

# Chapter 8

## Musculoskeletal system

## Introduction

The human musculoskeletal system is built on a complex bony architecture that supports and organizes the body into several anatomical regions: the head (face and skull), the neck, the trunk (thorax, abdomen, pelvis), the upper limbs connected via the shoulder girdle, and the lower limbs attached to the pelvis through the pelvic girdle.

The skeleton is composed of bones with various structures—long, flat, short, or pneumatic—whose arrangement reflects their mechanical or protective functions. These bones are connected by joints, which differ in their range of mobility:

- **Synarthroses** (immovable joints) connect bones through connective tissues without allowing significant movement.
- **Diarthroses** (movable joints), which are the true functional joints, have articular surfaces covered with cartilage, an articular capsule made of a synovial membrane and a fibrous layer, a joint cavity filled with synovial fluid, and various stabilizing elements such as ligaments and menisci.

Cartilage and bone form the supporting tissues of the body. In these specialized connective tissues, as in other connective tissues, the extracellular elements dominate their microscopic appearance.

### 8.1. Bone tissue

Bone tissue is a specialized connective tissue characterized by a hard, dense, and highly resistant extracellular matrix (ECM), which has the unique ability to calcify (70% of the ECM is made up of inorganic elements, including calcium phosphate). Bone tissue serves multiple functions, including support, protection, mineral storage, and hematopoiesis. Bones enable articulation or movement through their specialized cartilaginous ends. Despite its strength and rigidity, bone is a dynamic, living tissue that is constantly renewed and remodeled throughout life.

#### 8.1.1. Macroscopic Structure of Bone Tissue

Bone is a vascular connective tissue made up of cells and a calcified intercellular substance. It can be dense (compact) or spongy (trabecular). Spongy bone consists of interconnected plates called trabeculae, which are made up of several layers or lamellae. These plates define a wide system of small, interconnected spaces called marrow cavities. Within the osteomedullary space of spongy bones lies the hematopoietic bone marrow. Compact bone is solid and appears as a continuous mass, with no visible spaces to the naked eye. The two types of bone are not sharply separated and gradually blend into each other.

In a long bone, the shaft or diaphysis appears as a hollow cylinder of compact bone. A central canal—the medullary cavity—runs through it, containing bone marrow. The ends of long bones, called epiphyses, are primarily made of spongy bone covered by a thin layer of compact bone. Bone is covered by a dense, irregular, fibroelastic connective tissue called the **periosteum**. Flat bones, such as those in the skull, also consist of both compact and spongy bone. The outer and inner surfaces are made of thick layers of compact bone, while the space between them is filled with spongy bone. Short bones are mostly made up of spongy bone and are surrounded by periosteum, except at their articular surfaces.

### 8.1.2. Bone Tissue Cells

#### a. Osteoblasts

Osteoblasts are bone-forming cells with a cuboidal shape and more or less elongated cytoplasmic extensions. These cells are located on the surface of growing bone tissue. Their cytoplasm is rich in organelles involved in protein and glycoprotein synthesis (abundant rough endoplasmic reticulum and a large Golgi apparatus).

#### b. Osteocytes

Osteocytes are osteoblasts that have become completely surrounded by the mineralized bone extracellular matrix. They are smaller in size and contain less developed organelles compared to osteoblasts. Their bodies are spindle-shaped, with many fine, variably long cytoplasmic extensions. Osteocytes reside in small cavities called **lacunae**, from which tiny canaliculi radiate, containing their cytoplasmic processes.

