Physiotherapy Department

PT201: Biomechanics

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Lecture 2
Biomechanics of Skeletal Muscles, Tendon, and Ligament

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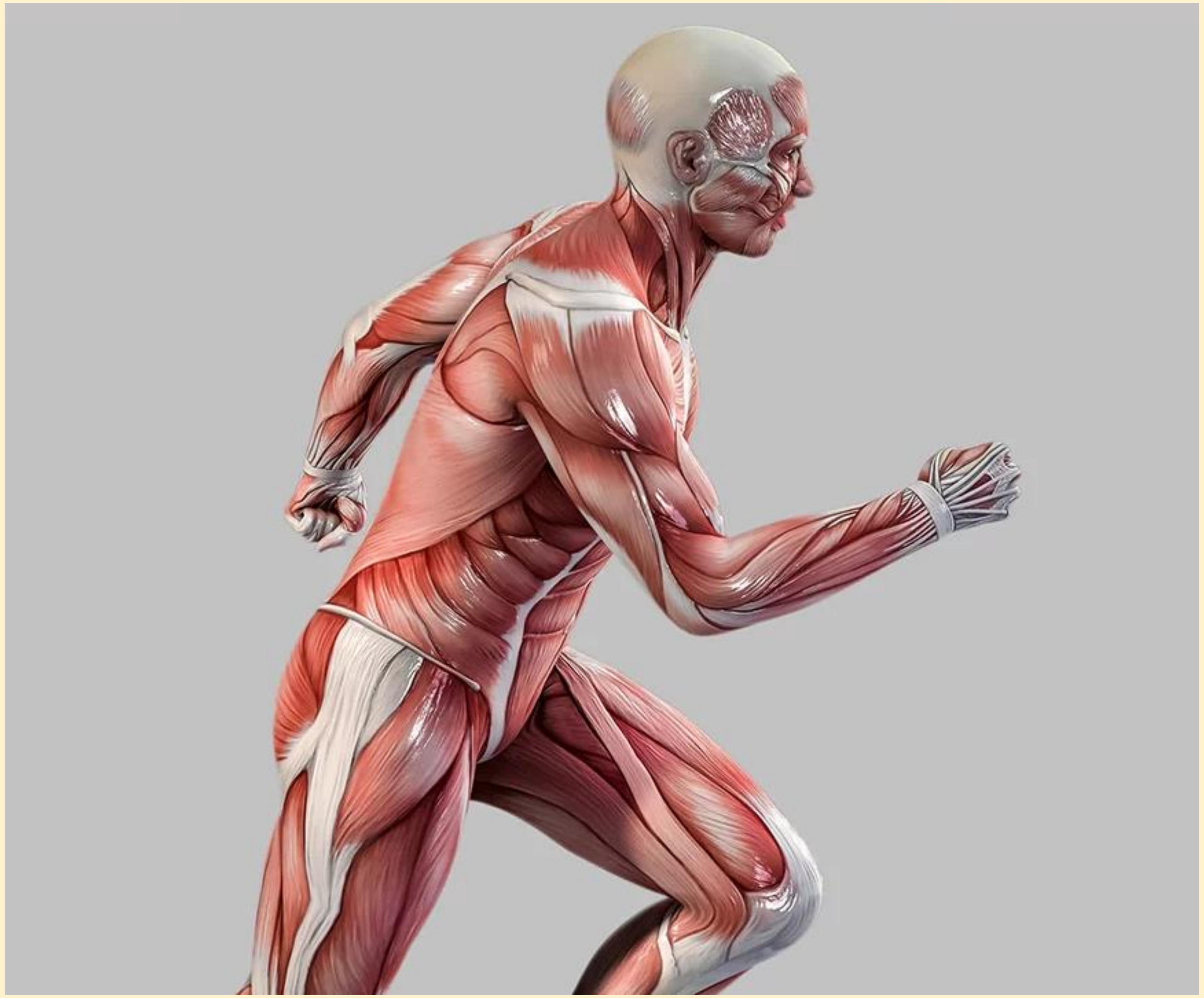


Synopsis

- Biomechanics of skeletal muscle
- Biomechanics of tendons
- Biomechanics of ligaments

Objectives

- By the end of this lecture, students should understand and be able to describe the basic biomechanics of the following connective tissue structures:
  - Skeletal muscle
  - Tendons
  - Ligaments

Skeletal muscle

- The functional unit that produces motion at a joint consists of two discrete units, the muscle belly and the tendon that binds the muscle belly to the bone

