INTRODUCTION:

The urinary, or renal, system is responsible for maintaining the homeostatic composition of the blood. It regulates the concentrations of nutrients, waste products, electrolytes, hormones, drugs, and literally hundreds of other types of molecules. The kidneys accomplish this by filtering out large amounts of both water and the solutes (up to 180 L of filtrate per day), then reabsorbing the things the body needs to retain. The fluid that remains becomes urine (1-2 Liters/day) and consists of excess water and solutes that were not reabsorbed from the filtrate. Urine color (pale to dark) is often a reflection of water homeostasis.

Urine also helps remove potentially harmful nitrogenous wastes such as urea and uric acid as well as many other products of cellular metabolism. One of these, called creatinine, is a waste product created in muscle cells from an energy-storage molecule called creatine phosphate, and its clearance from the kidney is often used to evaluate kidney function and potential kidney diseases. Urine passes out of the kidneys into the ureters, which transport it to the bladder where it is stored until it can be voided through the urethra. We will examine these organs at both the histologic and gross anatomy levels, correlating structures with their functions.

LEARNING OBJECTIVES:
At the end of this exercise, students should be able to:

- Identify all of the organs of the human urinary system and their functions
- Identify the regions of the kidney and their functional relationships
- Describe the flow of blood through the kidney and relate this to elements of urine formation
- Identify the parts of a nephron and their functions
- Describe the histology of the human kidney and urinary bladder
- Describe the normal and abnormal characteristics and constituents of human urine

GROSS ANATOMY OF THE HUMAN URINARY SYSTEM

**Exercise 1:** Using Figures 23.1, 27.10, and 28.1 in your Saladin text, identify the right and left kidneys, renal arteries and renal veins, ureters, urinary bladder, and urethra. Since the male and female urethras are different, be sure you examine models with both male and female genitalia.

The kidneys are located on either side of the vertebral column in the abdomen. Notice that they are posterior to all of the other abdominal organs, just anterior to the lower two ribs and the muscles forming the posterior wall of the abdomen. Although not shown on these models, the kidneys are retroperitoneal - that is, they are located posterior to the parietal peritoneum which lines the abdominal cavity. The kidneys are situated just inferior to the liver, and the right kidney is slightly more inferior compared to the left kidney because of the larger mass of the liver on the right side. The anterior and posterior surfaces and the lateral edge of each kidney are convex while its medial surface is slightly concave.
The large left and right renal arteries are branches of the abdominal aorta carrying blood to the kidneys. Renal veins return this blood to the inferior vena cava. These vessels enter the kidney together at its medial border, the hilum. Compare the size of these vessels to the size of other branches of the abdominal aorta - they are relatively large, indicating that the kidneys receive a large amount of blood. In fact, about 25% of the total cardiac output goes through capillaries in the kidney - probably the highest blood flow based on size of any organs in the body. It is this blood that will be filtered and then modified to form urine. A ureter exits the hilum of each kidney and runs inferiorly toward the bladder. This muscular tube is also retroperitoneal (even though the peritoneum is not shown on the torso models), lateral to the bodies of the vertebrae and then anterior to the sacrum of the pelvis and its overlying muscles. It enters the bladder through that organ’s posterior surface, near its lateral and superior surfaces. The urinary bladder lies deep in the pelvis, posterior to the pubic bone. It is spherical in shape and flattened on its superior surface. The ureters enter the posterior surface on either side. In women, the uterus is tipped posteriorly over the superior surface of the bladder. In men, the intestine lies along its superior surface. The urethra exits the bladder inferiorly, carrying urine to the external urethral orifice. In women, the urethra is immediately anterior to the vagina and is relatively short, passing inferiorly to end between the minor labia. The urethra is much longer in men, initially directed inferiorly but then turning anteriorly to enter the penis. Just inferior to the bladder it is surrounded by the prostate, and within the penis it is surrounded by one of the erectile bodies called the corpus spongiosum.

**Question for discussion:**

Urine is not pulled through your ureters by gravity: it moves from your kidneys to your bladder just fine even if you are standing on your head. Explain to other members of your lab group why this is true.