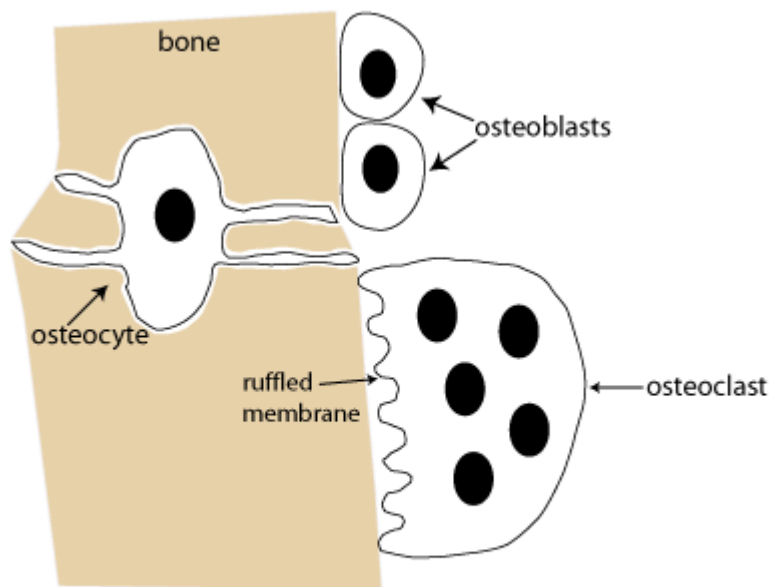


Figure.51. Bone cells

### 8.1.3. The Extracellular Matrix (ECM) of Bone Tissue

The bone's extracellular matrix is made up of an organic matrix (ground substance and collagen fibers) that becomes mineralized.

### 8.1.4. The Organic Matrix

The organic ECM is primarily composed of numerous type I collagen microfibrils. The ground substance is minimal and contains glycoproteins, mucopolysaccharides, serum proteins, water, and electrolytes.

#### a. Mineral Salts

The hardness of bone is due to the mineralization of its organic matrix. This mineral content is made up of hydroxyapatite crystals (crystallized calcium phosphate) and calcium carbonate. Bone contains 98% of the body's calcium, making it a major calcium reservoir and playing a key role in calcium-phosphate metabolism.

### 8.1.3. Microscopic Structure of Bone Tissue

Compact bone is surrounded by dense irregular collagenous connective tissue, the **periosteum**, which is attached to the **outer circumferential lamellae** by **Sharpey's fibers**. Blood vessels of the periosteum enter the bone via larger nutrient canals or small **Volkman's canals**, which not only convey blood vessels to the **Haversian canals** of **osteons** but also interconnect adjacent Haversian canals. Each osteon is composed of concentric lamellae of bone whose collagen fibers are arranged so that they are perpendicular to those of contiguous lamellae. The **inner circumferential lamellae** are lined by endosteal lined cancellous bone that protrudes into the marrow cavity.