- Muscle belly consists of:
  - Muscle cells, or fibers, that produce the contraction and
  - Connective tissue that binds the cells together, thus encasing the muscle fibers

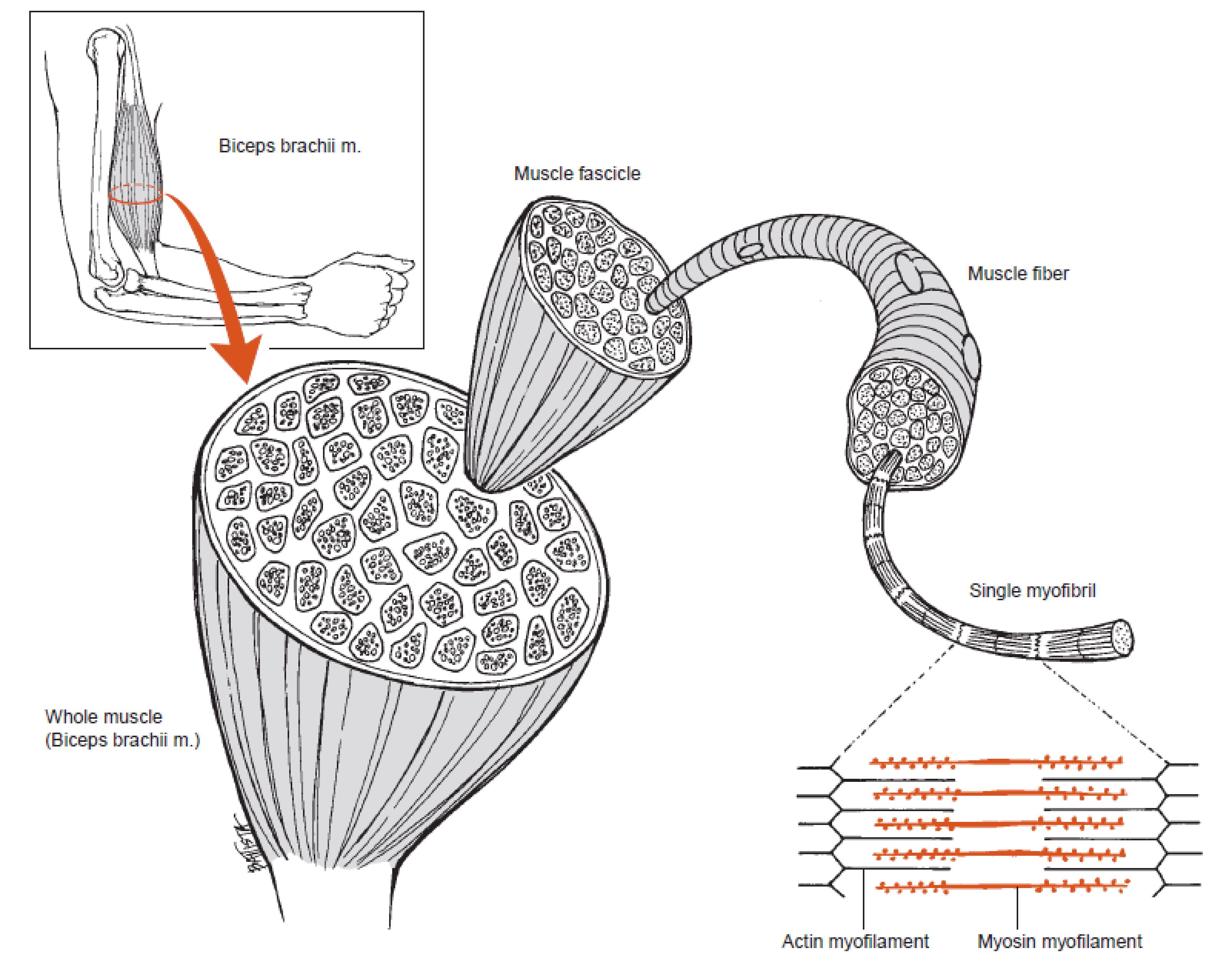
Skeletal muscle

Muscle fiber

- A skeletal muscle fiber is a long cylindrical, multinucleated cell that is filled with smaller units of filaments
- The filaments are roughly aligned parallel to the muscle fiber
- The largest of the filaments is the myofibril, which composed of subunits called sarcomeres that are arranged end to end the length of the myofibril
- Each sarcomere also contains filamentous structure, known as myofilaments