**Exercise 2:** On Figure 23.4 of your Saladin text, identify the following regions of a kidney:
- The capsule is a layer of dense irregular connective tissue which surrounds the entire organ;
- The cortex forms the outer part of the kidney, just deep to the capsule.
- The medulla is a broad region deep to the cortex. It consists of approximately a dozen cone-shaped renal pyramids (all of them will not show, of course: some are above or below the level of section in this diagram) separated by renal columns.
- The pelvis is deepest region of the kidney, near the hilum on its medial surface. This is a hollow space in which urine gathers before it enters the ureter. Large extensions of the pelvis facing toward the medulla are called major calyces (singular = calyx), which branch to form smaller minor calyces. Notice that the tip of each cone-shaped renal pyramid extends into a minor calyx.

**Exercise 3:** Identify each of the regions listed in bold in Exercise 2 on the large model of the kidney and on the fresh sheep or pig kidneys in the sink. Please wear gloves when examining the latter.

**Exercise 4:** Get a preserved sheep kidney from the bucket near the sinks, wearing gloves as you handle it. Identify the structures listed above in Exercise 2. Return the kidney to the bucket.

**Exercise 5:** On Figures 23.5 and 23.6 of your text, identify the following vessels within the kidney and trace the pattern of blood flow. Remember: the function of arteries is to deliver blood to capillaries, where the exchange of molecules can occur into and/or out of the blood, then the function of veins is to gather this blood and carry it out of the organ. Unlike most organs, however, the blood flows through two sets of capillaries between the arteries and the veins.
A renal artery divides into segmental arteries and then interlobar arteries running through the renal columns of the medulla toward the cortex. At the boundary between the medulla and cortex the vessels curve to run parallel to this boundary as the arcuate arteries. Cortical radiate arteries, more commonly called interlobar arteries, branch off and extend into the cortex, giving off afferent arterioles that carry blood into the capillaries forming the glomeruli where the process of filtration occurs. An efferent arteriole then carries blood out of each glomerulus and delivers it into another set of capillaries surrounding the tubules of the nephrons. These are called the peritubular capillaries in the cortex of the kidney and the vasa recta in the medulla of the kidney, and they reabsorb both water and solutes to return them to the blood. Thus, the capillaries of the glomeruli, the efferent arterioles, and the peritubular capillaries or vasa recta form a portal system similar to what we observed between the hypothalamus and anterior pituitary gland.

From these, blood gathers into veins which follow the same pathways (in reverse, of course) as the arteries: interlobular or cortical radiate veins, then arcuate veins, then interlobar veins, then lobar veins, then the renal vein leading out of the kidney.

**Exercise 6:** On the model of the kidney, identify each of the vessels listed bold letters in Exercise 5 above. You will have to use all three “levels” of magnification shown on this model: a) the gross model; b) the model of one nephron; and c) the model of one glomerulus with its afferent and efferent arterioles. Be sure you can trace the flow of blood through these vessels, from the aorta to the inferior vena cava.

**Exercise 7:** Close your book. In the space below, sketch the structure of one kidney showing
- capsule
- cortex
- medulla
- pyramids
- columns
- pelvis
- hilus

major and minor calyces,
renal artery and vein
interlobar arteries and veins
arcuate arteries and veins
interlobular arteries and veins.
proximal ureter

Next, sketch the microscopic structure of a kidney showing the flow of blood through
- arcuate arteries
- interlobular arteries
- afferent arteriole
- glomerular capillaries
efferent arterioles
vasa recta and peritubular capillaries
interlobular veins.
arcuate veins

You are wasting your time if you try to get pretty, accurate drawings. Instead, these drawings are to see how well your brain understands the structure of the kidney. Therefore, do not simply copy a figure from your book. Draw it from memory, using your text as a reference when necessary.
Exercise 8: From memory (refer back to earlier pages of this handout or the book only as a very last resort) explain to other members of your lab group the vessels of the kidney through which blood follows from the time it leaves the aorta until it enters the inferior vena cava. Be sure you identify these vessels in the proper order. If other members of your lab group are not explaining this correctly, be sure to help guide them through the pathway so that they understand. You will only hurt them if you let them give a poor explanation. If you had to refer to the book to do this exercise, repeat the sequence of vessels again. Do not give up until every single person in the lab group can do this from memory.