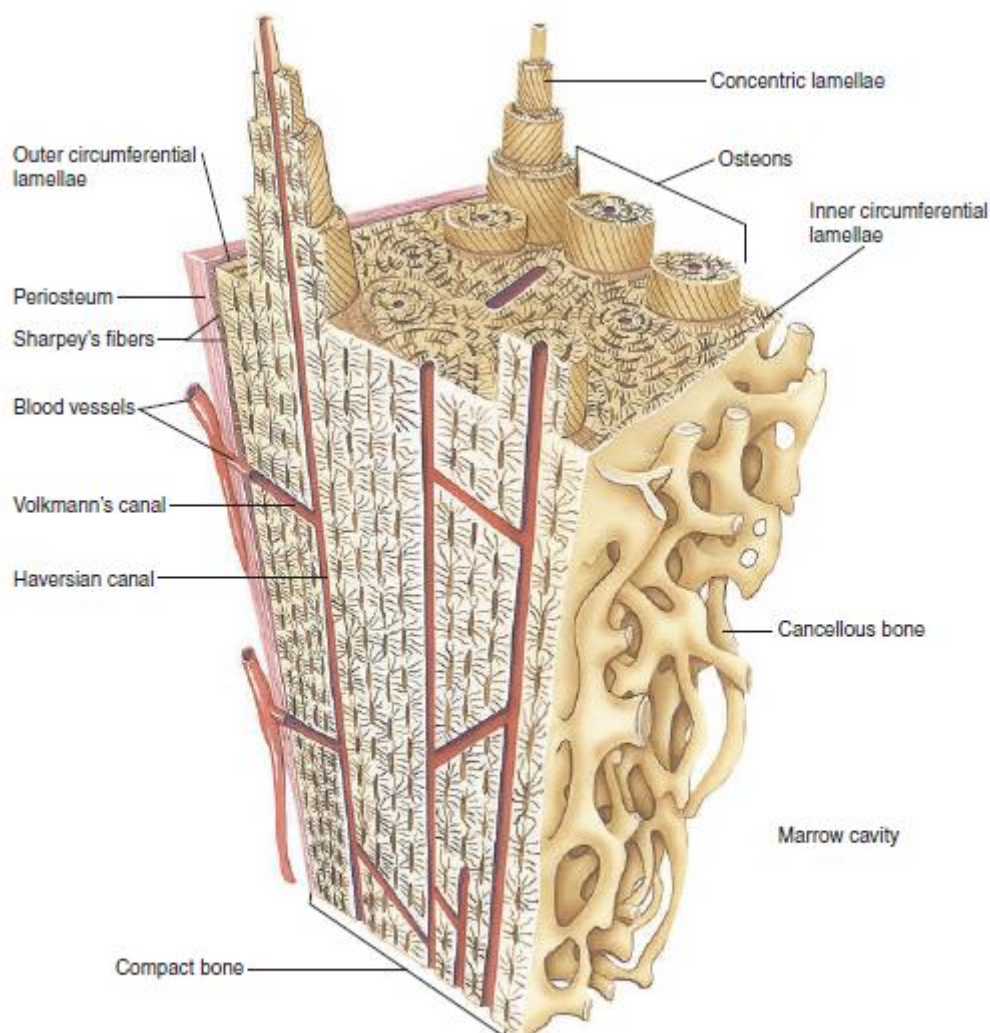


Figure.52. Microscopic structure of bone tissue

## 7.2. Cartilaginous Tissue

Cartilaginous tissue is a specialized connective tissue with a hard consistency, capable of resisting compression. It provides structural support, with cells embedded in a gel-like extracellular matrix (ECM).

This tissue lacks blood vessels, lymphatic vessels, and nerves. Instead, it is surrounded by a vascularized connective tissue called the perichondrium. The cartilage is entirely nourished by diffusion of nutrients from adjacent tissues through the aqueous phase of the ground substance. Despite its rigidity, the cartilage matrix contains about 75% water, contributing to its flexibility and resilience.

### 7.2.1. Components of Cartilaginous Tissue

#### a. Cells of Cartilaginous Tissue

There are two main types of cartilage cells: **chondroblasts** and **chondrocytes**.

##### a.1. Chondroblasts

Chondroblasts are **young, highly active cells** with an **ovoid shape** and a **central spherical nucleus**. Their cytoplasm contains **well-developed organelles**, along with **lipid and glycogen inclusions**.

Chondroblasts **secrete the extracellular matrix and fibers around them**. Once trapped in their own secretions, they become **chondrocytes**.

##### a.2. Chondrocytes

Chondrocytes are **large, rounded cells** located within **small cavities called lacunae (or chondroplasts)**. In a living state, they adapt to the **shape of their lacunae**.

Active chondrocytes have a **well-preserved nucleus**, along with a **visible Golgi apparatus, mitochondria, and endoplasmic reticulum cisterns**. They are responsible for **synthesizing and maintaining the surrounding matrix** and can **resorb the adjacent ground substance** to expand their lacunae.

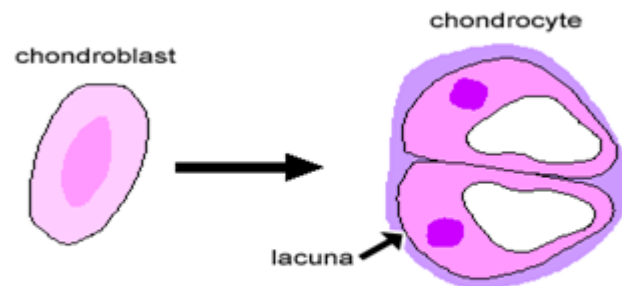


Figure.53. Cartilaginous cells

### b. Extracellular Matrix (ECM)

The high water content of the ECM (75% of its weight) allows cartilage to be flexible and deformable. The ECM consists of collagen fibers embedded in an amorphous ground substance, rich in proteoglycans.

The primary proteoglycan in cartilage is aggrecan, which gives cartilage its compressibility and elasticity. The main glycosaminoglycans (GAGs) present are:

- Chondroitin sulfate and keratan sulfate, which contribute to the water content and elasticity of cartilage.
- These proteoglycans are attached to hyaluronic acid, further enhancing the structural integrity of cartilage.

Additionally, the ECM contains:

- Proteolytic enzymes, responsible for breaking down and renewing the cartilage matrix.
- Growth factors and cytokines, produced by chondrocytes or other cells (e.g., monocytes/macrophages), which regulate cartilage maintenance and repair.