Skeletal muscle

- There are two types of myofilaments within each sarcomere
  - Thicker myofilaments
  - Thinner myofilaments
- The thicker myofilaments are composed of **myosin** protein molecules
- The thinner myofilaments are composed of **actin** protein molecules
- Sliding of the actin myofilament on the myosin chain is the basic mechanism of muscle contraction


Biceps brachii m.
Muscle fascicle
Muscle fiber
Single myofibril
Whole muscle
(Biceps brachii m.)
Actin myofilament
Myosin myofilament

Skeletal muscle

Types of muscle fibers

- There are three types of skeletal muscle fibers
    - ➢Type I
    - ➢Type IIA
    - ➢Type IIB

	Type I (Slow Oxidative)	Type IIA (Fast Oxidative Glycolytic)	Type IIB (Fast Glycolytic)
Diameter	Small	Intermediate	Large
Muscle color	Red	Red	White
Capillarity	Dense	Dense	Sparse
Myoglobin content	High	Intermediate	Low
Speed of contraction	Slow	Fast	Fast
Rate of fatigue	Slow	Intermediate	Fast

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Skeletal muscle

Connective tissue

- The muscle connective tissue binds the muscle cells together
- The outermost layer of connective tissue that surrounds the entire muscle belly is known as the epimysium
- The muscle belly is divided into smaller bundles or fascicles by another connective tissue known as perimysium
- Finally individual fibers within these larger sheaths are surrounded by additional connective tissue, the endomysium

