the nephron and just for reference, let's put a dotted line across this diagram at about this level and emphasize that everything above that dotted line is the cortex or the surface of the kidney and below the dotted line then the medulla. So, what comes up through the medulla? What vessel is seen here traveling between these pyramids? It's the inter what? Interlobar artery, so we'll show that as a rather large artery coming up. And then it divides into a semicircular artery called the arcuate artery which actually runs along and serves as a convenient boundary really between the cortex and the medulla. So, the arcuate provides a kind of dividing line between the outer surface of the kidney and the inner surface. With me so far? Let's backup. What's this one which is approaching this intersection between the cortex and the medulla? That's the?

>> Arteriole.

>> And then it divides into this one called the arcuate which is shaped like an arch. Coming off of that we have arteries which are smaller by now, but still arteries and these are branches, multiple branches of the arcuate, their name inter what? Interlobular. Coming off of that we now have vessels that are small enough to be called arterioles and those that approach the nephron and eventually enter the glomerulus, their names afferent; afferent arteriole. The glomerulus itself is a ball of capillaries inside Bowman's capsule. In fact, the word "glomerulus" means ball, b-a-l-l. So, this tuft of capillaries known as the glomerulus receives blood from the afferent arteriole and the vessel that comes out is called the efferent arteriole. This divides, that is becomes smaller and splits many times, eventually forming a network of capillaries which surrounds the nephron and those go by the appropriate name of peri what was it? Peritubular capillaries. Those eventually form veins which parallel the incoming arteries. So, the peritubular capillaries feed into this vein which will show alongside that artery and if that artery was the interlobular artery, then that is the interlobular vein. That hooks up to the arcuate vein which then carries blood out, finally, through the vein named for the vessel alongside it. The outgoing vein is the interlobar vein. So, that's complicated, but it can be simplified in a diagrammatic form. So, let's do this as a kind of journey through the kidney. If you're a blood cell how would you approach the kidney? You would get off and get onto the renal artery. That would take you into this one we've identified as the interlobar artery. You have a short little excursion through the arcuate. Then you'd hop off onto the interlobular artery. Then into the afferent, what is it now? Afferent arteriole which would spin you around inside the glomerulus and then you'd come out, out through the efferent arteriole, spend some time in

