The use of anabolic steroids to enhance athletic performance has become a common concern among sports medicine specialists. Laboratory investigations study the effects of anabolic steroids on tendon biomechanics and biochemistry suggest that long-term steroid use, particularly in combination with exercise, decreases tendon stiffness (Wood et al., 1988) and ultimate strength by stimulating collagen degeneration (Michna and Stang-Voss, 1983). Furthermore, anabolic steroids impair the healing of tendon injuries (Bach et al., 1987; Herrick and Herrick, 1987; Kramhoft and Solgaard, 1986). Ironically, substances used to enhance performance may ultimately predispose the individual to problems that will force him or her out of competition.

Aging

Tendon mechanical properties and composition are influenced markedly by age. Prior to skeletal maturity, tendons are more viscous and compliant (Frank, 1996). With increasing age, through middle age, the strength and stiffness of tendons are relatively steady. Then as muscular strength begins to diminish, there is a concomitant loss of strength in tendon. Maximal muscle strength in men and women is generally reached between the ages of 20 and 30 years, about the same time that the cross-sectional area of muscle is the greatest. The strength level tends to plateau through the age of 50, followed by a decline in strength that accelerates by age 65.

2.9 JOINTS

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2.9.1 CLASSIFICATION OF JOINTS

Joints are classified into three subtypes: fibrous, cartilaginous, and synovial (Table 2.9.1).

Table 2.9.1 Description, function, movement, and examples for the three major joint types in the human and animal body, i.e., fibrous, cartilaginous, and synovial joints.

TYPE	DESCRIPTION	FUNCTION	MOVEMENT	EXAMPLES
FIBROUS	Bones connected by fibrous (connective) tissue	stability		
	• syndesmosis		small	tibia/fibula
	• suture		non	skull
CARTILAGINOUS	Bones connected by cartilage	bending		
	• synchondrosis		small	sterno costalis connection
	• symphysis		small	sym. pubica spinal vertebrae
SYNOVIAL	Bones connected by ligaments	movement	small translation large rotation	knee hip

In *fibrous joints,* the bones are connected by connective fibrous tissue. Fibrous joints have the appearance of hair-line cracks and are designed for stability. The skull contains fibrous joints.

In *cartilaginous joints*, cartilage connects the bones. These joints allow for minimal movement, are relatively stiff, and are designed to provide stability and to transfer forces. Cartilaginous joints permit only limited movement, but a combination of such joints may facilitate a large range of motion. The connection of spinal vertebrae is a typical example of a cartilaginous joint.

Synovial joints are the main focus of this section. The bones in synovial joints are in contact, are not connected by fibrous structures or cartilage, and are able to move with respect to each other. Synovial joints allow for virtually free movement within a defined, but limited range, have little friction (see chapter 2.6), are designed to facilitate motion, and are able to transfer forces. A knee joint, for instance, does not heat up significantly during long movement exposure (e.g., during a marathon run) because of minimal joint friction. Furthermore, knee joints transfer forces during normal walking of up to three times body weight, hip joints of up to seven times body weight (Paul, 1976).

From a mechanical point of view, joints can be classified based on their shape (e.g., spherical, elliptical, hinge, saddle) and/or their translational and rotational movement possibilities (e.g., sliding or not sliding hinge joint).

2.9.2 FUNCTION

Functional, morphological, histological, and mechanical properties of biological materials have been discussed in chapters 2.3 to 2.7. However, joints should be considered as "organs" composed of several musculo-skeletal tissues. The integrity of a joint depends on the integrity of all its constituent parts. Failure of a single joint component, for instance, rupture of the anterior cruciate ligament in the knee, influences all tissues that make up the joint. Thus, understanding the mechanics and the function of joints requires (a) an understanding of the mechanics and function of muscles, tendons, ligaments, bones, and cartilage, and (b) a thorough understanding of the interaction of these tissues.

Selected aspects of joints are discussed in this section.

A joint is the junction between two or more bones of the human or animal skeleton.

The major functions of synovial joints include:

- To *permit limited movement*, and
- To *transfer forces* from one bone to another bone.