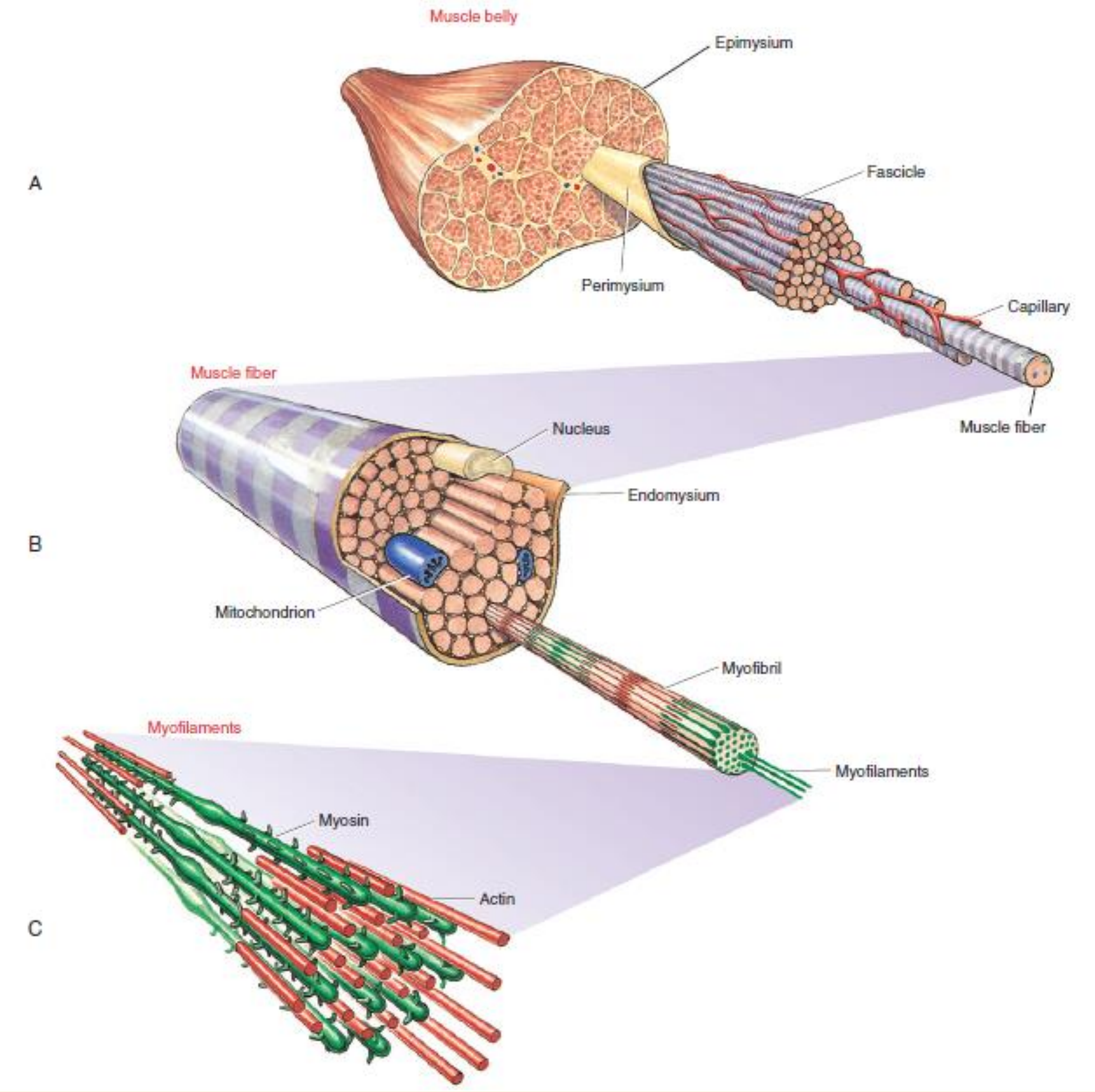
Skeletal muscle

- Thus, the entire muscle belly is invested in a large network of connective tissue that then bound to the connective tissue tendons at either end of the muscle

- The amount of connective tissue within a muscle and the size of the connecting tendons vary widely from muscle to muscle

- The amount of connective tissue found within an individual muscle influences the mechanical properties of that muscle

- The amount of the muscle connective tissue also helps explain the varied mechanical responses of individual muscles



Muscle belly
Epimysium
A
Fascicle
Perimysium
Capillary
Muscle fiber
Muscle fiber
Nucleus
Endomysium
B
Mitochondrion
Myofibril
Myofilaments
Myofilaments
Myosin
Actin
C

