**Lecture # 3**

**Biomechanics**

**The Biomechanics of Human Skeletal Articulations**

**Introduction:**

The joints of the human body largely govern the directional motion capabilities of body segments. The anatomical structure of a given joint, such as the uninjured knee, varies little from person to person, as do the directions in which the attached body segments, such as the thigh and lower leg, are permitted to move at the joint. However, differences in the relative tightness or laxity of the surrounding soft tissues result in differences in joint ranges of movement.

**JOINT ARCHITECTURE**

Anatomists have categorized joints in several ways, based on joint complexity, the number of axes present, joint geometry, or movement capabilities. Since this Course focuses on human movement, a joint classification system based on motion capabilities is presented.

**Immovable Joints**

1. Synarthroses (immovable) (syn = together; arthron = joint): These fibrous joints can attenuate force (absorb shock) but permit little or no movement of the articulating bones.
   1. Sutures: In these joints, the irregularly grooved articulating bone sheets mate closely and are tightly connected by fibers that are continuous with the periosteum. The fibers begin to ossify in early adulthood and are eventually replaced completely by bone. The only example in the human body is the sutures of the skull.
   2. Syndesmoses (syndesmosis = held by bands): In these joints, dense fibrous tissue binds the bones together, permitting extremely limited movement. Examples include the coracoacromial, mid-radioulnar, mid-tibiofibular, and inferior tibiofibular joints.

**Slightly Movable Joints**

1. Amphiarthroses (slightly movable) (amphi = on both sides): These cartilaginous joints attenuate applied forces and permit more motion of the adjacent bones than synarthrodial joints.
   1. Synchondroses (synchondrosis = held by cartilage): In these joints, the articulating bones are held together by a thin layer of hyaline cartilage. Examples include the sternocostal joints and the epiphyseal plates (before ossification).
   2. Symphyses: In these joints, thin plates of hyaline cartilage separate a disc of fibrocartilage from the bones. Examples include the vertebral joints and the pubic symphysis.

**Freely Movable Joints**

1. Diarthroses or synovial (freely movable) (diarthrosis = “through joint,” indicating only slight limitations to movement capability): At these joints, the articulating bone surfaces are covered with articular cartilage, an articular capsule surrounds the joint, and a synovial membrane lining the interior of the joint capsule secretes a lubricant known as synovial fluid (Figure 1). There are many types of synovial joints.

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| **Figure 1:** The knee is an example of a synovial joint, with a ligamentous capsule, an articular cavity, and articular cartilage. |

* 1. Gliding (plane; arthrodial): In these joints, the articulating bone surfaces are nearly flat, and the only movement permitted is non-axial (gliding). Examples include the intermetatarsal, intercarpal, and intertarsal joints, and the facet joints of the vertebrae.
  2. Hinge (ginglymus): One articulating bone surface is convex and the other is concave in these joints. Strong collateral ligaments restrict movement to a planar, hinge like motion. Examples include the ulnohumeral and interphalangeal joints.
  3. Pivot (screw; trochoid): In these joints, rotation is permitted around one axis. Examples include the atlantoaxial joint and the proximal and distal radioulnar joints.
  4. Condyloid (ovoid; ellipsoidal): One articulating bone surface is an ovular convex shape, and the other is a reciprocally shaped concave surface in these joints. Flexion, extension, abduction, adduction, and circumduction are permitted. Examples include the second through fifth metacarpophalangeal joints and the radiocarpal joints.
  5. Saddle (sellar): The articulating bone surfaces are both shaped like the seat of a riding saddle in these joints. Movement capability is the same as that of the condyloid joint, but greater range of movement is allowed. An example is the carpometacarpal joint of the thumb.
  6. Ball and socket (spheroidal): In these joints, the surfaces of the articulating bones are reciprocally convex and concave. Rotation in all three planes of movement is permitted. Examples include the hip and shoulder joints.

Synovial joints are commonly categorized according to the number of axes of rotation present.

1. Uniaxial joints that allow motion around one axe.
2. Biaxial joints that allow motion around two axes.
3. Triaxial joints that allow motion around three axes.