the peritubular capillaries and then hook up with the veins which are named for the incoming arteries. So, you would enter the interlobular vein, arcuate vein, interlobar vein, which would eventually take you out through the large renal vein. So, that's a tour if you were a blood cell. But what if you were a water molecule? Hum. A water molecule would take the same journey except that once inside the glomerulus it would actually be filtered through the glomerulus and thus become a potential, a potential part of the urine which is being produced along this nephron. So, a water molecule would leave the glomerulus, enter Bowman's capsule, then into the peri, excuse me, the proximal convoluted tubule, loop of Henle, distal convoluted tubule, collecting ducts, and from there incidentally, into the minor calyx, than major calyx, than renal pelvis, than the ureter, finally the bladder, ultimately outside the body, so those are the kinds of sequential thinking you should consider and practice more than once. Here's an actual view of the kidney photographed nicely, specifically now along the cortex and these, these circular things that look like Christmas Tree ornaments, are actually the glomeruli which are, of course, part of a nephron, and again, a million of these in every kidney. This is a glomerulus seen with high-power scanning electron photography and here we see the glomerulus and perhaps you can't see that, but that's a vessel coming in and it's labeled "A." This is a vessel coming out, that's labeled "E." What's the A? Afferent arteriole; the one coming out is the efferent arteriole. And remember, the glomerulus is a ball of capillaries. What are capillaries made of? What is the histology of any capillary? Simple squamous epithelium and the same can be said for Bowman's capsule which is also simple squamous epithelium. So, this is histology is very thin, very permeable and allows the filtration of material then from the bloodstream from the glomerulus into Bowman's capsule. This illustration you have and you might want to invest in some coloring of it, but it's essentially the same as what we've already placed on the board. Before going further into the anatomy, let's sort of step out and at least describe what we know to be urination. When you hear the word "urination" you think, you know, standing over a toilet or sitting on a toilet, but actually that's something called micturition when you actually empty your bladder. So, it might seem odd, but you're urinating right now. You never stop urinating until your dead and so urine formation is what we mean when we say urination. It's not a simple process, but it can be reduced to three overlapping events. The first one we've already illustrated and mentioned by name. This is the one that occurs through the glomerulus into Bowman's capsule. This pushes water and solutes into the glomerular capsule and its name is simply 'glomerular filtration." You would think that that might be all there is to it. But as you'll learn in physiology and perhaps you already know, many things that are filtered never end up in the urine at all, and one of the most common and familiar examples is glucose. Is there glucose in blood? Of course. Is glucose a small enough molecule to be filtered through the process of glomerular filtration? Yes indeed. But is there any glucose in the urine in normal individuals? The answer is no. So, what happened to all this glucose that was filtered? Much of it was reabsorbed, the third process shown here which takes things out of the filtrate, out of the nephron and puts it back into the peritubular network eventually returning it to the bloodstream. The opposite of tubular reabsorption is putting materials directly in the nephron essentially taking them out of the peritubular capillaries and putting them straightaway into what ultimately will be the urine. So, in summary, these are the three processes which contribute to urination. First and foremost, filtration, followed by some degree of tubular secretion, and then some degree of tubular reabsorption. So, simply put, the composition of your urine which changes minute to minute, is a function of how much filtration occurred, how much secretion occurred, how much reabsorption occurred and, therefore, the chemistry of urine is changing all the time based upon changes in these three events all of which add up to urination. Here's an illustration which you don't have, but I think it's a nice cartoonish look at these three processes. Here's the glomerular capsule and so this is the glomerulus itself, so what process is illustrated or suggested here? Number one, that must be glomerular filtration. Is everything that's filtered going to be excreted? No. Some of that can be returned, returned to the peritubular capillaries and that process tubular reabsorption. Very often materials in the urine are not filtered, but end up, end up in the urine by this secondary process, tubular secretion. So, to say again, filtration adds materials to the urine, reabsorption removes materials from the urine, and secretion adds them as well. So, it's quite a complicated series of events which produce the final urine. And incidentally, the urine is finalized by the time it reaches the end of the collecting duct. It's the nephron's responsibility then to create urine that's appropriate for the circumstances, that is to conserve water if needed or to eliminate various electrolytes whatever the circumstances dictate. Here's a nice illustration too which is instantly recognized I think. This must be that fishbowl that surrounds these capillaries. So, these capillaries are glomerulus and this space is Bowman's capsule also known as the glomerular capsule. And just to reiterate, these after all are capillaries, capillaries are made of simple squamous epithelium and the lining of Bowman's capsule is also simple squamous epithelium. So, how many cells does a water molecule have to go through before it's properly introduced into the nephron? Well, just two. Infiltration is a force, a process which is essentially propelled by blood pressure. So, here is a slide, this is actually William Bowman. I don't know why I thought that was cool, but sometimes you have these names that means nothing, but there he is dressed up in this is actually Friedrich Henle who was a contemporary of Bowman's that is they lived at the same time except that Henle was German and Bowman was English. So, let's move on. We've created urine. It's found its way into the collecting ducts and so with that said, let's talk about the flow of urine beyond this point. And really beyond this point, it's all plumbing. In other