### 7.2.2. Types of Cartilage

Cartilage classification is based on the **abundance and type of fibers** in the ECM. Depending on the **amount of collagen or elastic fibers**, cartilage is categorized into **three histological types**.

#### a. Hyaline Cartilage

Hyaline cartilage is **the most common** type in the body but **the least resistant**. It is found in:

- **Ribs (costal cartilage)**, connecting them to the sternum.
- **Nose**, forming the tip and wings.
- **Larynx, trachea, and bronchi**, providing structural support.
- **Ends of growing long bones and joint surfaces**.
- **Fetal skeleton**, where it serves as a **temporary model** before being replaced by bone.

In **fresh cartilage and histological sections**, the **ECM appears amorphous and homogeneous** because the **collagen fibers are not visible**—they have the **same refractive index** as the ground substance.

In hyaline cartilage:

- **Type II collagen** is the dominant fiber, forming **thin microfibrils** arranged in a **loose network**.
- The **perichondrium** covers hyaline cartilage **except in joints and epiphyseal plates** (growth regions of long bones).
- **Perichondrial cells** can still **generate new cartilage** through **appositional growth**.

#### b. Elastic Cartilage

Elastic cartilage is characterized by the **presence of numerous branched elastic fibers**. These fibers form a **dense filamentous network** within the **extracellular matrix (ECM)**, surrounding the **chondrocytes**.

Elastic cartilage is **more flexible** than hyaline cartilage, allowing certain structures to **maintain their shape** while still being **flexible**. It is found in:

- **External ear canal**
- **Auditory (Eustachian) tubes**
- **Epiglottis** (a flap that prevents food from entering the trachea)

This type of cartilage provides both **structural support** and **elasticity**, enabling these organs.

### c. Fibrocartilage (Fibrous Cartilage)

Fibrocartilage is an **intermediate** between **dense connective tissue** and **cartilaginous tissue**.

- **Chondrocytes** are arranged **in parallel rows**—either **isolated**, in **pairs**, or in **small linear groups**.
- The **ECM** contains **thick bundles of Type I collagen fibers**, making it **highly resistant to mechanical stress**.
- Unlike hyaline and elastic cartilage, **fibrocartilage has no perichondrium**.

**Fibrocartilage is the strongest** of the three cartilage types and is found in:

- **Intervertebral discs** (between vertebrae)
- **Menisci of the knees**
- **Labrum (cartilaginous rings) of the hip and shoulder joints**

This type of cartilage provides **great tensile strength**, making it **essential** for areas exposed to **high pressure and mechanical stress**