A few joints where only limited motion is permitted in any direction are termed nonaxial joints. Joint motion capabilities are also sometimes described in terms of degrees of freedom (df), or the number of planes in which the joint allows motion. A uniaxial joint has one df, a biaxial joint has two df, and a triaxial joint has three df.

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| **Figure 2:** Examples of the synovial joints of the human body |

**Articular Cartilage**

The joints of a mechanical device must be properly lubricated if the movable parts of the machine are to move freely and not wear against each other. In the human body, a special type of dense, white connective tissue known as articular cartilage provides a protective lubrication. A 1- to 5-mm-thick protective layer of this material coats the ends of bones articulating at diarthrodial joints. Articular cartilage serves two important purposes: (a) It spreads loads at the joint over a wide area so that the amount of stress at any contact point between the bones is reduced, and (b) it allows movement of the articulating bones at the joint with minimal friction and wear.

Under loading at the joint, articular cartilage deforms, exuding synovial fluid. At healthy synovial joints, where the articulating bone ends are covered with articular cartilage, motion of one bone end over the other is typically accompanied by a flow of synovial fluid that is pressed out ahead of the moving contact area and also sucked in behind the contact area. At the same time, the permeability of the cartilage is reduced in the area of direct contact, providing a surface on which fluid film can form under the load. When joint loading occurs at a low rate, the solid components of the cartilage matrix resist the load. When loading is faster, however, it is the fluid within the matrix that primarily sustains the pressure.

Cartilage can reduce the maximum contact stress acting at a joint by 50% or more. The lubrication supplied by the articular cartilage is so effective that the friction present at a joint is only approximately 17–33% of the friction of a skate on ice under the same load, and only one-half that of a lubricated bearing.

**Articular Fibrocartilage**

At some joints, articular fibrocartilage, in the form of either a fibrocartilaginous disc or partial discs known as menisci, is also present between the articulating bones. The intervertebral discs and the menisci of the knee (Figure 3) are examples. Although the function of discs and menisci is not clear, possible roles include the following:

1. Distribution of loads over the joint surfaces.
2. Improvement of the fit of the articulating surfaces.
3. Limitation of translation or slip of one bone with respect to another.
4. Protection of the periphery of the articulation.
5. Lubrication.
6. Shock absorption

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| **Figure 3:** Fibrocartilage is present in (A) the symphysis pubis that separates the pubic bones and (B) the intervertebral discs between adjacent vertebrae |

**Articular Connective Tissue**

Tendons, which connect muscles to bones, and ligaments, which connect bones to other bones, are passive tissues composed primarily of collagen and elastic fibers. Tendons and ligaments do not have the ability to contract like muscle tissue, but they are slightly extensible. These tissues are elastic and will return to their original length after being stretched, unless they are stretched beyond their elastic limits. A tendon or ligament stretched beyond its elastic limit during an injury remains stretched and can be restored to its original length only through surgery. The results of modeling studies suggest that tendons routinely undergo healing to repair internal micro failures over the course of the life span in order to remain intact.

Tendons and ligaments, like bone, respond to altered habitual mechanical stress by hypertrophying or atrophying. Research has shown that regular exercise over time results in increased size and strength of both tendons and ligaments, as well as increased strength of the junctions between tendons or ligaments and bone.

Evidence also suggests that the size of a ligament such as the anterior cruciate ligament (ACL) is proportionate to the strength of its antagonists (in this case, the quadriceps muscles). Tendons and ligaments can not only heal following rupturing but in some cases regenerate in their entirety, as evidenced by examples of complete regeneration of the semitendinosus tendon following its surgical removal for repair of anterior cruciate ligament ruptures.

**JOINT STABILITY**

The stability of an articulation is its ability to resist dislocation. Specifically, it is the ability to resist the displacement of one bone end with respect to another while preventing injury to the ligaments, muscles, and muscle tendons surrounding the joint. Different factors influence joint stability.

