Skeletal and muscular systems

CONNECTIONS

COMPARE the bones of the bullfrog's hind legs with those of a *CROCODILE*. The crocodile's femur, fibula, and tibia are relatively short and very robust. They are able to support the crocodile's great weight when it is walking. In contrast, the bullfrog's tibio-fibula and femur are very long, allowing the attached muscles to provide great thrust when the frog is leaping.

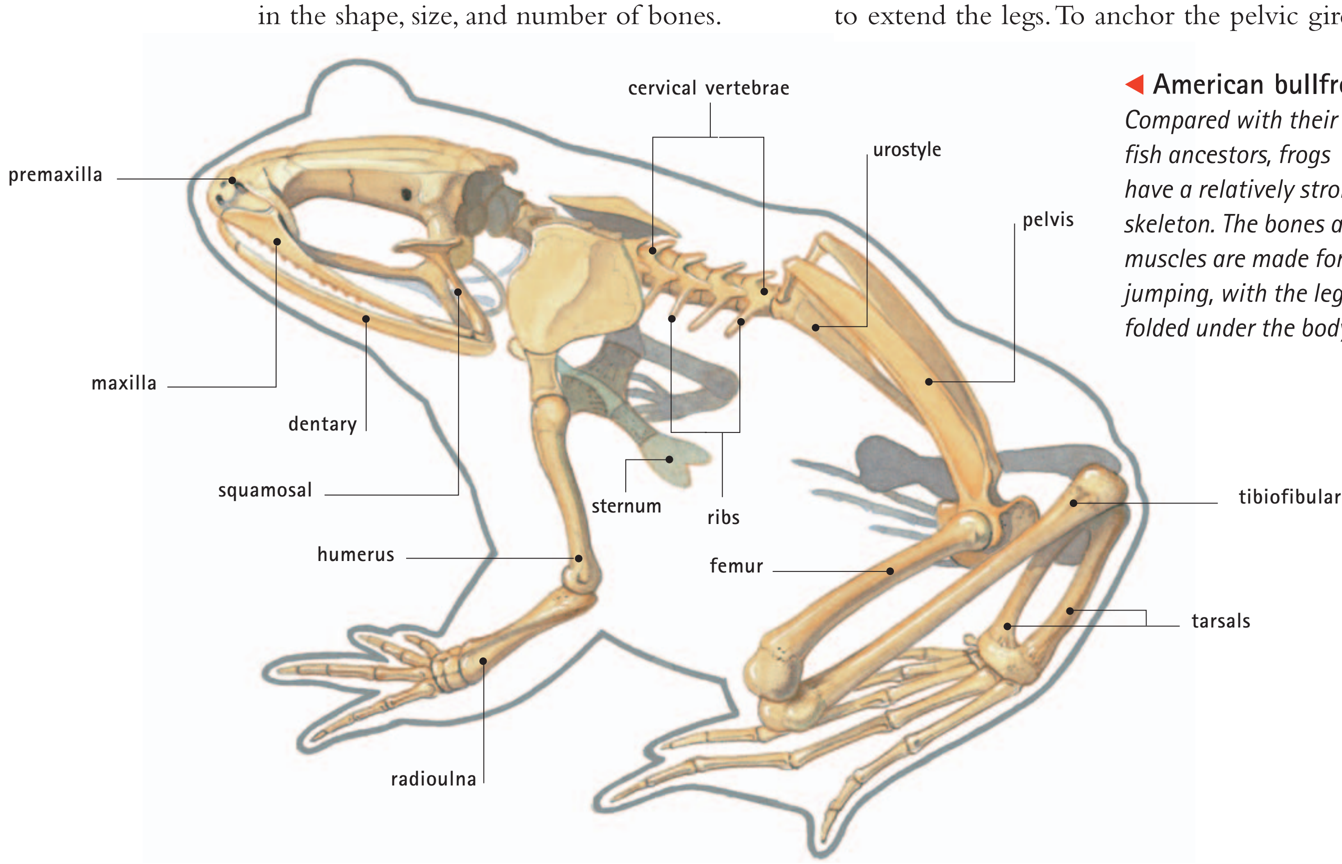
The skeleton of a frog is highly modified from the elongated form of a fish or a newt. In the evolutionary move from land to water over millions of years, the skeleton of amphibians has become stronger in comparison with those of fish, because air provides much less support for body weight than does water. The amphibian vertebral column supports the head and viscera (the organs of the abdominal cavity) and acts as a brace for the appendicular skeleton (the limbs and girdles) that raise the body off the ground.