## Cartilages in the Adult Body

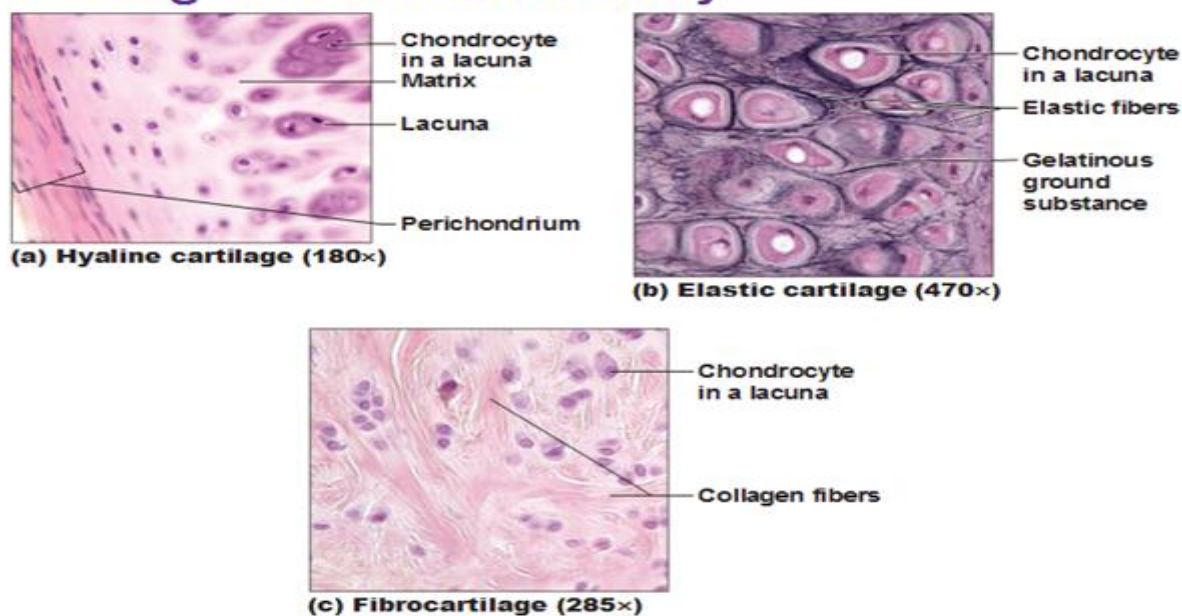


Figure.54. a,b and c . Cartilages types

### 7.3. Structure of the Articular Capsule

The articular capsule surrounds the cavity of a diarthrosis and connects the articulating bones.

It consists of two layers:

- **Outer layer: fibrous membrane**
  - Made of dense connective tissue rich in collagen fibers.
  - Function: provides mechanical strength and stability to the joint.
  - Inserts into the bones near the articular cartilage.
- **Inner layer: synovial membrane**
  - Lines the inner surface of the capsule except over the cartilage.
  - Vascularized and innervated: plays an active role in joint function (secretes synovial fluid).

#### 7.3.1. Synovial Membrane and Synovial Fluid Production

- The **synovial membrane** is a loose connective tissue that is highly vascularized and contains two main cell types:
  - **Type A synoviocytes:** macrophage-like cells responsible for phagocytosis and maintaining synovial fluid quality.

- **Type B synoviocytes:** fibroblast-like cells responsible for synthesizing hyaluronic acid and synovial proteins.
- **Synovial fluid** is a clear, viscous liquid composed of **hyaluronic acid, plasma proteins, and water.**
  - Functions:
    - Lubricates the articular surfaces.
    - Nourishes the avascular articular cartilage.
    - Removes metabolic waste.

### 7.3.2. Accessory Structures of Synovial Joints

Some synovial joints have additional structures that enhance their stability or improve joint congruence:

- **Ligaments:**
  - Dense, regularly arranged connective tissue rich in collagen.
  - Function: limits excessive joint movement.
- **Menisci** (e.g., in the knee):
  - Intra-articular fibrocartilage structures.
  - Increase joint congruence and absorb shock.
- **Articular labra** (e.g., shoulder, hip):
  - Ring-shaped fibrocartilage around some joint cavities.
  - Deepen the cavity to increase stability.
- **Synovial bursae:**
  - Small synovial-lined sacs located between bones and tendons or muscles.
  - Reduce friction during movement.

### 7.4. Skeletal muscle histology

The ability of animals to move is due to the presence of specific cells that have become highly differentiated, so that they function almost exclusively in contraction

**Skeletal muscle** is invested by dense collagenous connective tissue known as the

- **epimysium**, which penetrates the substance of the gross muscle, separating it into fascicles.
- Each fascicle is surrounded by **perimysium**, a looser connective tissue.
- Finally, each individual muscle fiber within a fascicle is enveloped by fine reticular fibers, the **endomysium**.

The vascular and nerve supplies of the muscle travel in these interrelated connective tissue compartments. There are three types of skeletal muscle fibers: **red**, **white**, and **intermediate** depending on their contraction velocities, mitochondrial content, and types of enzymes the cell contains (see Table 6-2). Each gross muscle, for example, biceps, usually possesses all three types of muscle cells. The innervation of a particular muscle cell determines whether it is red, white, or intermediate. Each skeletal muscle fiber is roughly cylindrical in shape, possessing numerous elongated nuclei located at the periphery of the cell, just deep to the sarcolemma. Longitudinally sectioned muscle fibers display intracellular contractile elements, which are the parallel arrays of longitudinally disposed **myofibrils**. In longitudinal section. The muscle fibers are extremely long and possess a uniform diameter. Their numerous **nuclei** (N) are peripherally located. The intercellular space is occupied by endomysium, with its occasional flattened **connective tissue cells** (CTs) and reticular fibers. Two types of striations are evident: longitudinal and transverse. The longitudinal striations represent **myofibrils** (M) that are arranged in almost precise register with each other. This ordered arrangement is responsible for the dark and light transverse banding that gives this type of muscle its name.

