Joints

Adjacent bones are united at joints, which show considerable variation in their structure and function. At some joints, the articulating bones are so interlocked that they are immovable, while at others, the joint structure permits a wide range of motion. Based on their histological structure, joints can be classified as fibrous, cartilaginous, or synovial.

Fibrous Joints

Fibrous joints are formed by dense fibrous connective tissue and permit little or no movement. Sutures are immovable fibrous joints found only in the skull. The gap between the articulating bones is filled by a fibrovascular connective tissue and is bridged at the surfaces by periosteum. Sutures are sites of osteogenic activity and allow for growth of the skull. They are temporary joints; with aging the fibrous connective tissue gradually is replaced by bone to form a permanent boney union (synostosis). The adjoining edges of the bones are highly irregular and interlock to create a firm union. A syndesmosis, such as occurs at the inferior tibiofibular joint, contains much more connective tissue than does a suture, allowing somewhat more movement. A third type of fibrous joint is the gomphosis, a peg-and-socket joint restricted to the fixation of teeth in the alveolar bone of the jaws.

Cartilaginous Joints

Cartilaginous joints are present when bones are united by a continuous plate of hyaline cartilage or a disc of fibrocartilage. The hyaline cartilage of an epiphyseal plate forms a temporary joint uniting the shaft and epiphysis of a long bone during its development. This type of immovable joint, a synchondrosis, sometimes is classed as a primary cartilaginous joint. Permanent or secondary cartilaginous joints are represented by symphyses, which include unions such as those between the pubic bones (pubic symphysis) and between the vertebral bodies. The articulating surfaces are covered by thin layers of hyaline cartilage that in turn are joined to a central disc of fibrous cartilage. The bone, hyaline cartilage, and fibrous cartilage are intimately united, and the joint allows only limited movement (amphiarthrosis). The degree of movement possible depends on the thickness of the fibrous cartilage. A slitlike cavity may appear in the fibrous cartilage of some symphyses (e.g., symphysis pubis), but the specialized sliding surfaces of a synovial joint are absent.

In the spine, specialized discs of fibrous cartilage form the intervertebral discs that make up the major connections between adjacent vertebral bodies. The outer part of the disc, the annulus fibrosus, consists of a peripheral zone of collagen fibers and an inner zone of fibrous cartilage that is especially rich in collagen. The central part of the disc, the nucleus pulposus, is soft and gelatinous in the young but with aging is gradually replaced by fibrous cartilage. The articular surfaces of each vertebra are covered by thin plates of hyaline cartilage. The annulus fibrosus is firmly attached to the vertebral body by collagen fibers that pierce the cartilaginous end-plates and enter the compact bone of the vertebral body as Sharpey's fibers.

Synovial Joints

Synovial joints, also called diarthroses, are complex, freely mobile joints capable of a wide range of motion. Most of the joints of the limbs fall into this category. The bones involved in the joint are contained within and linked by a capsule of dense irregular connective tissue that is continuous with the periosteum over the articulating bones. Additional stability may be provided by intra- and extracapsular ligaments that also are dense irregular connective tissue. The opposing boney surfaces are covered by articular cartilages that provide low-friction gliding surfaces. Although it appears smooth to the naked eye, the free surface of the articular cartilage is beset with various undulations, troughs, and valleys.

The inner surface of the capsule is lined by a synovial membrane that elaborates the lubricating synovial fluid. An articular disc may be interposed completely or partially between the articular surfaces; a partial disc is called a meniscus. Discs and menisci consist of fibrous cartilage with an abundance of collagen fibers; at the periphery, they are connected to the capsule.

The articular cartilages of most joints are hyaline in type but show a greater content of collagen than usual. In some joints (e.g., temporomandibular), frank fibrous cartilage is present. Articular cartilage lacks a perichondrium, and joint contact is made between the free, uncovered surfaces of the opposing articular cartilages.

