The Urinary System
Function of the Urinary System

- cleansing the blood and ridding the body of waste.
- regulation of pH, a function shared with the lungs and the buffers in the blood.
- regulation of blood pressure (a role shared with the heart and blood vessels)
- regulating the concentration of solutes in the blood.
- the kidney is important in determining the concentration of rbc. Eighty-five percent of the erythropoietin (EPO) produced to stimulate red blood cell production is produced in the kidneys.
- The kidneys perform the final synthesis step of vitamin D production, converting calcidiol to calcitriol, the active form of vitamin D.
- The urinary system, controlled by the nervous system, also stores urine until a convenient time for disposal.
- provides the anatomical structures to transport this waste liquid to the outside of the body.
Watch this video (http://openstaxcollege.org/l/urineintro) from the Howard Hughes Medical Institute for an introduction to the urinary system.
Physical Characteristics of Urine

- Characteristics of the urine change, depending on influences such as water intake, exercise, environmental temperature, nutrient intake, and other factors.
- Some of the characteristics such as color and odor are rough descriptors of your state of hydration.
<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Normal Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Color</td>
<td>Pale yellow to deep amber</td>
</tr>
<tr>
<td>Odor</td>
<td>Odorless</td>
</tr>
<tr>
<td>Volume</td>
<td>750–2000 mL/24 hour</td>
</tr>
<tr>
<td>pH</td>
<td>4.5–8.0</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>1.003–1.032</td>
</tr>
<tr>
<td>Osmolality</td>
<td>40–1350 mOsmol/kg</td>
</tr>
<tr>
<td>Urobilinogen</td>
<td>0.2 – 1.0 mg/100ml</td>
</tr>
<tr>
<td>WBC</td>
<td>0-2 HPF (high-power field of microscope)</td>
</tr>
<tr>
<td>Leukocyte Esterase</td>
<td>None</td>
</tr>
<tr>
<td>Protein</td>
<td>None or trace</td>
</tr>
<tr>
<td>Bilirubin</td>
<td>&lt;0.3mg/100 ml</td>
</tr>
<tr>
<td>Ketones</td>
<td>None</td>
</tr>
<tr>
<td>Nitrates</td>
<td>None</td>
</tr>
<tr>
<td>Blood</td>
<td>None</td>
</tr>
<tr>
<td>Glucose</td>
<td>None</td>
</tr>
</tbody>
</table>
Characteristics of Urine

- Normally, only traces of protein are found in urine, and when higher amounts are found, damage to the glomeruli is the likely basis.
- Unusually large quantities of urine may point to diseases like diabetes mellitus or hypothalamic tumors that cause diabetes insipidus.
- The color of urine is determined mostly by the breakdown products of red blood cell destruction. The “heme” of hemoglobin is converted by the liver into water-soluble forms that can be excreted into the bile and indirectly into the urine. This yellow pigment is urochrome. Urine color may also be affected by certain foods like beets, berries, and fava beans. A kidney stone or a cancer of the urinary system may produce sufficient bleeding to manifest as pink or even bright red urine. Diseases of the liver or obstructions of bile drainage from the liver impart a dark “tea” or “cola” hue to the urine. Dehydration produces darker, concentrated urine that may also possess the slight odor of ammonia.
- Most of the ammonia produced from protein breakdown is converted into urea by the liver, so ammonia is rarely detected in fresh urine.
- In diabetes mellitus, glucose appears in the urine. The osmotic nature of glucose attracts water, leading to its loss in the urine. In the case of diabetes insipidus, insufficient pituitary antidiuretic hormone (ADH) release or insufficient numbers of ADH receptors in the collecting ducts reduce water absorption, resulting in high volumes of very dilute urine.
Characteristics of Urine

- The pH (hydrogen ion concentration) of the urine can be affected by diet: meats lower the pH, whereas citrus fruits, vegetables, and dairy products raise the pH. Chronically high or low pH can lead to disorders, such as the development of kidney stones or osteomalacia.

- Specific gravity is a measure of the quantity of solutes per unit volume of a solution and is traditionally easier to measure than osmolarity. Urine will always have a specific gravity greater than pure water (water = 1.0) due to the presence of solutes. Laboratories can now measure urine osmolarity directly, which is a more accurate indicator of urinary solutes than specific gravity. Remember that osmolarity is the number of osmoles or milliosmoles per liter of fluid (mOsmol/L).

