Curriculum Units by Fellows of the Yale-New Haven Teachers Institute
1985 Volume VII: Skeletal Materials- Biomineralization

Anatomy and Physiology of the Human Knee Joint

Curriculum Unit 85.07.06
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Introduction

This unit takes an indepth look at a very complex part of the human anatomy, the knee joint. There are numerous structures that are found in this joint, classified as a diarthrodial or synovial joint. Study of this area must include a review of the skeletal and muscular systems in order to see how they interact under normal use. Some knee injuries and the pathologies will be considered.

The objectives of this unit are:

1. to introduce the student to the skeletal system with emphasis on the lower extremity;
2. to explain the chemical make-up of bone and the process of ossification;
3. to differentiate between the types of joints in the human body;
4. to introduce the student to the muscular system, with emphasis on those muscle groups of the leg;
5. to describe other structures that are essential for normal movement of this diarthrodial joint, including ligaments, tendons, cartilage and bursa;
6. to explain, demonstrate, and illustrate the coordination of the different systems and each of their specializations;
7. to describe some knee injuries and the pathologies.

The outline of the unit is divided into the following five parts:

I. Bone, as a tissue

a. Histology of bone
b. Other tissues related to bones as organs

II. Skeleton, bones as organs or structures

a. Structure
b. Function

III. Muscles

a. Structure
b. Action of muscles

IV. Knee

a. Special “adaption” for human use
b. Motion

V. Knee Injuries

a. Types
b. Rehabilitation

This unit is designed for use in a high school Human Physiology course, spanning approximately four weeks. The unit’s progression from a simple bony structure to a complex joint should be advantageous in enhancing the student’s comprehension of different, complex, body systems and the way in which they work together.

I. Bone, as a tissue

a. Histology of bone

Bone is a special type of connective tissue that contains cells, extracellular matrix, and mineral. The matrix protein, collagen, is an asymmetric or fibrous material, having mineral salts intertwining amongst them.

Bone is a composite of both organic and inorganic materials. The inorganic material that the skeleton stores is hydroxyapatite (calcium phosphate), magnesium and sodium. Other elements are also found in small amounts, like potassium, magnesium, and chlorine. The elements are found in compound form within the body. The most common compound of the skeleton is calcium phosphate.

Ossification as calcification is another process that continually takes place in bone. This is the hardening of bone by the deposition of calcium phosphate. Sufficient amounts of calcium and phosphate in the blood, are necessary to ensure this deposition and maintain mineralized tissues.

The transfer of elements between bone and blood is done by movement of ions. The process of passive exchange allows for movement of minerals between bone and blood, until an equilibrium is met. The chemical equilibrium between the extracellular solution and bone deposition determines the general level of calcium ions in the extracellular fluid and blood. If blood contains an excess mineral content, it will excrete some and deposits will occur due to the pathological process.

Some calcium exchange between bone and blood is done by ion transfer. Calcium is also regulated by the parathyroid gland that secretes hormones into the blood releasing calcium from the bone when needed. At the cellular level, Vitamin B also plays a role in calcification. It helps the parathyroids monitor calcium levels in the blood and also helps in the absorption of calcium.

The cells that make up bone are:

1. osteoblasts—they are found on the surface of bone and create the matrix and assist in precipitating mineral;
2. osteocytes—aid in bone development and later are buried in the lacunae (cavities) of the matrix and are in charge of tissue maintenance;
3. osteoclasts—are giant cells, usually seen in areas where bone is being resorbed. Spaces are made by these osteoclasts to allow layers of bone (lamellae) to develop between the trabeculae. During this process, Haversian canals are formed, that carry the blood vessels, allowing for a fine vascular system within the bone.

The two types of bone tissue are spongy (trabecular) and compact (densely mineralized). Generally, the exterior portions of the bone organ is compact bone and much of the interior is made up of the porous, spongy bone. Spongy bone, however, constitutes the bony tissue at the initial development of bone. Compact bone must replace the spongy type, at some areas.

Bone can be either:

1. endochondral—bone that was preformed from cartilage;

2. dermal—bone that was never cartilage but directly ossified from membrane, often called membranous bone.

Bone formation actually begins before birth during embryonic development. Ossification (tissue development) begins before birth and continues throughout life. The framework in bone organs are established early in this developmental stage.