Frogs and toads, in contrast to salamanders and newts, have a skeletal frame and body shape adapted for jumping rather than for walking. The body is shorter and more rounded, the tail has been lost, and the limbs—particularly the hind limbs—are long. The legs fold beneath the trunk rather than jutting out of the body at right angles, as in newts, salamanders, and early amphibians. Along with these differences are corresponding differences in the shape, size, and number of bones.

A frog's vertebral column has only one cervical (neck) vertebra and four to eight trunk vertebrae. The trunk vertebrae have peglike extensions, called zygapophyses, that interlock and brace the vertebral column, allowing only a small degree of bending from side to side. The strong forelimbs and flexible pectoral (shoulder) girdle absorb the impact of landing after a jump. Unlike other amphibians, frogs and toads have very short or completely missing ribs. However, they do have a breastbone (sternum), to which breathing muscles attach.

The forelimb bones of frogs follow the basic plan of a pentadactyl limb, with the humerus as an upper arm bone, and the carpals, metacarpals, and phalanges forming the bones of the "wrist" and "hand." However, the two lower forearm bones—the radius and ulna—are fused as the radioulna. The fifth digit, the "thumb," is very short.

The power for jumping comes from the lever system of muscles and bone that is used to extend the legs. To anchor the pelvic girdle



American bullfrog
Compared with their fish ancestors, frogs have a relatively strong skeleton. The bones and muscles are made for jumping, with the legs folded under the body.

IN FOCUS

Muscles and leaping frogs

All frogs and toads have the ability to jump, or at the very least, hop. When they jump, the forelimbs push off first, and straighten against the body, followed by the powerful thrust of the hind limbs. This action sends the animal in a shallow arc through the air at a launch angle of about 45 degrees. Just before landing, the animal extends its forelimbs, which flex at the wrist as the animal lands "hands" first, with the pectoral (shoulder) girdle absorbing the force of the impact.

The hind limbs provide the main force in jumping, and these muscles are particularly powerful and efficient. A large muscle called the semimembranosus muscle is connected between the pelvis and a point on the leg just below the knee. When this muscle contracts, it pulls the upper part of the hind limb backward. The muscle generates power throughout its range of contraction, not just at the beginning; this is unusual for skeletal muscle in vertebrates.

▶ *The hind limbs of a frog are well adapted for swimming as well as for jumping. When the frog is swimming, its hind legs force it through the water, with the webbed toes providing forward thrust.*

▼ *The long, shallow leap of this frog is powered by large leg muscles. The forelimbs are used to absorb the impact on landing.*

and hind limbs firmly, the lower vertebral column is greatly stiffened. The single sacral vertebra is attached to a highly elongated pectoral girdle. Behind this, the remaining vertebrae (postsacral vertebrae) are fused into a single structure, the urostyle. The pelvic girdle, which on each side is made up of three fused bones—the ilium, ischium, and pubis—absorbs much of the impact of landing after a jump.

The hind limb bones, like the bones of the forelimbs, follow the basic plan of a pentadactyl limb, but with the fusion of the two lower leg bones—the tibia and fibula—to form the tibiofibula. Unlike the forelimb, the hind limb has retained the full five digits.

The skull of anurans (frogs and toads) is broad and flat, and compared with the skull of a bony fish or a salamander it has fewer bones. The jaws are adapted for grasping rather than chewing and for the attachment of the muscular, extendable tongue.

Cells and their functions

CONNECTIONS

COMPARE the cells of a mammal, such as a ***HIPPOPOTAMUS***, with those of a nonmammalian vertebrate such as a ***JACKSON'S CHAMELEON***. In mammals the cells do not possess a nucleus, but in other vertebrates they do.