Skeletal muscle

Architecture of skeletal muscle

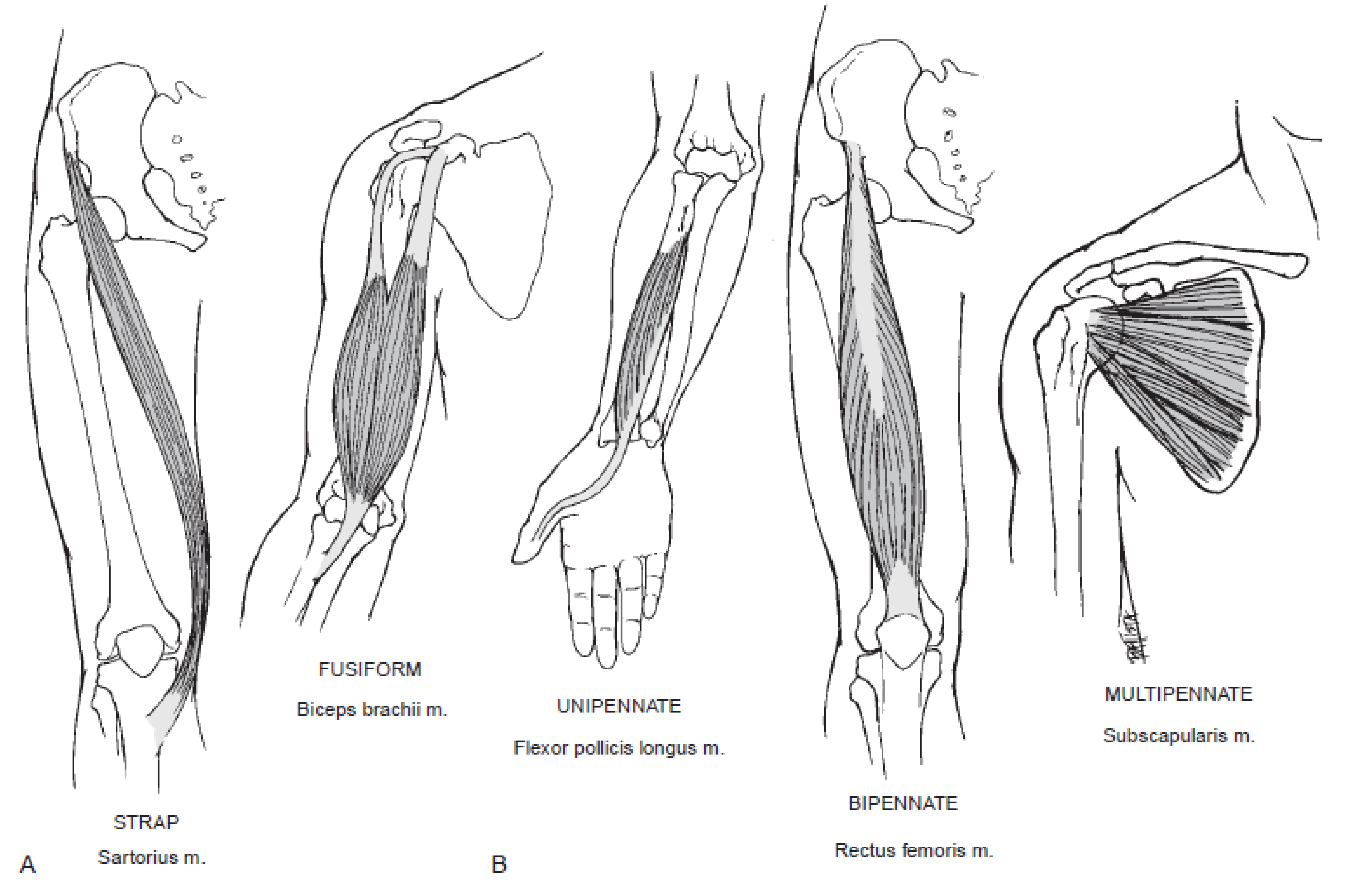
- Arrangement of skeletal muscle fibers

- Affects the ability of the muscle to produce movement and to generate force

- Broadly there are two categories of muscle architecture
  - ➢ Parallel (have longer muscle fiber)
  - ➢ Pennate (have shorter muscle fiber)

- Parallel include fusiform and/or strap

- Pennate include unipennate, bipennate, and multipennate muscles


STRAP
Sartorius m.
A
FUSIFORM
Biceps brachii m.
UNIPENNATE
Flexor pollicis longus m.
B
BIPENNATE
Rectus femoris m.
MULTIPENNATE
Subscapularis m.

Skeletal muscle

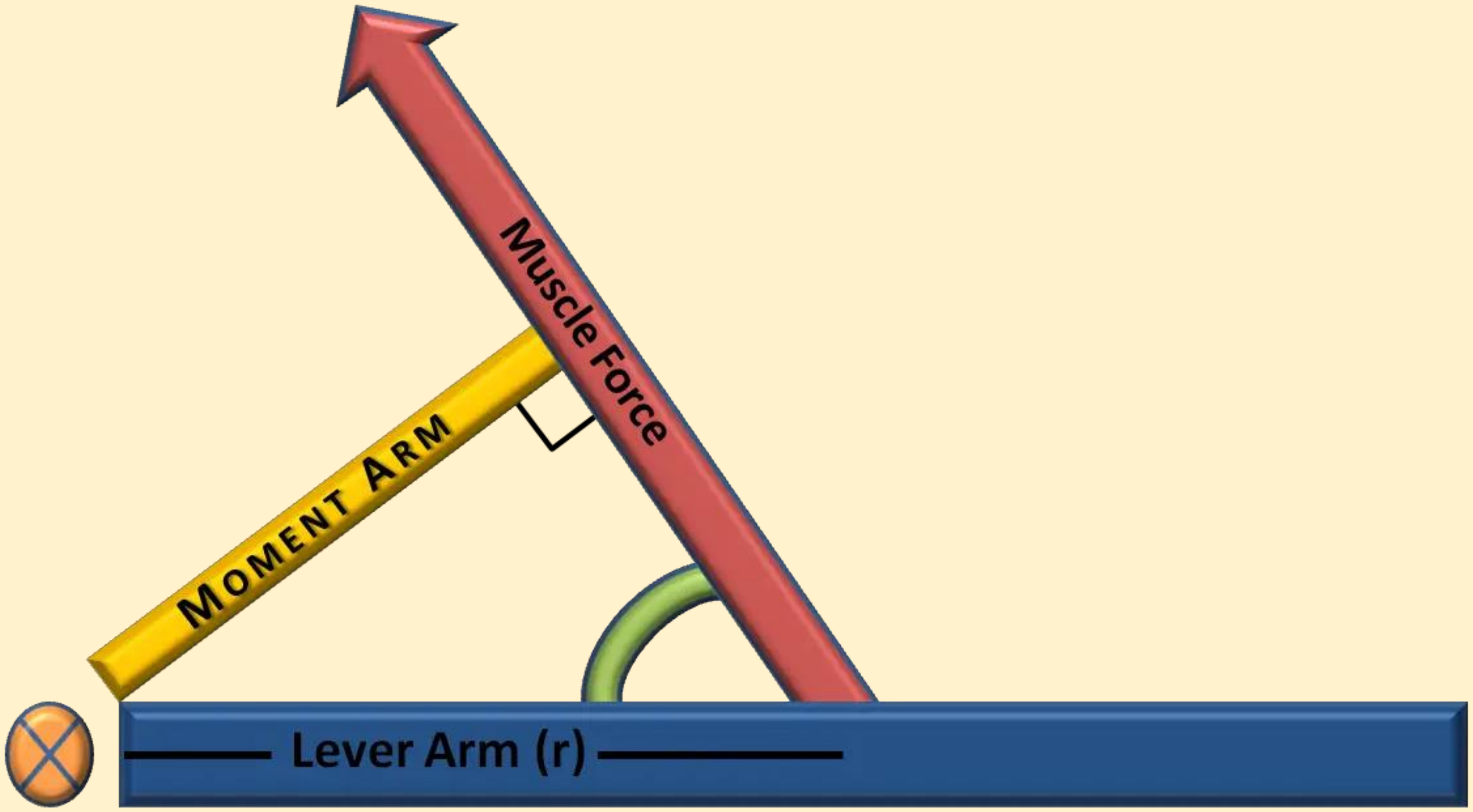
Factors that influence muscle ability to produce motion