words, the kidneys manufacture the urine, the rest of the system is just plumbing and that begins at the end of the collecting ducts which as we said, drain and drip urine first into the minor calyx, then into the larger major calyces, into the renal pelvis and then down and through the ureters to the bladder where it's stored for hours or longer in some cases, and then finally out, out through the singular tube called the urethra, into the outside world wherever that might be. So, let's back up a bit. Looking at this diagrammatically, the renal pelvis tapers down into these tubes which you've seen in the cat, maybe even the rat. These are known as ureters. You have two of them, of course, one for each kidney. These also are retroperitoneal, because after all, they come from the kidney which is itself retroperitoneal and their job is to transport urine naturally from the kidney down into the bladder and this is not passive, but active. Urine doesn't just drop like water over Niagara Falls here. It actually is pushed down through the activity of this tube which is endowed with muscle. What kind of muscle would you expect to squeeze that urine out? Of course, it's smooth muscle. So, in fact, the ureter is divisible into three layers, the outer layer which connective tissue, actually the same connective tissue which forms the renal capsule. And then the middle layers are smooth muscle, both a circular and a longitudinal layer working together to squeeze urine southward. And the inner lining which highly convoluted, is this unique kind of epithelium that you learned about very early in this course, so-called what? Transitional epithelium which has the capacity to stretch as you'd expect and assume when urine comes down this particular pathway. Now, naturally the ureters are intended to carry what where? They're carrying urine from the kidney to the bladder. But, just to depart a bit, you know that in some individuals rocky stones can form in the kidney and at first they may be tiny, the size of a grain of sand or something, and as such are insignificant. But when a kidney stone is sizable and when it tries to go through the ureter, that gets your attention. Anybody had kidney stones? And it comes on just like that doesn't it? A very sharp pain as if someone were stabbing you literally in the back and that's essentially the result of the scraping of this stone as it runs all the way down the ureter and that's a very painful and long-lasting journey. But it's over as quickly as it comes, because once that stone enters the bladder, the pain goes away. There's plenty of room in here and so the onset of an attack like that is when the stone leaves the kidney and it doesn't subside until that stone enters the bladder. And then, of course, there's the final hurdle of getting out of the bladder, but we'll defer that for now. Here's a look at the ureter. This is the lumen and this is the epithelium. What kind of epithelium? Transitional. The bladder is interesting and certainly familiar to everybody in a kind of general sense. It's location is known. It's in the pelvic cavity just behind the pubic symphysis and believe it or not, it can store up to what? What's that say? Up to a liter. Now you all know what a liter looks like and so do you have any proof of that in your own experience? Personally, I don't let my bladder fill up that much. I mean, I like to let it go a little earlier than that, but yeah a liter of urine, amazing. Now, the bladder is itself capable of stretch as this implies and not surprisingly is lined with a mucous membrane with the same sort of epithelium that we see in the ureter namely transitional epithelium. And so as you think back to your lab work when you studying histology, remember those slides that were labeled transitional epithelium? Very often they were cross-sections through a ureter, but they could also be cross-sections through a bladder. Deep to the epithelium, of course, you'd expect muscle and this muscle in this location is called the detrusor muscle which is actually just a multilayered, multidirectional area of smooth muscle. And naturally you'd expect smooth muscle. What would you want the bladder to do at a certain point, but rather contract and therefore push urine out of the urethra and indeed it does. Notice this interesting anatomy, because the ureters come down from above, of course, they enter the bladder relatively low and from behind and so there are two inlets for each of these two ureters. Then there's a single outlet, so if you draw a dotted line between the two inlets and the singular outlet, you would have a triangle which incidentally and interestingly is devoid of rugae. But why would we expect rugae elsewhere in the bladder? What was the function of that anatomy in the stomach? It wasn't so much to increase surface area, although it did, but it's to allow that organ to what? Expand. So, we find rugae in all of those organs which you're capable of a great deal of stretch. Does the stomach qualify? Does the bladder qualify? Does the vagina qualify? So, we're going to see rugae wherever the organ is capable of a lot of stretch, but there is no rugae in this area; this area known as the trigon. Now, naturally the bladder has an outlet which we've already given a name to, but clearly that deserves some kind of control mechanism there, because do we want to drip urine all the time? That would be really hard on our lifestyle, you know, we'd be just dripping all over the place. So, clearly there's a way of preventing the loss of urine and that's made possible by our old friends sphincters. And so, once again here we have an internal sphincter which is nothing more than the walls of the bladder which basically come together at this outlet and then internal sphincter is smooth muscle which means you have no control over that and it will basically give way or be pushed open when there's sufficient pressure, when there's sufficient volume of urine. But luckily at that point you have a choice don't you? When you feel that urgency, what do I mean? That urgency, that sense that you got to go, you have a choice. You can let it go or you can clamp down on your on your what? Clamp down on your external sphincter. And this will obviously prevent temporarily the flow of urine which allows you to go about your business that is until you can find a restroom or a bush or something to pee on, okay. Now, let's go to the final hurdle here which is the urethra. Maybe before we do that let's look at a few slides here. This is inside the urinary bladder at least that's what the label says, but what clue might there be that this could be the bladder anyway?

