CHAPTER 11: CARTILAGE

Cartilage is a specialized skeletal connective tissue characterized by firmness and resiliency. Because of its capacity for rapid growth, cartilage forms much of the fetal skeleton. Most fetal cartilages are eventually replaced by bone tissue through a process called endochondral ossification (discussed later). Some cartilage does persist at sites in the body where its mechanical properties are needed on a permanent basis.

As in all types of connective tissues, the extracellular matrix of cartilage is abundant. It consists of fibers plus large amounts of ground substance that includes glycosaminoglycans, proteoglycans, and glycoproteins. These components form a firm but highly hydrated and gel-like matrix. Since cartilage is usually avascular, the cells within the matrix (chondrocytes) must be nourished by diffusion of gases and nutrients from the surrounding connective tissues. This diffusion requirement places a limit on the maximum size to which a cartilage can grow.

There are three different morphologically distinguishable types of cartilage: hyaline cartilage, elastic cartilage, and fibrocartilage. Differences in the composition of the matrix determine the mechanical properties of each type.

HYALINE CARTILAGE

Hyaline cartilage is the most common type in both the fetus and the adult. It forms most of the fetal skeleton, is present at the epiphyseal plates of developing long bones in children and adolescents, and persists in adults at locations such as the articular cartilage of synovial joints, the ventral ends of ribs (costal cartilages), the nasal cartilages, most laryngeal cartilages, the tracheal rings, and the irregular cartilage plates in the walls of the bronchi.

In hyaline cartilage the matrix contains thin fibrils of type II collagen. Because these fibrils are so thin they are difficult to distinguish by light microscopy, giving the matrix a clear, glassy or “hyaline” appearance.

Chondrocytes are cartilage cells that are completely surrounded by matrix. Each chondrocyte occupies a space in the matrix known as a lacuna. The arrow indicates an empty lacuna where the chondrocyte that previously occupied it is now missing.
Hyaline cartilage is seen on the left side of this micrograph, while bone is developing on the right. The arrow indicates a well-preserved chondrocyte that completely fills its lacuna as it would during life. Chondrocytes are difficult to preserve in fixed tissue because the fixative must diffuse through the matrix in order to reach the cells, and this often does not occur rapidly enough for optimal preservation. As a result the chondrocytes may shrink and become flattened against one side of the lacunae.

All hyaline cartilages except for the articular cartilages of synovial joints are surrounded by a dense connective tissue layer called the perichondrium (peri = around; chondrium = cartilage). The perichondrium (arrow) is composed of two layers: an outer fibrous layer that contains fibroblast-like cells, and an inner chondrogenic layer that contains immature cells capable of differentiating into chondroblasts and then chondrocytes. These two layers are difficult to distinguish from one another except in very rapidly growing cartilage. In resting cartilages such as the one in this image, the chondrogenic cells also have a flat fibroblastic morphology.

Cartilages that have a perichondrium can grow in two different ways: interstitial growth or appositional growth. This image illustrates appositional growth. For orientation purposes, the tissue at the far left is skeletal muscle, then there is a layer of light-staining loose connective tissue, then the perichondrium (arrow), and finally the cartilage matrix at the far right. In appositional growth, some of the cells of the chondrogenic layer of the perichondrium differentiate, becoming rounder more basophilic cells called chondroblasts that begin to lay down cartilage matrix. When they become completely surrounded by matrix they are called chondrocytes. Appositional growth therefore involves addition of new cells and new matrix to the outer surface of the growing cartilage, just deep to the perichondrium.
The arrow indicates a cluster of chondrocytes called an isogenous group. Isogenous groups arise during the process of interstitial growth. They are formed when one chondrocyte divides and the daughter cells begin to lay down new matrix between them, gradually forming separate lacunae, each containing one chondrocyte. An isogenous group therefore represents a clone derived from the same parent cell. The cells are able to move away from one another because the matrix of cartilage is not as rigid as that of bone. Each may then divide again, establishing a new isogenous group. The result of interstitial growth is that the cartilage adds new cells and new matrix to the interior of the cartilage rather than on its outer surface. The cells responsible for interstitial growth are chondrocytes rather than the chondrogenic cells of the perichondrium.

The staining affinity of the matrix in hyaline cartilage depends on the relative amounts of collagen (eosinophilic) and proteoglycans (basophilic) that are present. It varies characteristically at different locations. Close to the lacunae the matrix tends to contain relatively more proteoglycan and is therefore more basophilic in good H&E preparations. The region immediately surrounding each lacuna is called the capsular or pericellular matrix. It may stain slightly darker than the basophilic region that surrounds each isogenous group, which is called the territorial matrix (arrow). In this image the territorial and capsular matrices are staining with nearly the same intensity and are therefore not easily distinguished.