Long bones are preformed from a special type of cartilage called anlage. Cartilage cells produce a gelatinous matrix, and assist in the calcification of the matrix. Eventually the cells die and much of the matrix dissolves. The osteoblasts lying on the surface of the growing bone, forming the epitheloid layer, move into the area and begin to form the bone matrix. During deposition of bone, many osteoblasts become entombed by the matrix and become osteocytes. The osteocytes do not die. unlike the cartilage cells, but come in contact with capillaries and other cells. The canaliculi, which are needed for metabolism and are found within bone matrix, connect osteocytes and the capillaries. Bone is a living tissue as the evidence above indicates.

The parts of a long bone are:

1. diaphysis—the shaft
2. epiphysis—the end
3. marrow—a. yellow—contains blood vessels and fat cells
b. red—contains blood forming tissue
4. medullary canal—contains the marrow
5. endosteum—membrane that lines the medullary canal
6. periosteum—membrane that covers the bone and contains blood vessels, nerves, and bone-forming cells.

The initial growth of long bones begins at the primary centers of ossification in the diaphysis with movement outward towards the epiphysis. Here, individual centers are formed as ossification continues at a slower rate than the primary center. In conjunction with this type of ossification, another type is being performed on the surface of the bone, developing thin bony layers, over and over again. Ossification at this level differs from that of replacing cartilage in that the bone matrix between the layers are calcified immediately.

The growth in width for long bones is called appositional growth. This type of ossification continues throughout life and is gradual and controlled, with the periosteum moving outward while older bone internally is being resorbed.

At each epiphysis, a secondary center of long bone ossification is formed, called an epipyseal center. Most cartilage is replaced by bony material but at each end, articular cartilage (forms at ends of bone that are adjacent to joints) remains. There is also a section between the epiphysis and diaphysis called the epiphyseal disk. Elongation of the long bone is performed from this disk, with active growth at the surface near the diaphysis. The width of the disk remains constant because old cartilage is replaced by bony matter while cartilage growth continues at the epiphysis end. When final growth is reached, all cartilage has been replaced by bone and the epiphysis and diaphysis meet at the epiphyseal line. Further growth is impossible.

The bone growth described is more rapid in early life than in later years; and the constant turn-over of cells makes for a complex, lattice-like matrix with a canal system necessary for nutrition, blood supply and nerves.

The function of bone, on a tissue level, include: storage of minerals; the growth and repair of bone; and the conduction of nerves and blood cells to the bone.

b. Other tissues related to bones as organs

There are several types of connective tissue that are essential in proper movement of the body or body parts. Cartilage, bursa, ligaments and tendons are included in this category.

Cartilage is a hard but yielding tissue. Forms of cartilage are hyaline and articular. Hyaline cartilage connects rids with the sternum and also supports the nose, trachea, and part of the larynx. Articular cartilage is found at sites of articulation, like the knee, and help with the support and form of the body.

Bursa, usually found at the interface between two moving structures, are fluid-filled sacs. The two forms of bursa are subcutaneous and synovial. Bursa generally can de found between a tendon and another structure, like bone, or between tendons and ligaments. The presence of a bursa is to reduce friction between two moving surfaces, and along with cartilage, is known as cushions or shock absorbers of the body.

Ligaments are pliable, slightly elastic tissues composed of collagenous bundles. They are found usually between two bones, allowing for mobility of the body.

Tendons are also tough, pliable tissues that are non-elastic. Generally, the tendons join muscle with another structure, like bone or cartilage, also allowing for movement of the body or body parts.

II. Skeleton, bones as organs or structures a. Structure

Bone, as well as being a tissue, are organs. There are 206 bones making up the skeleton and they are classified in five major groups:.

1. Short bones—usually cube-shaped, like bones of the wrist
2. Flat bones—actually thin bones, like those of the ribs
3. Irregular bones—those of various shapes, like those of the vertebrae
4. Long bones—usually cylindrical in shape, like the femur
5. Sesamoid bones—small, rounded bones, usually found at the site of muscle attachment, increasing the function of muscle as a lever

The skeleton itself is divided into two major divisions: a. the axial skeleton, which constitutes the medial section of the body, including the skull, vertebral column (backbone); and ribs; b. the appendicular skeleton, which consists of those bones of the pectoral and pelvic girdles, with emphasis on the limbs of the body.