Cells in multicellular organisms specialize to become different in structure and function. For example, animal nerve cells, called neurons, transmit information gathered from all around the body and from the outside world to the brain, and then trigger an appropriate response. Specialized neurons receive different kinds of information from various sense organs: visual information through eyes or light-sensitive cells; sound information through ears; touch information from whiskers or skin; and chemical information such as taste and smell. Chemical receptors are located in the mouth and nose of most vertebrates but may be mounted on antennae or scattered all over the body surface in other animals. Some animals have additional senses, for example for detecting vibrations, electrical signals, or magnetism. However, regardless of its source, all sensory information is ultimately processed by some part of the nervous system, and neurons are specialized to do the job as quickly and efficiently as possible.

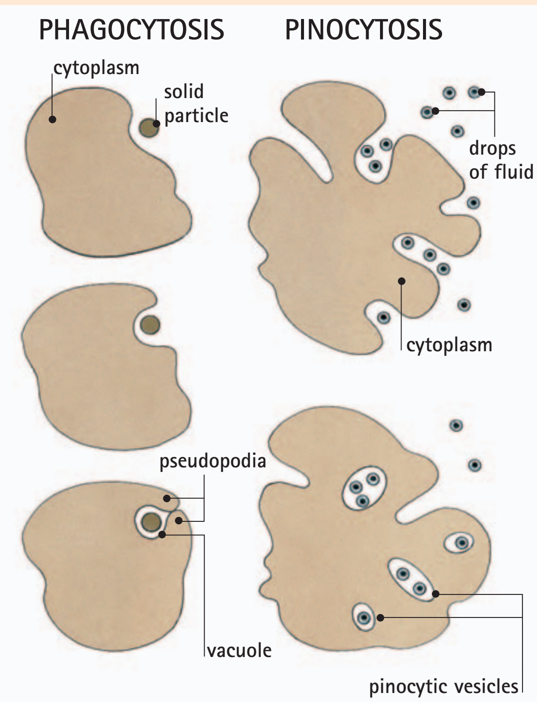
Muscle cells

Differentiation is the process by which cells become specialized. Neurons are just one example, and muscle cells are another. Muscle cells, or myocytes, make proteins that allow the cells to contract. When muscle cells work together, they can generate movement on a much larger scale—that of the whole muscle or whole animal. Humans and other vertebrates have three types of muscle cells: skeletal, smooth, and cardiac. Skeletal muscles are attached to the skeleton and move the torso and limbs. As skeletal muscle cells form, they align to create long linear fibers, hence their alternative name: striated (or striped) muscle. Skeletal muscle cells also fuse to create larger

IN FOCUS

How cells eat

All cells need to harvest macromolecules to provide the building blocks of their own proteins, carbohydrates, fats, and nucleic acids. Cells also need energy to assemble and disassemble these molecules. Autotrophs, or "self-feeders," can create their own macromolecules from inorganic raw materials, such as carbon dioxide, water, and light energy. Plants and bacteria that use photosynthesis to construct sugar and other molecules are autotrophs. Animals and fungi are heterotrophs, which obtain macromolecules and energy by eating or decomposing the tissues or cells of other organisms. All heterotrophs are ultimately dependent on autotrophs for food, and the vast majority also depend on oxygen, a byproduct of photosynthesis.



► *In phagocytosis, large solid particles are enclosed by folds of the plasma membrane. In pinocytosis, the membrane folds inward, beneath the molecule, enclosing dissolved material.*

cells with many nuclei, which contract in one dimension. Smooth muscle cells are found in the walls of the stomach, intestines, and blood vessels. These cells are smaller and less organized than skeletal muscle cells and contract in waves. Cardiac muscle cells assemble to form the heart, which contracts repeatedly and without tiring to pump blood around an animal's body.