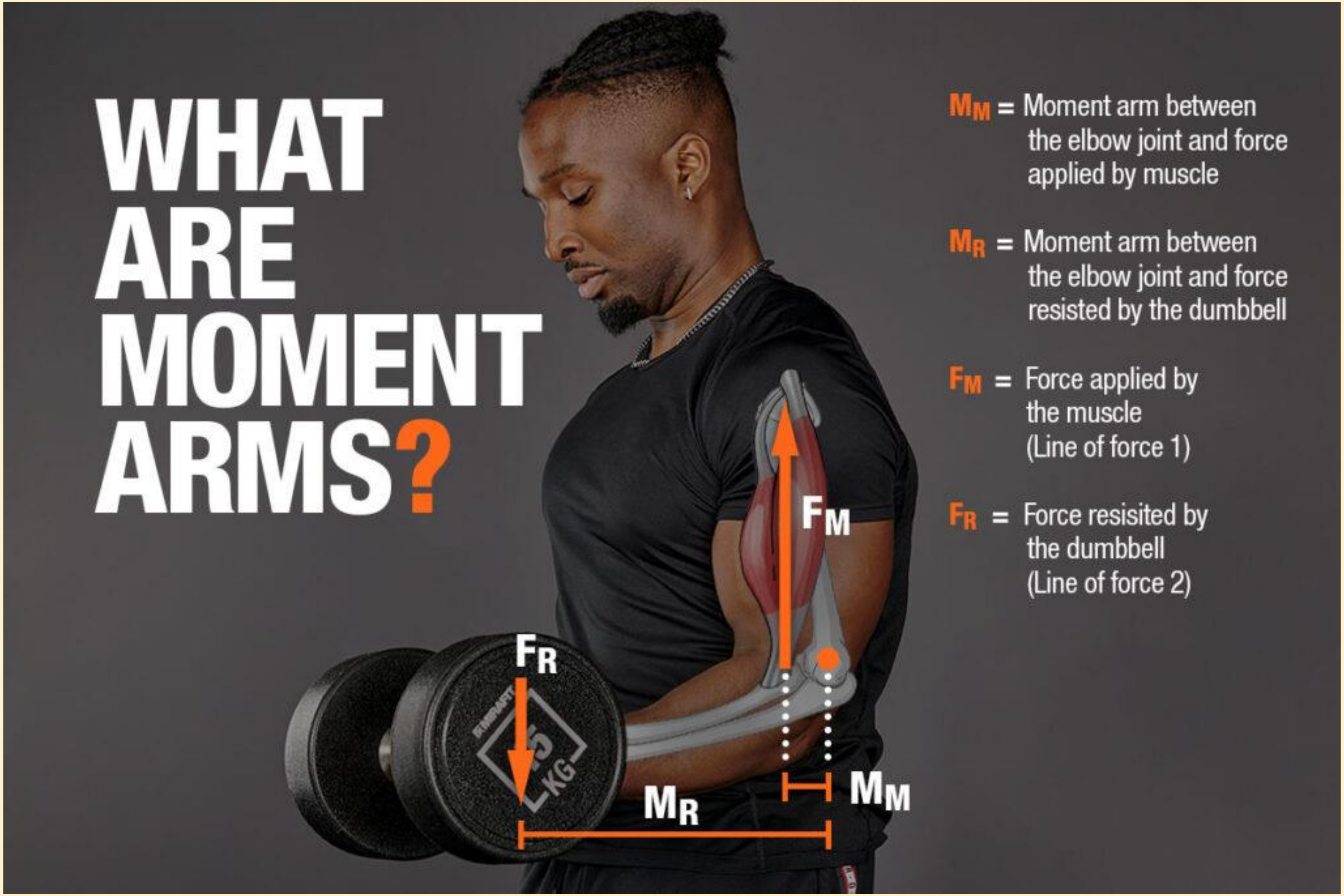
- ➢Length of the fibers composing the muscle
- ➢Length of the muscle's moment arm