* **Shape of the Articulating Bone Surfaces**

In many mechanical joints, the articulating parts are exact opposites in shape so that they fit tightly together (Figure 4). In the human body, the articulating ends of bones are usually shaped as mating convex and concave surfaces.

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| **Figure 4:** Mechanical joints are often composed of reciprocally shaped parts. |

Although most joints have reciprocally shaped articulating surfaces, these surfaces are not symmetrical, and there is typically one position of best fit in which the area of contact is maximum. This is known as the close-packed position, and it is in this position that joint stability is usually greatest. Any movement of the bones at the joint away from the close-packed position results in a loose-packed position, with reduction of the area of contact.

Some articulating surfaces are shaped so that in both close- and loosepacked positions, there is either a large or a small amount of contact area and consequently more or less stability. For example, the acetabulum provides a relatively deep socket for the head of the femur, and there is always a relatively large amount of contact area between the two bones, which is one reason the hip, is a stable joint. At the shoulder, however, the small glenoid fossa has a vertical diameter that is approximately 75% of the vertical diameter of the humeral head and a horizontal diameter that is 60% of the size of the humeral head. Therefore, the area of contact between these two bones is relatively small, contributing to the relative instability of the shoulder complex. Slight anatomical variations in shapes and sizes of the articulating bone surfaces at any given joint among individuals are found; therefore, some people have joints that are more or less stable than average.

* **Arrangement of Ligaments and Muscles**

Ligaments, muscles, and muscle tendons affect the relative stability of joints. At joints such as the knee and the shoulder, in which the bone configuration is not particularly stable, the tension in ligaments and muscles contributes significantly to joint stability by helping to hold the articulating bone ends together. If these tissues are weak from disuse or lax from being overstretched, the stability of the joint is reduced. Strong ligaments and muscles often increase joint stability. For example, strengthening of the quadriceps and hamstring groups enhances the stability of the knee.

* **Other Connective Tissues**

White fibrous connective tissue known as fascia surrounds muscles and the bundles of muscle fibers within muscles, providing protection and support. A particularly strong, prominent tract of fascia known as the iliotibial band crosses the lateral aspect of the knee, contributing to its stability. The fascia and the skin on the exterior of the body are other tissues that contribute to joint integrity.

**JOINT FLEXIBILITY**

Joint flexibility is a term used to describe the range of motion (ROM) allowed in each of the planes of motion at a joint. Static flexibility refers to the ROM present when a body segment is passively moved (by an exercise partner or clinician), whereas dynamic flexibility refers to the ROM that can be achieved by actively moving a body segment by virtue of muscle contraction. Static flexibility is considered to be the better indicator of the relative tightness or laxity of a joint in terms of implications for injury potential. Dynamic flexibility, however, must be sufficient not to restrict the ROM needed for daily living, work, or sport activities. Research indicates that these two components of flexibility are independent of each other.

**Measuring Joint Range of Motion**

Joint ROM is measured directionally in units of degrees. In anatomical position, all joints are considered to be at zero degrees. The ROM for flexion at the hip is therefore considered to be the size of the angle through which the extended leg moves from zero degrees to the point of maximum flexion (Figure 5). The ROM for extension (return to anatomical position) is the same as that for flexion, with movement past anatomical position in the other direction quantified as the ROM for hyperextension. A goniometer used for measuring joint ROM.

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| Figure 5: The range of motion for flexion at the hip is typically measured with the individual supine. |

**Factors Influencing Joint Flexibility**

Different factors influence joint flexibility. The shapes of the articulating bone surfaces and intervening muscle or fatty tissue may terminate movement at the extreme of a ROM. When the elbow is in extreme hyperextension, for example, contact of the olecranon of the ulna with the olecranon fossa of the humerus restricts further motion in that direction. Muscle and/or fat on the anterior aspect of the arm may terminate elbow flexion.

For most individuals, joint flexibility is primarily a function of the relative laxity and/or extensibility of the collagenous tissues and muscles crossing the joint. Tight ligaments and muscles with limited extensibility are the most common inhibitors of a joint’s ROM.