MICROSCOPIC ANATOMY OF THE URINARY SYSTEM

Each kidney contains over a million nephrons, which are the anatomical structures responsible for removing materials from the blood to form urine. As shown in Figures 23.6 of your Saladin textbook, each nephron consists of two parts: a glomerulus (consisting of capillaries) where this filtration occurs and a renal tubule in which the composition of this filtrate is modified to form the urine. The proximal end of each renal tubule, called the glomerular (Bowman’s) capsule, is enlarged and surrounds the glomerulus. The glomerulus and glomerular capsule together are often called a renal corpuscle.

The rest of the renal tubule has four primary regions, called the proximal convoluted tubule, the loop of Henle (called “nephron loops” in your Saladin text), the distal convoluted tubule, and the collecting duct. Actually, each collecting duct is shared by many nephrons. The glomeruli (that’s plural of glomerulus), the proximal convoluted tubules, and the distal convoluted tubules of all nephrons are always located in the cortex of the kidney. The loops of Henle (nephron loops) dip down into the renal pyramids in the medulla and then back up into the cortex. The collecting ducts gather the urine from the distal convoluted tubules in the cortex and pass through the medulla to empty it into the minor calyces of the pelvis of the kidney. The entire renal tubule is surrounded by an extensive network of peritubular capillaries in the cortex and vasa recta in the medulla of the kidney.

Notice from Figure 23.6 in your text that some nephrons lie more superficially in the cortex, with short loops of Henle that barely dip into the medulla. These are called cortical nephrons. Other nephrons are situated more deeply in the cortex and have long loops of Henle (nephron loops) that dip deeply into the medulla. These are called juxtamedullary nephrons.

Exercise 9: Examine a model of a nephron - this will be part of the model that shows the gross structure of the kidney. Identify the following:

- **Collecting duct**
- Distal convoluted tubule (not very “convoluted” on the model, unfortunately)
- Glomerular capsule
- Glomerulus
- Loop of Henle / Nephron loop
- Proximal convoluted tubule
- Renal tubule

Although they are not well shown, try to visualize where the peritubular capillaries and vasa recta would be.

On the third part of the model, showing one renal corpuscle, identify the glomerulus and parietal wall of the glomerular capsule. Notice that blood enters the glomerulus through one vessel, called the afferent arteriole, and leaves through a second vessel called the efferent arteriole, although you will not be held responsible for differentiating between these two. Observe how the space of the glomerular capsule is continuous with the proximal part of what must be a proximal convoluted tubule.
Exercise 10: In the space below, draw the structure of one nephron and label all of its parts. Here again, the purpose is not to get a pretty drawing, but rather it is to see how well your brain understands the structure of a nephron. Do not copy a figure from your book. Draw it from memory, using your text as a reference when necessary.

From your reading, you should be able to correlate the structure of the nephron with its function:

a) The plasma of your blood consists of water with hundreds of other types of molecules dissolved in it.
b) Water and other molecules filter out of the capillaries of the glomerulus into the glomerular capsule;
c) This filtrate then passes through the various parts of the renal tubule, which allows many molecules (including most of the water) to be reabsorbed from the urine back into the blood of the peritubular capillaries and vasa recta. Thus, these molecules are still in the blood when it later leaves the kidney;
d) Certain types of molecules, such as ammonia, which were not filtered out of the blood in the capillaries of the glomerulus are actively secreted from the tubules into the forming urine in order to eliminate them from the body.
e) Although more than 180 liters of liquid per day is actually filtered out of the blood from the glomeruli into the glomerular capsule, you only eliminate one or two liters of urine each day. This is because 99% or more of the filtrate is reabsorbed back into the blood as it passes through the renal tubule.

For physiological reasons we won’t go into in this lab, it is the dipping of the nephron from the cortex into the medulla and then back up into the cortex, followed by the passage of the collecting duct back through the medulla, which allows you to concentrate your urine. Otherwise, you would lose very large amounts of water every time you urinate.

Questions for discussion:

What would happen to you if your glomeruli lost their ability to filter water and other molecules out of your blood?

What would happen to you if your nephrons lost their ability to reabsorb almost all of the liquid which is filtered out of the blood in the glomerulus?