The collagen fibers of articular cartilage have a unique arrangement. At the surface, the fibers are organized into tight bundles that tend to run at right angles to one another and are parallel to the surface. This forms the tangential zone. In the deeper transitional and radial zones, the collagen fibers are randomly arranged. Where it abuts the underlying bone, the articular cartilage becomes calcified and fuses with the bone, thus forming the calcified zone in which the collagen fibers are perpendicular to the surface. The diameters of the collagen fibers increase progressively as they pass from the tangential zone to the calcified zone. The fibers of the calcified layer penetrate the subchondral bone, where they are firmly embedded like Sharpey's fibers. Overlying the tangential zone is the lamina splendens, a layer that contains randomly arranged fine fibrils.

The junction between bone and calcified cartilage is irregular and shows fine ridges, grooves, and interdigitations that help unite the subchondral bone and articular cartilage. The junction between the calcified and radial zones appears, in sections, as a basophilic "tide line" that represents the advancing front of the calcification process.

The cells of the articular cartilage also show zonal differences. The tangential zone contains several layers of flattened, fibroblast-like cells whose long axes, like those of the collagen fibers, are parallel to the surface. Their oval or elongated nuclei usually have smooth outlines, but some are irregular and show a variety of undulations, deep indentations, or clefts; the patchy, clumped chromatin stains deeply. The cytoplasm contains short cisternae of granular endoplasmic reticulum (GER), a small Golgi complex, and small, round mitochondria. Inclusions such as lipids and glycogen are rare, but pinocytotic vesicles are plentiful. In the transitional zone, the cells are rounded and show many long cytoplasmic processes that often bifurcate at their tips. The round, usually eccentric nuclei contain finely granular chromatin and frequently show one or more nucleoli. Granular endoplasmic reticulum is abundant, the Golgi apparatus is well developed, and secretory granules are prominent. The cells are scattered randomly throughout the transitional zone.

The cells of the radial zone also are rounded but tend to form short columns or isogenous groups. The endoplasmic reticulum is less developed, the Golgi complex is sparse, and mitochondria are small and dense. Intracellular filaments are increased in number, and lipid droplets and glycogen granules are common.

The calcified zone is characterized by short columns of enlarged, pale staining cells that are in the advanced state of degeneration. The nuclei are dense and pyknotic, the nuclear envelope is fragmented, and cytoplasmic organelles are lacking.

The organization of the chondrocytes of articular cartilage into successive zones is reminiscent of the arrangement of cells in an epiphyseal plate during endochondral bone formation. Indeed, during growth, articular cartilage does serve as a growth zone for the subchondral bone. When epiphyseal growth is complete, the deep zones of chondrocytes in the articular cartilage are converted to compact bone and incorporated into the subchondral bone layer.
Like other cartilage, articular cartilage is avascular and aneural. The central regions of the cartilage receive their nutrition by diffusion from the synovial fluid, which bathes the cartilages, and, to a lesser extent, from vessels in the subchondral bone. At their edges, the articular cartilages are well nourished from blood vessels in the nearby synovial membrane.

Synovial Membrane

The synovial membrane is one of the characteristic features of a synovial joint. It is a loose-textured, highly vascular connective tissue that lines the fibrous capsule and extends onto all intraarticular surfaces except those subjected to compression during movement of a joint. Thus, articular cartilages, articular discs, and menisci are not covered by synovial membranes. Occasional finger-like projections, the synovial villi, and coarser folds of the synovial membrane project into the joint cavity.
The free surface (synovial intima) of the synovial membrane consists of one to three layers of flattened synovial cells embedded in a granular, fiber-free matrix. The surface cells do not form a continuous layer, and in places, neighboring cells are separated by gaps through which the synovial cavity communicates with tissue spaces in the synovial membrane. Where the cells do make contact, their surfaces may be complex and interdigitated. Desmosomal junctions have been described in rat synovial membranes, but their presence in humans has not been confirmed.
Ultrastructurally, two types of synovial cells have been described. A-cells are predominant and resemble macrophages (hence their alternate name, M-cells). The cell membrane shows numerous invaginations, filopodia, and micropinocytotic vesicles, while the cytoplasm contains large Golgi complexes and numerous mitochondria and lysosomes but only scant profiles of GER. B-cells resemble fibroblasts and sometimes are called F-cells. They have a smooth outline and contain abundant GER and scattered free ribosomes. Both cell types contain much glycogen but only a few lipid inclusions. The relationship between A- and B-cells is unknown, but the existence of intermediate forms (AB-cells) suggests that the two may be merely different functional forms of a single type.
The subintimal tissue varies from place to place within the same joint, and based on the structure of this tissue, the synovial membrane is classified as areolar, adipose, or fibrous. In areolar synovial membranes, the underlying tissue is a loose connective tissue with relatively few collagen fibers and an abundant matrix. Cellular constituents include fibroblasts, mast cells, macrophages, and lymphocytes. Adipose synovial membranes line the articular fat pads, and the subintimal tissue mainly consists of fat cells. In fibrous synovial membranes, the underlying tissue is a dense irregular connective tissue and is found in regions subjected to tension; where such forces are extremely high, fibrous cartilage may be present.
Synovial fluid is a clear or slightly yellow viscous fluid that bathes the joint surfaces. Normally, the volume of fluid is sufficient only to form a thin film over all the surfaces within a joint. In composition, synovial fluid is an ultrafiltrate of plasma to which mucin has been added. Mucin is a product of the surface synovial cells and consists mainly of highly polymerized hyaluronic acid, which gives viscosity to the synovial fluid. Normal synovial fluid contains only 50 to 100 cells per milliliter, and these consist of macrophages, free synovial cells, and an occasional