- Cells are not normally found in the urine. The presence of leukocytes may indicate a urinary tract infection. Leukocyte esterase is released by leukocytes; if detected in the urine, it can be taken as indirect evidence of a urinary tract infection (UTI).

- Protein does not normally leave the glomerular capillaries, so only trace amounts of protein should be found in the urine, approximately 10 mg/100 mL in a random sample. If excessive protein is detected in the urine, it usually means that the glomerulus is damaged and is allowing protein to “leak” into the filtrate.
Characteristics of Urine

- Ketones are byproducts of fat metabolism. Finding ketones in the urine suggests that the body is using fat as an energy source in preference to glucose. In diabetes mellitus when there is not enough insulin (type I diabetes mellitus) or because of insulin resistance (type II diabetes mellitus), there is plenty of glucose, but without the action of insulin, the cells cannot take it up, so it remains in the bloodstream. Instead, the cells are forced to use fat as their energy source, and fat consumed at such a level produces excessive ketones as byproducts. These excess ketones will appear in the urine. Ketones may also appear if there is a severe deficiency of proteins or carbohydrates in the diet.

- Nitrates (NO₃⁻) occur normally in the urine. Gram-negative bacteria metabolize nitrate into nitrite (NO₂⁻), and its presence in the urine is indirect evidence of infection.

- There should be no blood found in the urine. It may sometimes appear in urine samples as a result of menstrual contamination, but this is not an abnormal condition.
# Urine Volumes

<table>
<thead>
<tr>
<th>Volume Condition</th>
<th>Volume</th>
<th>Cause</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>1–2 L/day</td>
<td></td>
</tr>
<tr>
<td>Polyuria</td>
<td>&gt;2.5 L/day</td>
<td>Diabetes mellitus; diabetes insipidus; excess caffeine or alcohol; kidney disease; certain drugs, such as diuretics; sickle cell anemia; excessive water intake.</td>
</tr>
<tr>
<td>Oliguria</td>
<td>300–500 mL/day</td>
<td>Dehydration; blood loss; diarrhea; cardiogenic shock; kidney disease; enlarged prostate.</td>
</tr>
<tr>
<td>Anuria</td>
<td>&lt;50 mL/day</td>
<td>Kidney failure; obstruction, such as kidney stone or tumor; enlarged prostate.</td>
</tr>
</tbody>
</table>
Gross Anatomy of Urine Transport

- Urethra
- Bladder
- Ureter
The **urethra** transports urine from the bladder to the outside of the body for disposal. The **urethra is the only urologic organ** that shows any significant anatomic difference between males and females; all other urine transport structures are identical.

- Voiding is regulated by an involuntary autonomic nervous system-controlled **internal urinary sphincter**, **consisting of** smooth muscle and voluntary skeletal muscle that forms the **external urinary sphincter** below it.
The urinary bladder collects urine from both ureters. The bladder lies anterior to the uterus in females, posterior to the pubic bone and anterior to the rectum. During late pregnancy, its capacity is reduced due to compression by the enlarging uterus, resulting in increased frequency of urination. In males, the anatomy is similar, minus the uterus, and with the addition of the prostate inferior to the bladder. The bladder is partially retroperitoneal (outside the peritoneal cavity) with its peritoneal-covered “dome” projecting into the abdomen when the bladder is distended with urine.

The bladder is a highly distensible organ comprised of smooth muscle called the detrusor muscle.

Volumes in adults can range from nearly zero to 500–600 mL.

The detrusor muscle contracts with significant force in the young. The bladder’s strength diminishes with age, but voluntary contractions of abdominal skeletal muscles can increase intra-abdominal pressure to promote more forceful bladder emptying. Such voluntary contraction is also used in forceful defecation and childbirth.
Micturition is a less-often used, but proper term for urination or voiding.

It results from an interplay of involuntary and voluntary actions by the internal and external urethral sphincters. When bladder volume reaches about 150 mL, an urge to void is sensed but is easily overridden. Voluntary control of urination relies on consciously preventing relaxation of the external urethral sphincter to maintain urinary continence. As the bladder fills, subsequent urges become harder to ignore.