What would happen to you if your nephrons lost their ability to secrete waste products into the urine within your nephrons? (assume these are molecules which did not filter out of your blood from the glomeruli into the glomerular capsule).

What would happen to you if your collecting ducts lost their ability to reabsorb water from the urine back into your blood?
HISTOLOGY OF THE URINARY SYSTEM

Exercise 11:  Examine Slide #16 with your naked eye. This is a coronal section of the kidney from a mouse, but it has exactly the same structure as the human kidney (Figure 23.4). You should be able to identify the hilus, cortex, medulla, and pelvis under this minimal magnification.

Now examine this slide in the usual way, starting at 40x magnification and then 100x. Move the slide so you can see the cortex and identify a glomerulus, which appears as a ball of tightly packed material (these are actually capillaries, of course) surrounded by a thin space (the glomerular capsule). Examine a glomerulus at 400x magnification (Figure 23.7). You can now see the nuclei of the capillary cells and of the simple squamous epithelial cells which line the glomerular capsule.

Still at 400x, move the slide slightly and examine the cortex immediately surrounding the glomerulus. It is composed of thousands of proximal convoluted tubules and distal convoluted tubules, although you will not be held responsible for differentiating these from each other on this slide. Since these are "convoluted" or coiled up, they will be cut in many different orientations on your slide. Don’t be surprised if you see an arteriole, venule, or larger blood vessel as well as many capillaries.

Return to low magnification and move your slide so you see the medulla of the kidney. This is also composed of thousands of microscopic tubules, but the characteristic feature is that adjacent tubules are all running in the same direction rather than being “convoluted” as they were in the cortex. Scan around the medulla under low power. In some regions these tubules will be cut longitudinally; in other regions obliquely; in other regions in cross-section. These are a mixture of collecting ducts and the ascending and descending limbs of the loops of Henle, plus many blood vessels.

Move even deeper in the kidney and you will observe large, empty-appearing regions near the hilum of the kidney. These are parts of the pelvis, including major and minor calyces. Under high power magnification notice that these spaces are lined by transitional epithelium.

Questions for discussion:

What type of epithelium forms the proximal and distal convoluted tubules in the cortex of the kidney?

Which blood vessels would you expect to see in the cortex of the kidney?

Which blood vessels would you expect to see in the medulla of the kidney?

Exercise 12:  Slide 18 is a slide of part of the urinary bladder - obviously, the entire organ would be too large to fit on one slide. Examine this under low power and then high power. Identify the transitional epithelium which lines its lumen - this is in the relaxed (cuboidal) state, and the entire epithelium is in fact wrinkled or folded into rugae to reduce the size of the organ. Deep to the epithelium, identify the thick layer of smooth muscle which forms its muscularis layer - this if often called the detrusor muscle. Your slide will probably not show the adventitia of this organ.

Questions for discussion:

How do the cells of the transitional epithelium lining your bladder change as it fills up with urine?

How do these cells change when you empty your bladder during urination?
Exercise 13: A molecule called creatinine is a cellular waste product which is normally produced by muscle cells and must be transported through the blood to the kidney for disposal in the urine. From memory (don’t refer back to earlier pages of this handout or the book unless you absolutely have to!) explain to other members of your lab group the pathway that a molecule of creatinine (or, of course, a molecule of any other waste product) would follow from the time it is filtered out of the blood until it exits your urethra with the urine. Identify, in order, every part of the nephron, every part of the kidney, and all other organs that it will pass through. If other members of your lab group are not explaining this correctly, be sure to help them understand. You are only hurting them by letting them give a poor explanation. Do not give up until every single person in the lab group can do this from memory.

URINARY ANATOMY OF THE HUMAN CADAVER

Exercise 14: On the cadaver, identify the kidneys, ureters, and bladder. Identify the renal arteries and renal veins and trace these back to the large vessels from which they arise. You should be able to describe the positions of each of these organs relative to surrounding structures such as ribs, vertebrae, and bones of the pelvis.