leukocyte. Amorphous particles and fragments of cells and fibrous tissue may be present and are believed to result from slow wearing of the joint surface.

Although most joints serve to allow movement, sutures are immobile and act only to unite bones. Sutures in the young provide areas where bone can grow, and it is only after they have been replaced by boney unions that their uniting functions become paramount. Even the articular cartilages of synovial joints serve as areas of growth for subchondral bone during development. The cartilaginous joints of the spine, although permitting some degree of motion, serve primarily as shock absorbers to dampen and distribute mechanical forces acting on the spine. This is mainly the function of the nucleus pulposus, which, because of its high water content, can act as a water cushion. The joints specifically designed for movement are the synovial joints. The fibrous capsule and ligaments provide a tough, unyielding binding for the articulating bones yet remain flexible enough to allow movement of the joint. The synovial membrane mainly produces the lubricant of the joint, the synovial fluid, but also may participate in removing particulate matter from the joint cavity. Synovial villi increase the surface area for secretion and absorption, while the larger folds serve as flexible pads that can accommodate to the changing shape and size of the joint space and its recesses during movement. The function of the articular discs and menisci is uncertain, but they may act as shock absorbers, improve the fit between the joint surfaces, spread lubricant, distribute weight over a larger area, or protect the edges of the articular cartilages.

Cartilages form the bearings on which the articulating surfaces of the joint move and offer a wear-resistant surface of low friction - about half that of Teflon, the most slippery of synthetic materials. The arrangement of fibers in the tangential zone places a dense mat of collagen fibers right at the articulating surface. The cartilage is anchored to the underlying bone by collagen fibers (Sharpey's fibers) that are embedded in subchondral bone. The irregular and interlocking margin between the calcified zone and bone further stabilizes the cartilage. The calcified zone also may help regulate diffusion of materials between bone and cartilage.

Synovial fluid provides for the nutrition of articular cartilages, menisci, and articular discs and also lubricates the joint surfaces. Exactly how the synovial fluid performs its lubricating function is unknown. It has been suggested that the fluid forms a thin film between the bearing surfaces and that the lubricating activity depends on internal properties of the fluid such as cohesiveness, shear rate, and flow rate. Another mechanism, "weeping lubrication," has been proposed as a method of joint lubrication. Because of the content of proteoglycans, articular cartilage avidly binds water that, during compression, exudes ("weeps") from the cartilage to lubricate the surface. When compression is removed, fluid is reabsorbed into the cartilage. Thus, weeping lubrication also could serve as a method for pumping nutrients and wastes into and out of the cartilage. A mechanism of "boosted lubrication" takes into account the irregularities normally seen on the surface of articular cartilage. As the cartilage is compressed, pools of synovial fluid are trapped in the furrows and valleys of the articular surfaces. As compression increases, a mobile component of the fluid containing small molecules is forced into the cartilage at the areas of pressure. The fluid in the valleys thus becomes increasingly rich in hyaluronidate and more viscous so that as the pressure increases, the synovial fluid progressively becomes more effective as a lubricant.