Ultimately, voluntary constraint fails with resulting incontinence, which will occur as bladder volume approaches 300 to 400 mL. The micturition reflex is active in infants but with maturity, children learn to override the reflex by asserting external sphincter control, thereby delaying voiding.
As urine passes through the ureter, it does not passively drain into the bladder but rather is propelled by waves of peristalsis.

Going down the bladder, it creates an one-way valve (a physiological sphincter rather than an anatomical sphincter) that allows urine into the bladder but prevents reflux of urine from the bladder back into the ureter. Children born lacking this oblique course of the ureter through the bladder wall are susceptible to “vesicoureteral reflux,” which dramatically increases their risk of serious UTI. Pregnancy also increases the likelihood of reflux and UTI.

The ureters are approximately 30 cm long.
Gross Anatomy of the Kidney
The kidneys lie on either side of the spine in the retroperitoneal space between the parietal peritoneum and the posterior abdominal wall, well protected by muscle, fat, and ribs. They are roughly the size of your fist, and the male kidney is typically a bit larger than the female kidney. The kidneys are well vascularized, receiving about 25 percent of the cardiac output at rest.
The left kidney is located at about the T12 to L3 vertebrae, whereas the right is lower due to slight displacement by the liver.

Upper portions of the kidneys are somewhat protected by the eleventh and twelfth ribs. Each kidney weighs about 125–175 g in males and 115–155 g in females. They are about 11–14 cm in length, 6 cm wide, and 4 cm thick.

On the superior aspect of each kidney is the adrenal gland. The adrenal cortex directly influences renal function through the production of the hormone aldosterone to stimulate sodium reabsorption.
A frontal section through the kidney reveals an outer region called the **renal cortex** and an inner region called the **medulla**.

The renal columns are connective tissue extensions that radiate downward from the cortex through the medulla to separate the most characteristic features of the medulla, the **renal pyramids** and **renal papillae**.

The **papillae** are bundles of collecting ducts that transport urine made by nephrons to the **calyces of the kidney** for excretion.

The **renal** columns also serve to divide the kidney into 6–8 lobes and provide a supportive framework for vessels that enter and exit the cortex.

The pyramids and renal columns taken together constitute the kidney lobes.
Internal Anatomy of the Kidney

- Cortical blood vessels
- Interlobar blood vessels
- Renal vein
- Renal nerve
- Renal artery
- Medulla
- Ureter
- Capsule
- Arcuate blood vessels
- Minor calyx
- Major calyx
- Renal pelvis
- Pyramid
- Papilla
- Renal column
- Cortex
The renal hilum is the entry and exit site for structures servicing the kidneys: vessels, nerves, lymphatics, and ureters.
Blood Flow in the Kidney

Renal artery
Segmental artery
Interlobar artery
Arcuate artery
Interlobular artery
Afferent arteriole
Glomerulus
Efferent arteriole
Peritubular capillaries
Interlobular vein
Arcuate vein
Interlobar vein
Renal vein
Interactive Link

- Visit this [link](http://openstaxcollege.org/l/bloodflow5) to view an interactive tutorial of the flow of blood through the kidney.
Microscopic Anatomy of the Kidney

- **Nephrons: The Functional Unit**
  - Nephrons take a simple filtrate of the blood and modify it into urine. The principle task of the nephron population is to balance the plasma to homeostatic set points and excrete potential toxins in the urine. They do this by accomplishing three principle functions—filtration, reabsorption, and secretion. They also have additional secondary functions that exert control in three areas: blood pressure (via production of renin), red blood cell production (via the hormone EPO), and calcium absorption (via conversion of calcidiol into calcitriol, the active form of vitamin D).
Symptoms of Kidney Failure

- Weakness
- Lethargy
- Shortness of breath
- Widespread Edema
- Metabolic alkalosis
- Metabolic acidosis
- Heart arrhythmia
- Uremia (high levels of urea in the blood)
- Loss of appetite
- Fatigue
- Excessive urination
- Oliguria
The volume of filtrate formed by both kidneys per minute is termed the **glomerular filtration rate (GFR)**.

The heart pumps about 5 L blood per min under resting conditions. Approximately 20 percent or one liter enters the kidneys to be filtered.

On average, this liter results in the production of about 125 mL/min filtrate produced in men (range of 90 to 140 mL/min) and 105 mL/min filtrate produced in women (range of 80 to 125 mL/min).