CHARACTERISTICS OF URINE

In this lab, you will have the opportunity to examine your own urine (or a sample from one of your lab partners) and will perform a urinalysis to determine its

a. appearance (color and clarity)
b. odor
c. pH
d. specific gravity
e. chemical composition

The primary constituent of urine is water and, of course, the more water your drink the more water you will need to eliminated in your urine. Water normally constitutes more than 95% of its volume, but as discussed in the reading assignment for this lab it also contains a large variety of other molecules which have been removed from your blood in order to maintain homeostasis. Many, but certainly not all, of these are listed in Table 23.2 of your Saladin text, including waste products, ions, and many organic molecules. Urine also normally contains epithelial cells which have been shed from the organs through which the urine has passed, and crystals of molecules which have precipitated out of the urine as it is forming. A very small number of erythrocytes, leukocytes, and bacteria may be seen in a normal urinalysis. It is not unusual to see live sperm in a normal urine sample from either a man or a woman if the individual has recently had sexual intercourse.

What changes in your urine would you expect to see if your pituitary gland completely stopped producing antidiuretic hormone? Explain to the other members of your lab group what changes in the kidney would produce that.
Exercise 15: Choose a volunteer for your group (2-4 per group) and have her or him take the small plastic container to the bathroom and collect about 30 ml (half full) of urine, preferably mid-stream. Bring the sample back to the lab to perform the urinalysis.

Part 1: Describe the color of the urine: ______________________________________________

Describe the clarity of the urine ______________________________________________

It should be clear, pale yellow, or even amber depending on the concentration of the pigments called urochromes. These are waste products which result from the breakdown of hemoglobin. As a general rule, a deeper yellow color indicates a more highly concentrated urine which occurs when you are dehydrated and your body is conserving water. Abnormal urine color such as brown, black, green, or red may also be due to certain foods (e.g., beets), drugs, bile, or blood. Cloudy urine usually indicates the presence of large numbers of bacteria or of large amounts of protein or lipids which should not normally be in the urine.

Describe the smell of your urine _________________________________________________

It should have a characteristic, slightly aromatic odor which is stronger in more concentrated urine, but the actions of bacteria can give it an unpleasant, ammonia-like odor even within just a few minutes of standing. Some drugs, foods (e.g. asparagus), or diseases (e.g. diabetes mellitus) can also add compounds to the urine which change its odor.

Part 2: Obtain a bottle of “Multistix” from the counter. These are used to test a variety of characteristics in a single sample of urine. Remove one of these dipsticks from the bottle, being careful not to touch any of the pads at one end, then close the bottle tightly again. Notice that the dipstick has eight pads; compare those to the color chart on the bottle and identify what each one will measure. Note also that each measurement has a specific time after exposure to the urine at which it should be observed.

If your urine sample is large enough, dip the dipstick into it for one or two seconds. If the sample is smaller, use a plastic pipette to thoroughly wet each of the test pads with urine. Immediately start timing the reactions. At the specified time noted on the bottle for each test, compare each color to the color chart on the bottle and record your results on the next page. You may need to estimate a value from one of the test pads if the color is between two colors on the chart.

Glucose: __________ mg/dL (30 sec) pH: __________ (60 sec)
Bilirubin: __________ (30 sec) Proteins: __________ mg/dL (60 sec)
Ketones: __________ mg/dL (40 sec) Urobilinogen: __________ mg/dL (60 sec)
Specific Gravity: __________ (45 sec) Nitrite: __________ (60 sec)
Blood: __________ (60 sec) Leukocytes: __________ (2 minutes)

Based on the following information, indicate whether each of your measurements is within the “normal” range for a healthy individual:
a) There should normally be no **glucose** ("negative") in the urine. Any amount in the urine is considered abnormal and usually indicates a high concentration in glucose in the blood (hyperglycemia), most often in people with diabetes mellitus.

b) **Bilirubin** is a normal waste product of hemoglobin breakdown. Most of it is removed from the blood by the liver, but small amounts are usually present in normal urine. However, its concentration is usually below the level which can be detected by a test strip, so the expected result is "negative". Higher levels usually indicate damage to the liver or blockage of its formation of bile, or excessive damage to circulating erythrocytes (hemolysis).