The skeletal system can move at joints. Cartilage covering the joint surfaces allows for relative movement of adjacent surfaces with minimal resistance. Furthermore, the joint surfaces are shaped to allow for restricted (e.g., tibio-femoral joint) or unrestricted (e.g., shoulder joint) movement. Each joint in the human or animal skeleton has structures, which *limit* its range of motion, including ligaments, joint capsules, muscle-tendon units, and/or bony shapes. The resistance to movement is typically small in the physiological range of motion but increases dramatically towards the boundaries of this range of motion. Because of the rigidity of the contacting bones, synovial joints are well-suited to *transfer forces* between segments.

Joints are well-designed for their mechanical purposes. Human and animal joints, unlike their man-made equivalents, function under demanding conditions for 70 or 80 years, frequently without malfunction.

2.9.3 DEGREES OF FREEDOM OF JOINTS

Relative movement between two adjacent segments of a joint can be described using six independent variables (degrees of freedom = DOF), three for translation, and three for rotation.

The degree of freedom (DOF) of a system of interest (a segment or a set of connected segments) is the number of independent variables (coordinates) needed to describe the motion of the system of interest.

The DOF of a system of rigid segments can be determined using the general relationship:

$$\text{DOF} = \text{number of generalized coordinates} - \text{number of constraints}$$

For three- and two-dimensional cases, the relationships read as:

$$\text{3-D: DOF} = 6N - C$$
$$\text{2-D: DOF} = 3N - C$$

where:

DOF	=	degree of freedom
N	=	number of segments
C	=	constraints

The degree of freedom provides information about the movement possibilities of one segment with respect to another segment of a joint (e.g., movement possibilities of the tibia with respect to the femur). Ideal *spherical joints* have three rotational and no translational DOF. The determination of the DOF for an ideal *elliptical joint* is complex. If the elliptical joint of interest has an elliptic cross-section for two principal axes, and a circular cross-section for one principal axis, the elliptical joint can rotate about an axis that is perpendicular to the circular cross-section. This corresponds to one rotational and no translational DOF. However, the two segments can also rotate about an axis that is perpendicular to an elliptical cross-section. In this case, the joint has two rotational and no translational DOF. *Sliding hinge joints* have one rotational and one translational DOF. *Saddle joints* have two rotational and two translational DOF.

Generally, joint axes have been found to change orientation during movement (Lundberg et al., 1989). This finding suggests that one degree of freedom is not sufficient for the description of actual joint motion. However, it has been proposed (Wilson et al., 1996) that unloaded joint motion at the human ankle and knee can be described using a one degree of freedom model because there is a distinct movement path in these joints that offers minimal resistance. In the absence of other forces, the joint follows that minimal resistance movement path.

Human and animal joints are not ideal theoretical joints. Real joints allow for movements that are not discussed when assuming ideal theoretical joints. The surface geometry of opposing bones and the corresponding cartilage at joints is such that the two surfaces are not congruent. In the knee, for instance, the femoral condyles are curved, allowing for rolling, gliding, and twisting movements on the relatively flat tibial surfaces. The hip joint is a ball and socket joint, but its articular surfaces are not completely spherical and the two surfaces are incongruent (Bullough et al., 1968).

In biomechanics, joints are treated in two distinctly different ways. The first way corresponds to a purely mechanical thinking of a joint (e.g., section 2.9.3). In this case, the joint is defined as a point (coordinate) or a point and a directed line (axis) going through the point. This description is sufficient from a mechanical point of view to solve the inverse dynamics problem, to generate forward simulations or to attack the distribution problem. The second way corresponds to a biological thinking of a joint. In this case, joints are described as "organs" made up of contacting bones, their corresponding articular cartilage surfaces, and the structures providing stability and/or movement (ligaments, tendons, muscles, etc.). These two approaches are virtually unrelated. Thus, when discussing a joint in biomechanics, one should be clear at any time, whether one is interested in the mechanical or the biological joint.

In the first part of this chapter joints were discussed in general terms. Every synovial joint in the human or animal body is specific and different from all the others. A full description of the anatomy, mechanics, and function of all joints goes well beyond the scope of this book. In the following sections, selected mechanical and functional aspects of joints are discussed using examples from the human ankle and the cat knee. Of course, the findings relate directly to the specific joints chosen and the comments might not be exactly appropriate for any other joint. However, general findings are often the same across joints. Thus, the specific examples may be considered in a broader sense than just being applicable for the joint discussed.