Note that the **light band** (I) is bisected by a narrow, dark line, the **Z disc** (Z). The **dark band** (A) is also bisected by the clear **H zone** (H). The center of the H zone is occupied by the M disc, appearing as a faintly discernible dark line in a few regions. The basic contractile unit of skeletal muscle is the **sarcomere** (S), extending from one Z disc to its neighboring Z disc. During muscle contraction, the myofibrils of each sarcomere slide past one another, pulling Z discs closer to each other, thus shortening the length of each sarcomere. During this movement, the width of the A band remains constant, whereas the I band and H zone disappear.

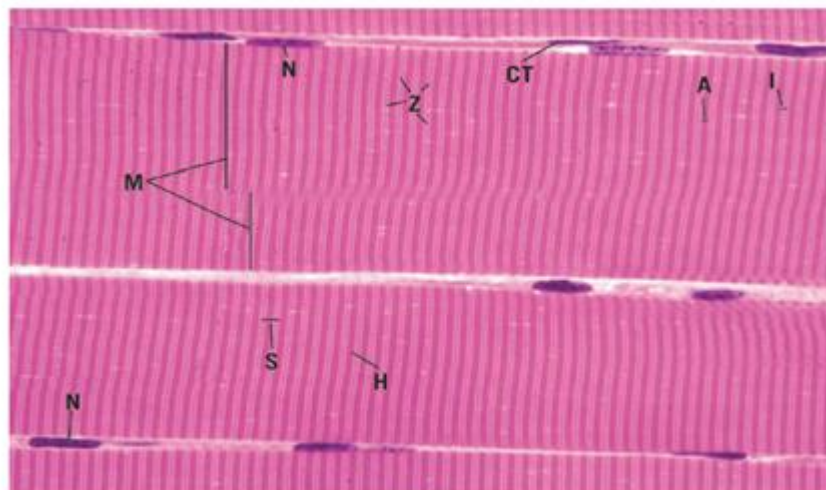


FIGURE 1

Figure.55. Skeltal muscle histology

## 7.5. functional junctions in the musculoskeletal system

### 7.5.1. Myotendinous Junction (MTJ)

The myotendinous junction is the transitional region between skeletal muscle and tendon. It is the interface where the force generated by muscle contraction is transmitted to the tendon, and Terminal muscle fibers insert into the collagen fibers of the tendon through deep extensions of the plasma membrane called **sarcoplasmic digitations**.

- The interaction surface is increased by these invaginations, allowing for better distribution of tension and reducing the risk of tearing.
- Presence of **adhesion protein complexes** (integrins, dystrophin, talin, vinculin) that anchor the muscle cytoskeleton to the connective tissue of the tendon.

#### Function

- Direct mechanical transmission of muscle forces to the skeleton.
- A zone vulnerable to mechanical injuries, particularly during intense exercise or explosive movements.
- Adaptable in response to training (strengthening of adhesion and connective tissue).
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## 7.5.2. Entheses (Tendon or Ligament Insertions)

Entheses are the sites where tendons or ligaments attach to bone. They serve as mechanical and functional links between fibrous tissues (tendon/ligament) and bone tissue.

### a. Types of Entheses

#### 1. Fibrous Entheses

- Dense connective tissue of the tendon inserts directly into compact bone.
- Mainly found in areas subject to moderate traction.
- **Examples:** insertion of the collateral ligaments of the knee.

#### 2. Fibrocartilaginous Entheses

- Gradual transition through four histological zones:
  1. Tendinous or ligamentous tissue
  2. Unmineralized fibrocartilage
  3. Mineralized fibrocartilage
  4. Bone
- This organization allows for progressive force transmission, reducing mechanical stress.
- **Examples:** Achilles tendon, patellar ligament.

### b. Histological Characteristics

- Presence of **Sharpey's fibers**: collagen extensions penetrating deeply into the bone.
- Adaptation to mechanical stress through increased mineralization and thickness of the fibrocartilaginous zones.
- Rich in specialized cells: **chondrocytes** in cartilaginous zones, **fibroblasts** in tendinous parts.

### c. Function

- Absorption and dissipation of mechanical forces at the tendon-bone or ligament-bone interface.
- Prevention of injuries from repeated traction.

- Involved in common pathologies: **enthesopathies, tendinopathies.**