The skeletal system is an internal framework and the basis for architecture of the body. Genetics, vitamins, and hormones all play a role in the product, an individual's unique framework, and continue to keep the framework as a living part of the body.

b. Function

The function of the skeletal system is to provide protection of the body's internal organs, like ribs protecting the lungs; is the source of attachment for muscles that are needed for movement, as well as, an anchor for tendons and ligaments; as support for the body; and bone, as an organ, contains the marrow where blood cells are manufactured.

III. Muscles

a. Structure

Muscle is a specialized tissue that allows for movement of body parts and organs. Two basic types of tissue are smooth and striated. Smooth, involuntary muscles are found in the walls of most internal organs. Striated muscle comprises all skeletal muscles with the exception of cardiac muscle. Cardiac muscle is the striated, involuntary muscle of the heart. Skeletal muscle is the striated, voluntary muscle that allows for mobility.

Skeletal muscle is a specialized organ that works in cooperation with the skeletal system. The muscle is also a tissue consisting of muscle fibers, each rather uniquely being a cell that is long and thick, the thickest is visible to the naked eye, unlike the fibers of cardiac muscle. The fiber is covered by a membrane called the sarcolemma and contain many nuclei within the membrane. The fiber contains a various number (may be up to 10,000) of myofibrils. Myofibrils are fine threads that run lengthwise in the cell's cytoplasm (sarcoplasm). The myofibrils are bundles of two types of protein filaments, actin and myosin. These filaments are arranged in a pattern giving the entire fiber its striated characteristic. The myosin filaments are thicker than the actin filaments, which combined with the proteins, tropomyosin and troponin, make up the thin filaments. These thick and thin filaments are in a set pattern causing the striations to appear. Other substances found in small amounts are the elements calcium, sodium, chlorine, potassium and magnesium.

The skeletal muscle form is generally divided into three sections, the insertion, origin, and belly. The origin is the rigid, stronger attachment in comparison to the insertion. The insertion moves towards the origin during contraction. The belly is simply the meat of the muscle, found between the two ends, the origin and the insertion.

Muscle may be attached to bone in different ways:. a. through tendons, a type of connective tissue; b. an aponeuroses, which is a flat, broader tissue, formed by the expansion of a tendon; c. connective tissue around the muscle fuses directly to the bone's periosteum. A function of the periosteum is to anchor some ligaments and tendons, a vital connection of the muscular and skeletal systems.

b. Action of muscles

Movement of the body or body part is the essential function of the striated (skeletal) muscle type, although it also exhibits some elasticity. Most striated muscles work in pairs, so that when a muscle/muscle group contracts, another muscle/muscle group will extend. The muscle that contracts is called the agonist, while the one that extends is referred to as the antagonist.

Two types of contractions that may occur as a result of different resistance(s) are isotonic and isometric. Isotonic contraction involves active exercise where movement occurs without a significant change in the resistance. This type of contraction can be achieved by using free weights.

Isometric contraction is also achieved through active exercise but there is no joint movement and the resistance is stable. Pressing your hands against a door frame illustrates this form of contraction.

IV. Knee

a. Special “adaption” for human use

The bones of the lower extremity are the femur (thigh), tibia (larger done of the lower leg) and the fibula (smaller bone of the lower leg). The tarsals (ankle), metatarsals (foot), and phalanges (toes) comprise the other bones of the lower extremity. The patella (kneecap) forms the junction between the femur and, tibia and fibula.

The femur is the strongest and longest bone of the human body and is aided by the tibia and fibula in providing the strength and support of the body.

The patella, or kneecap, is located between the femur and tibia. Its connection on a skeletal level is provided by connective tissue, including ligaments and tendons, along with the skin. The connective tissues provide attachment, but the relative necessity of this bony structure appears puzzling when looking at a skeleton.