2.9.4 THE HUMAN ANKLE JOINT COMPLEX

Humans and animals have numerous joints with specific characteristics. In this section, the human ankle joint complex is used to discuss some general biomechanical aspects relevant to joints.

The ankle joint complex consists of the calcaneus, talus, tibia, fibula, and all ligamenteous and muscle-tendon structures crossing the joints between the four bones.

The subtalar joint is the joint between talus and calcaneus.

The ankle joint (or talo-crural joint) is the joint between tibia and talus.

ANATOMY OF THE ANKLE JOINT COMPLEX

The ankle joint complex consists of bones, ligaments, and muscle-tendon units. The bones of the ankle joint complex are the calcaneus, talus, tibia, and fibula. They are supported by several groups of ligaments (Fig. 2.9.1).

The tibio-fibular ligaments (anterior and posterior) connect tibia and fibula on the lateral side. The talo-fibular (anterior and posterior) and the calcaneo-fibular ligaments connect talus and calcaneus with the fibula laterally. Medially, the ankle joint complex is supported by the long plantar ligament and by the plantar calcaneo-navicular (spring) ligament.

The muscle-tendon units of the ankle joint complex (Fig. 2.9.2) include the triceps surae (gastrocnemius and soleus), the posterior compartment muscles (tibialis posterior, flexor digitorum longus, flexor hallucis longus), the lateral compartment muscles (peroneus brevis and longus), and the anterior compartment muscles (tibialis anterior, extensor hallucis longus, extensor digitorum longus, peroneus tertius). Each of these muscles has a specific function. The tibialis posterior tendon, for instance, originates at the lateral side of

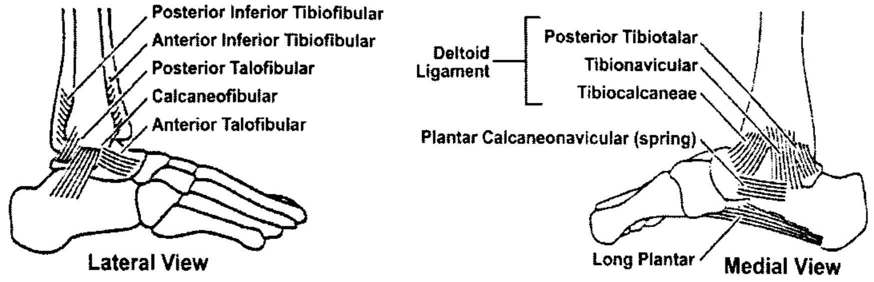

Figure 2.9.1 **Illustration of the medial (right) and lateral (left) ligaments of the ankle joint complex.**

the foot, crosses the ankle joint complex on the medial side below the medial malleolus, and attaches to the navicular, the cuneiforms, and the cuboid bones. A contraction of the tibialis posterior may produce foot movement and/or compression of the bony structures of the rear- and mid-foot.

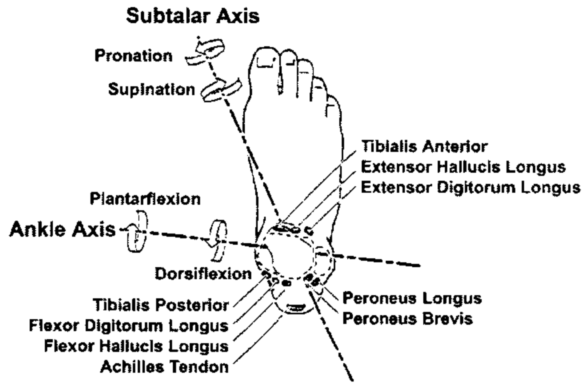

Figure 2.9.2 **Illustration of the extrinsic muscle-tendon units crossing the ankle joint complex and the functional axes of the subtalar and ankle joints.**

The ankle joint complex has two major functional axes, the subtalar joint axis, determined by talus and calcaneus, and the ankle joint axis, determined by talus and tibia (Fig. 2.9.2). The position of the calcaneus and tibia can be determined with acceptable accuracy. However, the position of the talus is hidden from the outside view. Thus, orientation of, and movement about the ankle and the subtalar joint axes, are difficult to determine (van den Bogert et al., 1994). For this reason, foot movement is often quantified about an anterior-posterior (in-eversion), a medio-lateral (plantar-dorsiflexion), and an inferior-superior axis (ab-adduction); i.e., axes that do not correspond to an anatomical joint.