- Length of fiber composing the muscle: the longer the fiber, the more the sarcomeres, the more the shortening, and the greater the ability to produce motion
- Length of the muscle's moment arm is the perpendicular distance between the muscle and the point of rotation. Thus, the longer the moment arm, the greater the ability to produce motion

MOMENT ARM

= THE PERPENDICULAR DISTANCE FROM AN AXIS TO THE LINE OF ACTION OF A FORCE




WHAT ARE MOMENT ARMS?
MM = Moment arm between the elbow joint and force applied by muscle
MR = Moment arm between the elbow joint and force resisted by the dumbbell
FM = Force applied by the muscle (Line of force 1)
FR = Force resisited by the dumbbell (Line of force 2)
FM
FR
MR
MM

Skeletal muscle

Factors that influence muscle strengths

- The primary factors influencing the muscle's strength are
  - Muscle size
  - Muscle moment arm
  - Stretch of the muscle
  - Contraction velocity
  - Level of muscle fiber recruitment
  - Fiber types composing the muscle

Skeletal muscle

Adaptation of muscle to altered function

- Prolonged stretch of a muscle induces protein synthesis and the production of additional sarcomeres, thus the muscle hypertrophies

- Prolonged shortening accelerates loss of sarcomeres, thus the muscle atrophies

- Increased activity results in hypertrophy and increased force production

- Decreased activity leads to atrophy and decreased force production

Tendon and Ligaments

- Tendons and ligaments are dense connective tissue structures that connect muscle to bone and bone to bone respectively

- Tendons and ligaments are located in and around the joints of the body, and as a result, they are both subjected to large distractive or tensile loads

- Tendons and ligaments are the structures that are largely responsible for providing joint stability during movement and function

- Tendons and ligaments are biologically active structures, and as a result, injuries, aging, and abnormal conditions such as joint immobilization produce alterations in their composition and structure

Tendon and Ligaments

Structure of tendon and ligament

- Tendons and ligaments are composed of connective tissue

- Connective tissues provide and maintain form in the body, functioning mechanically to connect and bind cells and organs together, thus giving support to the body

- Connective tissues are typically classified into three major groups:
  - ➢Proper connective tissue: Loose (e.g., areolar tissue, epithelial); Dense (e.g., dermis, tendon, ligament)
  - ➢Supporting connective tissues e.g., Bone and Cartilage
  - ➢Specialized connective tissues e.g., Adipose tissue and Hematopoietic tissue

Tendon and Ligaments

- Tendons and ligaments are classified as dense, regular connective tissue
- Fiber bundles in tendons and ligaments are densely packed and are oriented parallel to one another as well as to frequently applied forces
- The arrangement makes them particularly well adapted to resisting traction or tensile forces

Tendon and Ligaments

- Like all dense connective tissues, tendons and ligaments are composed of two major compartments:
  - Cells
  - Extracellular matrix

- Primary cell type in tendons and ligaments are the fibrocytes (also called the fibroblasts, when they are actively manufacturing proteins)

- Cells (fibrocytes/fibroblast) make up only about 20% of the total tissue volume

- Fibroblasts manufacture and secrete the components of the extracellular matrix that makes up the remaining 80%