The sex cells

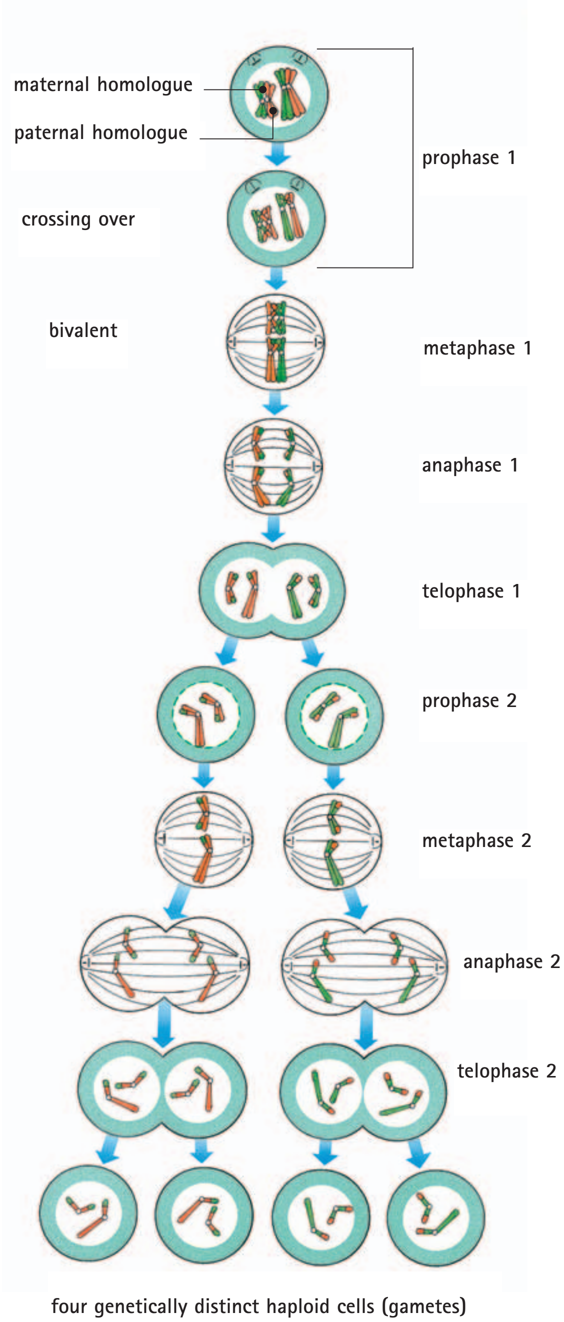
Sex cells, or gametes, are specialized to create offspring. Male gametes, called spermatozoa or sperm, have a tail called a flagellum (plural, flagella) that helps them move to find an egg for fertilization. Female gametes, called eggs or ova (singular, ovum), are typically large and carry nutrients and energy to sustain the zygote, or fertilized egg, at the beginning of development. Both eggs and sperm are haploid, carrying only half the DNA normally needed by a new individual. When each contributes its DNA to the zygote, the zygote is then diploid, having two copies of each chromosome. If sex cells were diploid, the next generation would have four sets of instructions (tetraploid), the next would have eight copies (octoploid), and so on. Meiosis is the process of cell division by which the number of DNA-containing structures, called chromosomes, is halved to produce haploid gametes.

Guard cells

Other cells guard against damage. Epithelial cells cover all surfaces in the human body, holding organs and tissues together and protecting them from invaders like bacteria and viruses. Epithelial cells also cover internal surfaces such as the respiratory tract, from the nostrils to the lungs; and the digestive tract, from the mouth to the stomach, intestines, and anus. Skeletal tissues, such as bones and cartilage, guard against damage by giving the body structure and protecting internal organs. For example, the rib cage protects the heart, lungs, and liver; and the skull and vertebrae protect the brain and spinal cord.

Plant cells

Plants also have specialized cells. Parenchyma cells in leaves contain chloroplasts that gather light energy and use it to manufacture the sugar glucose from carbon dioxide and water using a process called photosynthesis. Parenchyma cells in the stem and roots store starch. Collenchyma and sclerenchyma cells help provide structural support. Collenchyma cells are stiff but flexible, and are found in younger plants because they give the plant structure without restricting its growth. Sclerenchyma cells are less flexible and are found in older plants. Vascular plants also contain two sorts of conducting tissues: xylem, which carries water from the roots to the rest of the plant; and phloem, which moves food molecules throughout the plant.



◀ MEIOSIS
Each chromosome is made up of a pairing of a paternal homologue (from the father) and a maternal homologue (from the mother). At prophase 1, the chromosomes duplicate, forming X-shaped chromosomes. During a process called crossing over, the chromosomes that form these pairs exchange some genetic material. Telophase 1 produces two new cells containing half the full complement of chromosomes: that is, they are haploid. In prophase 2 onward there is no duplication of DNA. The subsequent phases result in the production of two sibling chromatids, which separate to produce four distinct haploid offspring cells. When a male gamete (sperm) fertilizes (fuses with) a female gamete (egg or ova) the resulting cell, or zygote, has two sets of chromosomes; so, it is diploid.