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DEPARTMENT: NURSING

The composition of urine is related to the current composition of the blood, and the current regulation of nephrons. Filtrate is comprised of all blood components that are able to pass through the filtration membrane of the nephron. The filtration membrane blocks molecules from entering the filtrate based upon their size and charge. As a result, large elements like blood cells, platelets, antibodies, and albumin are excluded, as are some charged molecules.

Following filtrate production, the components in filtrate are modified by the nephron tubules until the final composition of urine has been attained in the collecting ducts. In the tubules, a good deal of water, electrolytes, and nutrients are removed from the filtrate and returned to the blood in the peritubular capillaries and vasa recta. Some additional wastes are also removed from the blood in those same capillaries and transported into the tubular filtrate. Both filtrate generation and nephron activity governing final urine composition are tightly regulated.

Typical constituents of filtrate and urine

All typical blood components able to pass through the filtration membrane, such as ions, glucose, amino acids, vitamins, hormones, and wastes create a filtrate composition very similar to plasma, but missing large and negatively charged molecules. The glomeruli create about 180 liters of this filtrate every day, yet you excrete less than two liters of waste you call urine. The nephron tubules are responsible for returning the vast majority of needed constituents to the blood. The actual constituents in the final urine depend highly, and represent a concentrated solution of both waste and excess nutrients.

Nitrogenous wastes

Nitrogen wastes are produced by the breakdown of proteins during normal metabolism. Proteins are broken down into amino acids, which in turn are deaminated by having their nitrogen groups removed. Deamination is the process by which amino groups are removed from amino acids. The amino (NH2) groups are subsequently converted into ammonia (NH3), ammonium ion (NH4+). The liver rapidly converts these toxic molecules into less toxic urea (Figure 1). Uric acid is produced by the metabolism of purines (a type of nucleic acids). Creatinine is a metabolite of creatine phosphate in muscles. These four nitrogenous wastes are removed from the blood by nephrons. Human urinary wastes typically contain primarily urea with small amounts of ammonium and creatinine, and very little uric acid.

Figure 1. This figure shows the chemical structure of ammonia, urea, uric acid, and creatinine. For the molecular structures, nitrogen = blue, carbon = black, oxygen = red, and hydrogen = white.

Characteristics of the urine change, depending on influences such as water intake, exercise, environmental temperature, nutrient intake, and other factors (See Table 1). Some of the characteristics such as color and odor are rough descriptors of your state of hydration.

Table 1. Normal Urine Characteristics

Characteristic Normal values

Color Pale yellow to deep amber

Odor Odorless

Volume 750–2000 mL/24 hour

pH 4.5–8.0

Specific gravity 1.003–1.032

Osmolarity 40–1350 mOsmol/kg

Urobilinogen 0.2–1.0 mg/100 mL

White blood cells 0–2 HPF (per high-power field of microscope)

Leukocyte esterase None

Protein None or trace

Bilirubin <0.3 mg/100 mL

Ketones None

Nitrites None

Blood None

Glucose NoneThis color chart shows different shades of yellow and associates each shade with hydration or dehydration.

Figure 2. Urine Color

Characteristics of a healthy urine specimen

Color

The color of urine is determined mostly by the breakdown products of red blood cell destruction (Figure 2). 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, and certain medications. Dehydration produces darker, concentrated urine.

Specific gravity

Specific gravity is an easy way to estimate the osmolarity of a urine sample. The specific gravity of urine is a ratio of the density of a urine specimen to water. The density of water is 1.000 g/ml. Because urine samples always contain solutes, even a urine sample that is very pale in color will have a density that is slightly higher than water. The urine sample of a dehydrated person will be darker in color, and will have a density that is substantially higher than water, as it will contain a great deal of solutes. As a result, the specific gravity of a well-hydrated individual’s urine will be roughly 1.003, whereas the specific gravity of a dehydrated individual’s urine will be closer to 1.032.

Laboratories can now measure osmolarity directly, which provides a more accurate assessment of the urine specimen. Remember that osmolarity is the number of osmoles or milliosmoles per liter of fluid (mOsmol/L). Urine osmolarity ranges from a low of 50–100 mOsmol/L to as high as 1200 mOsmol/L H2O.

Odor

Fresh urine often has very little odor. Most of the ammonia produced from protein breakdown is converted into urea by the liver, so ammonia is rarely detected in fresh urine. The strong ammonia odor you may detect in bathrooms or alleys is due to the breakdown of urea into ammonia by bacteria in the environment. About one in five people detect a distinctive odor in their urine after consuming asparagus; other foods such as onions, garlic, and fish can impart their own aromas! These food-caused odors are harmless.

pH

The pH (hydrogen ion concentration) of the urine can vary more than 1000-fold, from a normal low of 4.5 to a maximum of 8.0. A urine specimen is typically slightly acidic with a pH of roughly 6.0, but pH can vary substantially with an individual’s diet. Individuals who consume a lot of meat and protein will tend to have a more acidic urine specimen (pH below 6.0). Individuals with diets low in protein and high in fruits and vegetables (such as vegan diets) will tend to have an alkaline urine specimen (pH above 7.0). Ideally, urine should be acidic, as a lower pH will limit bacterial growth and urinary tract infections.

Urine volume

Urine volume varies considerably. The normal range is one to two liters per day. The kidneys must produce a minimum urine volume of about 500 mL/day to rid the body of wastes. Output below this level may be caused by severe dehydration or renal disease and is termed oliguria. The virtual absence of urine production is termed anuria. Excessive urine production is polyuria..

Table 2. Urine Volumes

Volume condition Volume Causes

Normal 1–2 L/day

Polyuria >2.5 L/day Diabetes mellitus; diabetes insipidus; excess caffeine or alcohol; kidney disease; certain drugs, such as diuretics; sickle cell anemia; excessive water intake

Oliguria 300–500 mL/day Dehydration; blood loss; diarrhea; cardiogenic shock; kidney disease; enlarged prostate

Anuria <50 mL/day Kidney failure; obstruction, such as kidney stone or tumor; enlarged prostate

In diabetes mellitus, blood glucose levels exceed the number of available sodium-glucose transporters in the kidney, and 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 release or insufficient numbers of antidiuretic hormone receptors in the collecting ducts means that too few water channels are inserted into the cell membranes that line the collecting ducts of the kidney. Insufficient numbers of water channels (aquaporins) reduce water absorption, resulting in high volumes of very dilute urine.

Urinalysis

Urinalysis (urine analysis) is performed to provide clues to diseases, including many renal diseases. For example, if a urinalysis detects substances in the urine that should not be able to cross the filtration membrane, such as blood or protein, this could indicate renal damage or disease. Therefore, the purpose of urinalysis is to identify any potentially abnormal constituents in urine.

Abnormal constituents 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.

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). The presence of erythrocytes in the urine suggests trauma to the urinary system, a pathological condition such as kidney stones, or damage to the glomeruli.

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.

Ketones are byproducts of fat metabolism. While normally present at low levels, finding excessive 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.

Glucose is normally present in filtrate. However, it should be reabsorbed by the proximal convoluted tubules. Presence of glucose in urine suggests that the blood has a tremendous excess of glucose that is overwhelming glucose transporters in the proximal convoluted tubules. Excess glucose in the blood can occur when an individual recently ate a meal excessively rich in carbohydrates, or when the individual has diabetes. These two situations can be discerned by whether the urine sample also has elevated ketones.

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.

Bile pigments in a urine specimen suggest a pathology such as hepatitis, cirrhosis, or gallstones.