>> The rugae.

>> This is the rugae. Incidentally, rugae are not seen when the bladder is stretched only when the bladder is contracted, in other words, a full bladder will tend to flatten out the rugae whereas an empty bladder we'd see that. The final hurdle from the bladder into the urethra, is quite different in the sexes as you know, but first to comment about this structure in general, it's the final outlet to the outside world and it passes through the floor of the pelvis through a muscular boundary there which is called the urogenital diaphragm. So, north of the urogenital diaphragm is the pelvis and anything south of that is, well, into the genitalia or to the outside world. Now, there are some sexual differences obviously and let's go to those. In males the urethra is about 8 inches long and every time I say that and people say, well wait a minute I thought it was 6 inches, well actually they're thinking of the penis itself, but the urethra that's

what we're talking about, is what? Eight inches. So, there's 2 inches of urethra before we even get to the penis, but let's go ahead and name those segments in anyway. Notice that the first or proximal part of the urethra in men passes through a gland we've yet to mention, but certainly well-known and that's the prostate which is not related to the urinary system at all but rather a member of the reproductive system. Still, this segment which might be an inch-and-a-half is called then the prostatic urethra and this brings up a valid and important point, does the urethra have a function in males that is not represented or found in any equivalent way in females? Of course. Because we know that urine passes through the urethra, but also may and sometimes does pass through here is the semen which may or may not contain sperm. So, that reminds us that the urethra has two functions in men, whereas the urethra in a woman has a single function and that is the passage of urine. Beyond the prostatic urethra, there's a short little segment which is called the membranous urethra and the balance of it is simply called the, excuse me, the penile urethra sometimes also called the cavernous urethra for reasons that we'll get to in a moment. But, flipping over to the female we notice the entire structure is much shorter, maybe an inch-and-a-half and it opens superior to the vaginal orifice and this is fact which is not necessarily widely known. Some people think that urine is secreted into the vagina, but actually urine, urine actually empties superior to the vaginal orifice and that makes a powerful case, because in women the reproductive system is totally separate from the urinary system, but not so in men. So, these are the important differences there. Here's a final slide which we may as well use just to sort of wrap it up again. The surface of the kidney was called the.

>> Cortex.

>> Cortex. Deep inside was the medulla divisible into these pie-shaped segments which were called pyramids, they taper down into a nozzle or nipple which we gave the name papilla and then the urine goes into a cup called the minor calyx most of those join in to form a major calyx, then the renal pelvis and finally out the ureter. The blood supply in is naturally begun with the renal artery which divides into the interlobar, then the arcuate and so forth, so you need to basically imagine and connect the gross anatomy to the microanatomy. What's not shown here, of course, is the nephron because it is microscopic. Dena.

>> In the, in the pyramids in the nodules are those nodules [audio issues]? Is there one nodule in the pyramid or is there?

>> One papilla? This is the renal papilla or a nipple.

>> The nephron.

>> Oh. I'm glad you mentioned that, because I said I was going to address this and I totally forgot, because it's one thing to point to this and say, okay it's the medulla and the other name is a renal pyramid, but what actually is this made of?

>> Nephrons.

>> Essentially, it's made of these components which you see below this vessel called the arcuate. In other words, lots and lots of collecting ducts, lots and lots of loops. So, to ask that question in another way, what do we find in the cortex? What parts of the nephron occupy the cortex? Well, clearly the Bowman's capsule, proximal and distal convoluted tubules, and maybe the first segment of what then would be the collecting ducts. So, to answer a question, what actually is making up these renal pyramids? Is just all of these loops and all of these collecting ducts and it is, of course, the collecting ducts which are dripping urine into the minor calyces all the time. Was that kind of your question?

>> Yep.

>> Alright. Good.

>> Thank you.

>> So, have a great Thanksgiving.

>> You too.

>> And see you on the other side of the weekend.

[Background Conversations]