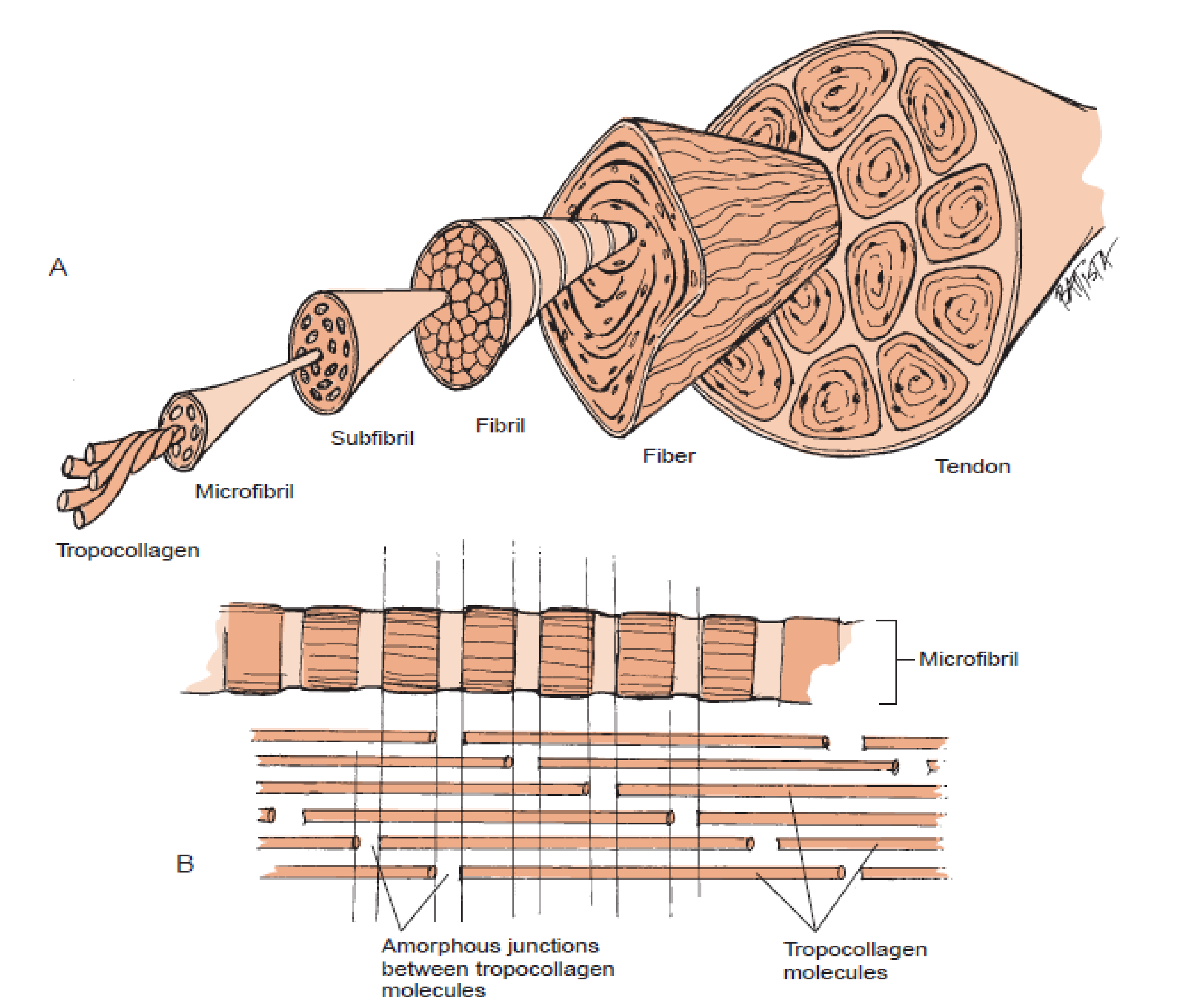
Tendon and Ligaments

- The extracellular matrix is composed of
  - Fibers
  - Ground substance

- The fibers consist of collagen (which gives tendons and ligaments their white appearance) and elastin

- The ground substance is the gelatinous material that fills the spaces between cells and fibers.

- The ground substance is composed of non-collagenous structural glycoproteins (fibronectin), proteoglycans (decorin, biglycan), and water



Structural composition of ligament and tendon

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Tendon and Ligaments

- Changes in physical and biological conditions alter the biochemical composition, histological structure and organization, and biomechanical properties of tissues

- Factors that cause deterioration of the biomechanical properties of tendons and ligaments include
  - Immobilization
  - Aging
  - Healing
  - Stress shielding

Tendon and Ligaments

- Application of physiological loads during immobilization and healing reduces the amount of deterioration of the biomechanical properties

- Normal ligaments can withstand increased stress loading within a range (about 133% of normal), after which the biomechanical properties of the overstressed ligaments deteriorate

- Maintenance of normal biomechanical functioning of tendons and ligaments is important to ensure normal joint kinematics and tolerance to loading during functional activities

Contributions and Questions

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References

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