This amount equates to a volume of about 180 L/day in men and 150 L/day in women.

Ninety-nine percent of this filtrate is returned to the circulation by reabsorption so that only about 1–2 liters of urine are produced per day.
The entire volume of the blood is filtered through the kidneys about 300 times per day, and 99 percent of the water filtered is recovered.

The GFR is influenced by hydrostatic pressure (pressure produced by a fluid against a surface. If you have a fluid on both sides of a barrier, both fluids exert a pressure in opposing directions. Net fluid movement will be in the direction of the lower pressure) and colloid osmotic pressure.

Under normal circumstances, hydrostatic pressure is significantly greater and filtration occurs. The hydrostatic pressure of the glomerulus depends on systemic blood pressure, autoregulatory mechanisms, sympathetic nervous activity, and paracrine hormones.

The kidney can function normally under a wide range of blood pressures due to the autoregulatory nature of smooth muscle.
With up to 180 liters per day passing through the nephrons of the kidney, it is quite obvious that most of that fluid and its contents must be reabsorbed. That recovery occurs in the PCT, loop of Henle, DCT, and the collecting ducts.

Various portions of the nephron differ in their capacity to reabsorb water and specific solutes. While much of the reabsorption and secretion occur passively based on concentration gradients, the amount of water that is reabsorbed or lost is tightly regulated.

This control is exerted directly by ADH and aldosterone, and indirectly by renin.

Most water is recovered in the PCT, loop of Henle, and DCT. About 10 percent (about 18 L) reaches the collecting ducts. The collecting ducts, under the influence of ADH, can recover almost all of the water passing through them, in cases of dehydration, or almost none of the water, in cases of over-hydration.
1. Renin–Angiotensin–Aldosterone
2. Antidiuretic Hormone (ADH)
3. Endothelin
   - Endothelins are extremely powerful vasoconstrictors. They are produced by endothelial cells of the renal blood vessels, mesangial cells, and cells of the DCT. They do not typically influence blood pressure in healthy people. On the other hand, in people with diabetic kidney disease, endothelin is chronically elevated, resulting in sodium retention. They also diminish GFR by damaging the podocytes and by potently vasoconstricting both the afferent and efferent arterioles.
4. Natriuretic Hormones
   - Natriuretic hormones stimulate the kidneys to excrete sodium—an effect opposite that of aldosterone. Natriuretic hormones act by inhibiting aldosterone release and therefore inhibiting Na+ recovery in the collecting ducts. If Na+ remains in the forming urine, its osmotic force will cause a concurrent loss of water. Natriuretic hormones also inhibit ADH release, which of course will result in less water recovery. Therefore, natriuretic peptides inhibit both Na+ and water recovery.
5. Parathyroid Hormone
The major hormones influencing total body water are ADH, aldosterone, and ANH.

Circumstances that lead to fluid depletion in the body include blood loss and dehydration.

Blood volume is important in maintaining sufficient blood pressure, and there are nonrenal mechanisms involved in its preservation, including vasoconstriction, which can act within seconds of a drop in pressure.

Thirst mechanisms are also activated to promote the consumption of water lost through respiration, evaporation, or urination.

Hormonal mechanisms are activated to recover volume while maintaining a normal osmotic environment. These mechanisms act principally on the kidney.
Regulation of Fluid Volume and Composition

- Diuretics increase urine volume.
- Mechanisms for controlling Na+ concentration in the blood include the renin–angiotensin–aldosterone system and ADH.
  - When Na+ is retained, K+ is excreted;
  - when Na+ is lost, K+ is retained.
  - When circulating Ca++ decreases, PTH stimulates the reabsorption of Ca++ and inhibits reabsorption of HPO₄²⁻.
  - pH is regulated through buffers, expiration of CO₂, and excretion of acid or base by the kidneys.
  - The breakdown of amino acids produces ammonia. Most ammonia is converted into less-toxic urea in the liver and excreted in the urine.
  - Regulation of drugs is by glomerular filtration, tubular secretion, and tubular reabsorption.
The Urinary System and Homeostasis

Vitamin D Synthesis
Erythropoeisis
Blood Pressure Regulation
Regulation of Osmolarity
Regulation of Electrolytes
pH Regulation