The matrix between neighboring isogenous groups or between widely spaced single lacunae contains relatively more collagen and therefore stains more eosinophilic in H&E. This region is known as the interterritorial matrix (arrow). You should be aware that proteoglycans and GAGS, which impart basophilia to the matrix, are relatively easily extracted during tissue preparation. If they have been lost, then even the capsular and territorial matrices will stain eosinophilic due to unmasking of the collagen that remains in those areas.
In this image that was examined previously, also note the difference in shape between the mature and immature chondrocytes. The mature cells are larger, rounder and have relatively more cytoplasm. The immature chondrocytes near the perichondrium at the top of the image are smaller and flatter.

During the initial development (chondrogenesis) of most hyaline cartilages, mesenchymal cells differentiate into chondroblasts, which then lay down matrix and become chondrocytes. The connective tissue surrounding this region condenses to become the perichondrium. Therefore an immature cartilage such as seen in this image will tend to have a thin and relatively cellular perichondrium. In a specimen that was fixed before significant interstitial growth began, few isogenous groups will be present.

Epiphyseal plates composed of hyaline cartilage are present in long bones that are undergoing endochondral ossification. The plates are located at both ends of the bone, between the end of the bone (the epiphysis) and the shaft (the diaphysis). The arrow indicates an epiphyseal plate, with the epiphysis to the left and the diaphysis to the right. As long as the epiphyseal plate is present and the chondrocytes in it continue to divide and lay down matrix (via interstitial growth of the cartilage), the bone can grow in length. When chondrocyte division and synthetic activity stops and the chondrocytes die, the epiphyseal plate disappears and the bone can no longer grow in length. Note that the outer surface of the epiphysis is covered by articular cartilage, which will be examined next.

The arrow indicates articular cartilage in which some isogenous groups can be distinguished. Deep to the cartilage, and continuous with it, is bone tissue. Within the bone are spaces filled with bone marrow. The joint cavity is at the top of the field. Articular cartilage is the one type of hyaline cartilage that has no perichondrium. As a result it cannot grow appositionally. Articular cartilage helps to cushion the ends of bones that articulate with one another at synovial joints.
ELASTIC CARTILAGE

Elastic cartilage is more flexible than hyaline cartilage, and is found in locations where flexibility may be important such as the auricle of the ear, the walls of the auditory tube (eustachian tube), the epiglottis, and the corniculate and cuneiform cartilages of the larynx. The matrix, like that of hyaline cartilage, contains thin fibrils of collagen type II, but also has an abundance of elastic fibers that give the matrix an opaque, yellowish appearance in fresh elastic cartilage. The elastic fibers may be so thick and plentiful that they can be observed in H&E stained sections, but specialized elastic stains can also be used to demonstrate them.

Note that elastic cartilage tends to be much more cellular than mature hyaline cartilage. You might confuse it with immature hyaline cartilage (see frame 7620), but recall that immature hyaline cartilage has a clear, glassy matrix and relatively few isogenous groups.

FIBROCARTILAGE

Fibrocartilage is fairly rare in humans. It is a strong tissue that can resist large compressive or shearing forces, and thus is found where strength is important, such as the annuli fibrosi of the intervertebral disks, the menisci of the knee, and at sites where ligaments and tendons insert onto bone. It lacks a perichondrium and instead blends into the surrounding tissues. At some non-synovial joints such as the pubic symphysis, the bones are united by a mixture of fibrocartilage and dense connective tissue, resulting in restriction of movement.

Fibrocartilage contains mainly type I collagen, which forms large fiber bundles that are visible in the matrix. This should be contrasted with the clear, homogeneous matrix of hyaline cartilage. Another major characteristic of fibrocartilage is that the fiber bundles often line up to form parallel columns, with short rows of chondrocytes sandwiched between the columns.

Fibrocartilage is similar to dense regular connective tissue in that the matrix stains very eosinophilic with H&E, and both lack a perichondrium. One feature that helps distinguish between
the two tissues is that the chondrocytes of fibrocartilage are rounder cells, whereas the fibroblasts of dense regular connective tissue tend to be very flat.

In this trichrome stain, the type I collagen fibers of the fibrocartilage matrix stain intensely blue. Notice that the chondrocytes of an isogenous group tend to line up single file in fibrocartilage rather than forming the more spherical clusters that are typical of hyaline and elastic cartilage. It is also evident that, in comparing fibrocartilage with elastic cartilage, fibrocartilage is much less cellular.

At higher magnification you may be able to see that the chondrocytes of fibrocartilage occupy true lacunae within the matrix. The small area of matrix directly surrounding the lacunae often stains lighter (with trichromes or H&E) than the rest of the matrix, and appears less fibrous. This is due to the fact that in this small region the major type of collagen present is type II rather than type I.