The patella is a triangular shaped bone that protects the diarthrodial (hinged) joint. Its positioning in front of the articulation of the femur and tibia, indicates its purpose is the restriction of complete, free movement. The knee joint is generally described as a joint, with limited movement, much like a door hinge. If the patella was not in position, hyperextension (complete flexion) of the leg would be the norm and support for the human body would be extremely limited. The patella (human) restricts the leg from bending posteriorly, thus allowing the body to stand upright.

b. Motion

Joints are generally classified into three major groups: diarthroses, synarthroses, and amphiarthroses. The amphiarthroses group allows for only slight movement, and found in the vertebrae and discs. Synarthroses do not allow for flexure, like the sutures of the skull. The diarthroses group includes the ball-and socket joint (shoulder and hip joint) and the hinged joints (elbow and knee joint), and is the one dealt with in this unit.

Movement is allowed, giving the body the ability to change positions.

One class of the diarthrodial joint is the hinged joint. The hinged joint works like a door hinge, moving in flexure across one plane. However, this joint is specialized and very complex and along with the hinge movement, there is some gliding and slight rotation occurring.

Inward rotation of several bones in the leg occurs during flexion. At this point, the tibia glides behind the end of the femur allowing for the slight rotation. The extension of the joint also allows for a slight rotation. During flexion, the patella rests on fat, that occupies the space between the femur and tibia. The patella moves up during extension making contact with the femur on the articular surfaces.

Muscles

The muscles above the patella are generally grouped into two groups, the hamstrings and quadriceps. The exception is the gluteus maximus which covers the hip joint and allows outward movement of the thigh.

The quadriceps are found in the anterior portion of the thigh and function as extensors. Extension is the type of movement allowed by the knee joint, which increases the angle between the femur and tibia. The individual muscles comprising this group are the vastus lateralis, vastus medialis, vastus intermedius, and rectus femoris. Tendons of the four converge to form a strong tendon that inserts into the patella.

The hamstrings are located in the back of the thigh and function as flexors. The motion of flexure by the knee joint allows for perambulation through the transfer of weight (force). The individual muscles comprising this group are the biceps femoris, semitendinosus, and semimembranosus. So, as the quadriceps extend and raise the leg, the hamstrings will flex the lower leg. The biceps femoris also allows for an outward rotation for the joint.

Two individual muscles of this area should include the sartorius which is the longest muscle in the body. It gives both medial and lateral movement to the leg. Also the gracilis which assists in the medial rotation of the leg, is another important muscle in this area.

Below the patella are two important muscles, the gastrocnemius and the soleus, that are essential to perambulation. The gastrocnemius, the larger of the two, in conjunction with the soleus, extends the foot in walking. The plantaris is a small muscle that assists the gastrocnemius and soleus in its extension role. The three converge into a tendon that inserts into the calcareous.

Cartilage

Articular cartilage, that is located at the knee, consists of the internal and external semilunar cartilages. This type of cartilage is thick at outer parts but thins in the inner borders. The cartilage covers nearly two-thirds of the articular surface of the tibia.

The internal cartilage is semicircular and attaches to the anterior section of the top of the tibia. It is positioned in front of the anterior crucisteligament.

The external cartilage is almost circular in shape. It is located in front of the tibia and to the outside of the anterior crucial ligament. It moves behind the ligament at which point it blends with the anterior cruciateligament.

Bursae

There are a number of bursae in this joint, a total of twelve within, on the sides, and in front of the knee. A large, extensive synovial membrane is found on the top part of the patella extending to the lower front of the femur. The vastus muscles cover the synovial membrane on each side of the patella. The membrane is also located below the patella.

Ligaments

Major ligaments of the knee are the cruciate, lateral, and capsular.

The cruciate ligaments are located behind the joint and are very strong ligaments. The anterior cruciate attaches to the front (diaphysis) of the tibia. It moves up, then back and out and is inserted into part of the femur. The posterior cruciate ligament is also a strong ligament but shorter than the anterior. It's attached to the back (diaphysis) of the tibia and moves up, forward and in and also attaches to the femur. "The main function of the cruciate ligaments is to act as a direct bond of union between the tibia and femur, preventing the former bone from being carried too far backward or forward". [1]

The lateral ligaments are both nearer the back of the joint than the front. They run from the femur to the bones of the lower leg. The internal ligaments attach to the surface of the tibia; the external extend to the fibula. The lateral ligaments resist the lateral bending of the joint.

The capsular ligament extends from the femur to the back part of the epiphysis of the tibia, and is inserted between the intervals left by the other ligaments.