c) **Ketones** are produced by the breakdown of fats, but are usually present in the blood in only small amounts. They will thus also be present in the urine in only small amounts, normally below the level which can be detected by a test strip, so the expected result is "negative". Higher levels usually indicate excessive breakdown of fats which occurs when the body is not getting enough energy from the metabolism of sugar, most often in people with diabetes mellitus.

d) The **specific gravity** of urine is a measurement of its osmolarity (total concentration of solutes) so it is a way to assess the kidney’s ability to concentrate urine. Pure distilled water (no solutes) has a specific gravity of 1.000, and the addition of solutes such as those listed in Table 23.2 of your Saladin text will increase that. Fresh urine normally has a specific gravity between 1.005 (very dilute) and 1.030 (quite concentrated). Along with the volume and color of the urine, specific gravity helps determine if a person is consuming enough water and if their kidneys are functioning normally.

e) There should normally be no **blood** in the urine. Its presence indicates bleeding in one of the organs through which the urine passes.

f) **pH** is a measurement of the acid/base balance of the urine. It uses a "logarithmic" scale in which each unit of change indicates a 10-fold change in acidity. By definition, a pH of 7.00 is neutral – neither acidic nor basic. The pH of fresh urine can range from 5 to 8, but it is usually slightly acidic, with a pH of approximately 6.0. Diet can significantly affect this as well, as can certain drugs or diseases. Bacterial infections of the urinary tract, in particular, raise the pH of the urine, making it more basic.

g) **Proteins** are normally present in urine in very small amounts, often below the level which can be detected by a test strip, so the expected result is “negative” or “trace”. Higher concentrations of protein in the urine usually indicate damage to the kidney and are usually seen in people with high blood pressure, diabetes mellitus, or kidney infections.

h) **Nitrites** are produced by a number of metabolic pathways in human physiology, but their concentration in the blood are normally so low that only minute amounts are excreted into the urine and a “negative” result is expected. Nitrites are also produced by many types of bacteria, so when they do appear in the urine it usually indicates infection of one of the organs of the urinary system.

i) Like bilirubin, **urobilinogen** is a normal waste product of erythrocyte breakdown and hemoglobin metabolism. Most urobilinogen is removed from the blood by the liver, but small amounts are usually present in urine. In fact, urobilinogen is produced by the metabolism of bilirubin itself, and a further breakdown product is the primary urochrome which gives the urine its yellow color. Higher levels of urobilinogen usually indicate damage to the liver or blockage of bile formation, or increased hemolysis of erythrocytes in the blood.

j) Only a very small number of **leukocytes** are normally found in the urine, so a “negative” result is expected. Leukocytes form the immune cells of the body, however, so they will be present in large numbers wherever an infection or inflammation is occurring and detectable numbers of them in the urine usually indicates such an infection or inflammation in one of the organs of the urinary system.
Questions for discussion:

Without referring back the information above (unless you need to) explain to the other members of your lab group what diseases or disorders might result in each of the following:

a) A concentration of 250 mg/dL of glucose in your urine

b) Large amounts of bilirubin and urobilinogen in your urine

c) A concentration of 100 mg/dL of ketones in your urine

d) The specific gravity of your urine rose to 1.050

e) Large numbers of leukocytes in your urine

f) Large amounts of blood in your urine

g) A concentration of 250 mg/dL of protein in your urine

Part 3: Properly dispose of the materials you used for urinalysis. Dump any remaining urine down the drain, rinse the cup, and throw it in the garbage. Urinalysis test strips can also be discarded in the garbage. Place the tightly capped bottle of test strips back on the counter at the side of the lab.

THE URINARY ANATOMY OF THE LIVING HUMAN – At Home Exercise

Exercise 16: On yourself or another person, identify the location of the kidneys, ureters, bladder, and urethra. This will require the removal of clothing (do not do it through your clothes), so please do this at home. Use a pen (preferably water soluble) to draw these structures on the skin. Pay attention to the location of the kidneys relative to the ribs, of the ureters relative to the vertebrae, and of the bladder and urethra relative to the pubic bone. Identify the opening of the urethra on yourself, including its relationship to the opening of the vagina (use a mirror) if you are female. If you have a willing partner of the other sex, identify her or his urethral opening as well.

If you wish, show your drawings to your friends and family and then go take a shower to wash them off.