V. Knee Injuries

a. Types

Knee injuries may occur through a variety of conditions. Sudden jarring may result in a strain, sprain or dislocation. A strain is a muscular injury from over-exertion or excessive physical effort. A sprain is an injury to muscles, ligaments or tendons around the joint, usually more traumatic than a strain. A dislocation is a displacement of a bone from its normal position. Severe jolting may result in torn cartilage or ligaments, or a combination of both.

Running and Jogging

Function and dysfunction of normal joints have recently become a topic of interest because of increased interest in the sports of running and jogging. The benefits of these forms of exercise include improvements in the performance of the respiratory and circulatory systems, endurance, and development of muscle tone. The psychosocial factors of self-improvement and physical appearance may also play a role in these sports popularity. There are some disadvantages that relate to the skeleton, which may be as numerous as their advantages. Generally, the constant pounding on the knee, hip, ankle, and foot eventually wear down the cartilage and bursae (cushions). The cartilage and bursae act as cushions and the lubricating fluid secreted within this synovial joint allows for the smooth movement of the knee joint. The pressure exerted on these tissues from running or jogging wear down the structures and cause dysfunction of the joint. Other factors to consider is the age, sex, and weight of the person that is involved in these forms of exercise. Each individual

has different levels of tolerance to different types of exercise, and although the advantages of running and jogging are great, there are limitations that each individual should consider before proceeding without medical advice.

Inflammation

Inflammation of the knee joint might include redness, tenderness, pain, swelling, and disturbed function. Different types of inflammation are: tendinitis, synovitis, bursitis, osteitis, and arthritis. In the above order, the areas of the structure that are inflammed are: the tendon, the synovial membrane, the bursa, the bone, and the joint. The causes of all these forms of inflammation are not all known, especially in the case of arthritis, but some factors that contribute to these disorders are: trauma, disease, and possibly genetics.

Infection

The most common form of infection of the musculoskeletal systems is osteomyelitis. The bacteria that causes the infection, is usually introduced by surgery or trauma. Fever, bone pain, and tenderness are all symptoms of infection. Rest and antibiotics are forms of treatment for the infection, but in some cases, surgery may be necessary.

Therapy may be adequate in repairing the damage or alleviating the symptoms of injury, inflammation, or infection. Surgery comes into play when therapy falls short, or when the damage is too extensive for therapy alone.

Several orthopedic surgical procedures that are available to correct joint dysfunction are:

1. Arthroplasty—a joint is given movement by either reshaping the bones of the joint, and a soft tissue or metal disc is placed between the reshaped ends; or the joint or part of the joint is replaced by a plastic or metal prosthesis
2. Tendon Lengthening—to extend the tendon without losing its function
3. Osteotomy—bone is cut for bone repair or joint repair
4. Arthrodesis—a fusion at the joint surface. Needed when support cannot de maintained
5. Arthroscopy—a small incision is made where an instrument, arthroscope, is inserted; to explore and also used to remove injured/diseased materials if necessary

b. Rehabilitation

Rehabilitation is the attempt to restore normal (as much as possible) function to the joint. “Prerequisites for successful rehabilitation of the knee include an appropriately motivated, cooperative patient and an appropriately designed physical therapy program.” [2] One wants to stay away from reinjury, so programs must be individualized in accordance with the injury type the therapist is dealing with.

General types of testing that may be used for a patient include: weightlifting, isokinetics, endurance and

observation by the therapist.

Weightlifting should be, at least initially, performed with a therapist or trained lifter present. The type of knee injury will dictate the type of program prescribed to the patient. Generally, an exercise machine or exercise boots are recommended.

Isokinetic testing measures muscle power at functional speeds. Your velocity, not the resistance, is measured. The resistance will change in accordance with the muscle's capabilities.

Endurance testing can include such highly regarded exercises as cycling and swimming. Both provide the leg with a wide range of motion, without the jarring that may occur with other exercises.

Finally, observations made by a therapist may also be helpful in the rehabilitative process. The attitude, posture, actions of the patient can indicate in what areas the patient might need assistance.

Therapy with a child would be slightly different due to bone and cartilage growth. Injury may disrupt growth. "With growth, particularly with the growth spurt, the muscles spanning the knee joint must adjust to the most rapidly growing bones in the body." [3] The adjustment described above is done normally, but injury or disease may interrupt this development and must be addressed in the rehabilitative program of the young patient.

Conclusion

This unit covered systems that give the body strength, support and mobility. No one system can accomplish all the above alone. That coordination and cooperation of the systems has been described and illustrated for better understanding by the student.

Sample Lesson Plan—1

Objective To increase the students' vocabulary through team competition.

Activity Using the vocabulary words of the unit (see glossary), set up a Jeopardy game board. The categories could be: Bones, Muscles, Connective Tissue, Joints, Knee, Miscellaneous.
The class could be divided into two teams with each student having a chance to identify the answer of the Jeopardy game.

Jeopardy is a popular game where an answer is revealed and the person must give the question. For example, an answer may read: femur, tibia, fibula. The student would have to respond: "What are bones of the lower leg."

When the game is over, a spelling and definition quiz will be given to reinforce the vocabulary skills of the student.

Materials
Teacher—chalk, blackboard

Student—pen, notebook

Sample Lesson Plan—2

Objective To allow the student to see and touch a human skeleton and also to illustrate the skeleton for their personal notebook.

Activity The human skeleton should be displayed in the front of the room. On various bones, a piece of adhesive tape with a number on it is found. A worksheet listing 15-20 bones will be handed to each student. In groups of two, the students must come up and using their worksheet, identify bones. If No. 1 on the worksheet is the humerus, the student must find the humerus and record the number (found on the piece of tape), on their worksheet. When they finish, the next two students come up. Try to limit each two-some to five minutes, to allow all students to get through the exercise in one day.
In conjunction with the exercise above, students, at their desks, will be drawing the skeleton, both front and rear view, and label the bones. They may copy from their book, or you may use an overhead projector with the drawings, for others. The illustrations become part of the student's notebook.

Materials

Teacher—human skeleton, tape, worksheet, overhead projector, transparency of the human skeleton.
Student—pen, notebook, pencil for drawing

Sample Lesson Plan—3

Objective To introduce the student to the skeletal and muscular systems as well as connective tissues.

Activity On a given day, a class can chip in a dollar and the teacher can pick up some fast food fried chicken. In the classroom, prior to lunch, a piece of chicken will be slowly dissected. The teacher should point out different organs/tissues as they go through the piece of chicken. Points of interest may include: skin, fat, muscle, tendons, bone, and joints.
After the demonstration, lunch may be served.

Materials

Teacher—chicken, dissecting kit, napkins Student—chicken, napkins, pen, notebook

GLOSSARY

Amphiarthrosis—a type of joint allowing only slight movement (vertebrae)
Anatomy—the study of the structure of animals and plants
Anterior—toward the front of the body
Articulation—the junction of bones, a joint
Calcification—the deposition of calcium and magnesium into bony tissue
Collagen—the dominant protein found in bone and connective tissue
Compound—two or more elements that are chemically combined
Diarthrosis—a type of joint that allows great movement (knee)
Distal—away from the place of attachment (origin)
Dorsal—toward the back of the body
Element—basic substances that cannot be divided into
simpler substances, chemically
Extensor—a muscle that straightens part of the body
Flexor—a muscle that bends part of the body
Histology—the study of tissues
Inorganic—a compound lacking the element, carbon
Organic—chemical substances containing carbon; essential for living organisms
Ossification—bone formation
Osteogenic—potential to form bone by using cells (osteodlasts, osteocytes, osteoclasts)
Physiology—the study of the biological functions of animals and plants
Posterior—toward the back of the body
Proximal—near the place of attachment (origin)
Synarthrosis—a type of joint, allowing no movement (sutures of the skull)
Transverse—dividing a structure in half; a cross-section
Ventral—the anterior section of the body, usually in reference to the abdomen

Figure 1
(figure available in print form)
Figure 2
(figure available in print form)
Figure 3
(figure available in print form)

Notes

1. Gray, Henry, Anatomy, *Descriptive and Surgical* (Bounty Books, Crown Publishers, Inc., New York) 1977 p. 280.
2. *The Orthopedic Clinics of North America* (Symposium on Special Considerations in Sports Medicine, W.D. Saunders Co., Phil.) 1983 Vol. 14 No. 2 p. 397

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