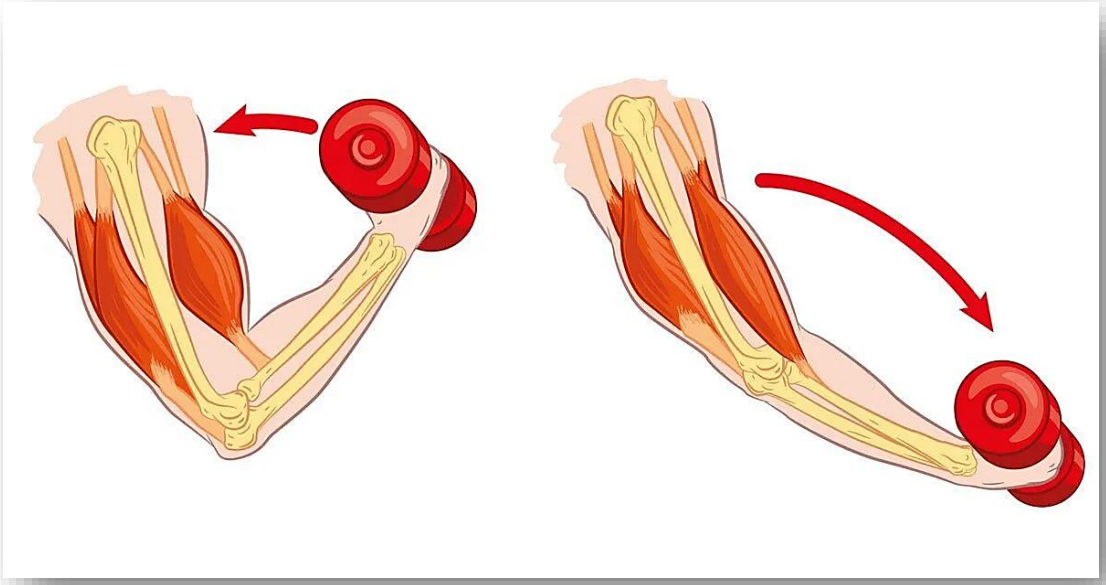
1ST YEAR MEDICAL STUDENTS
PHYSIOLOGY (LECTURE 16)
MECHANICS OF SKELETAL MUSCLE CONTRACTION



BY

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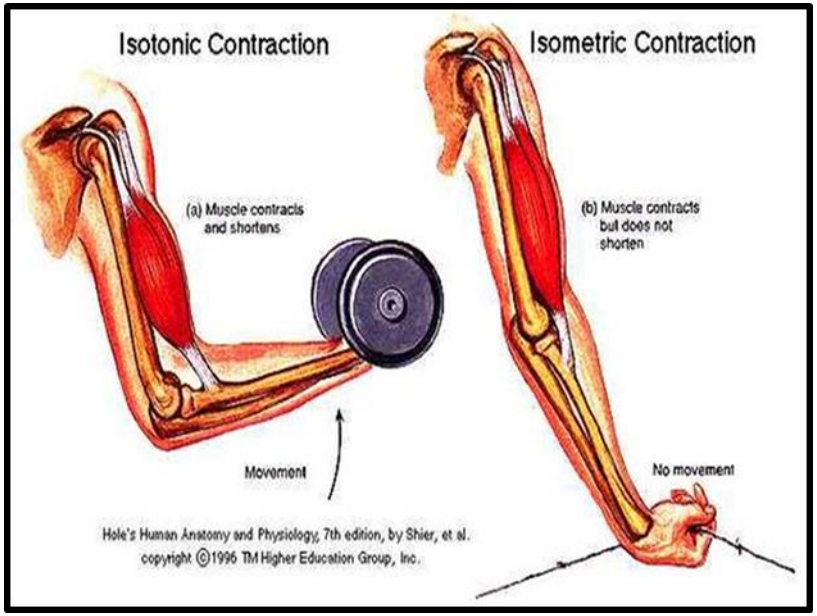
TYPES OF SKELETAL MUSCLE CONTRACTION

- **There are TWO TYPES of skeletal muscle contraction:**

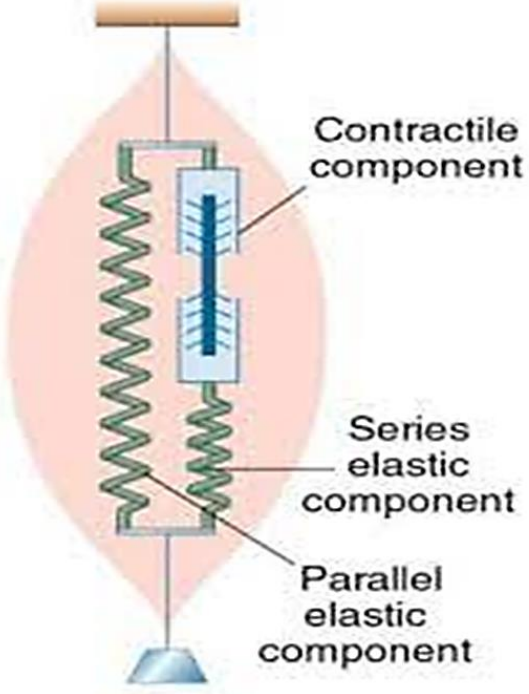
❑ **Isometric contraction.**

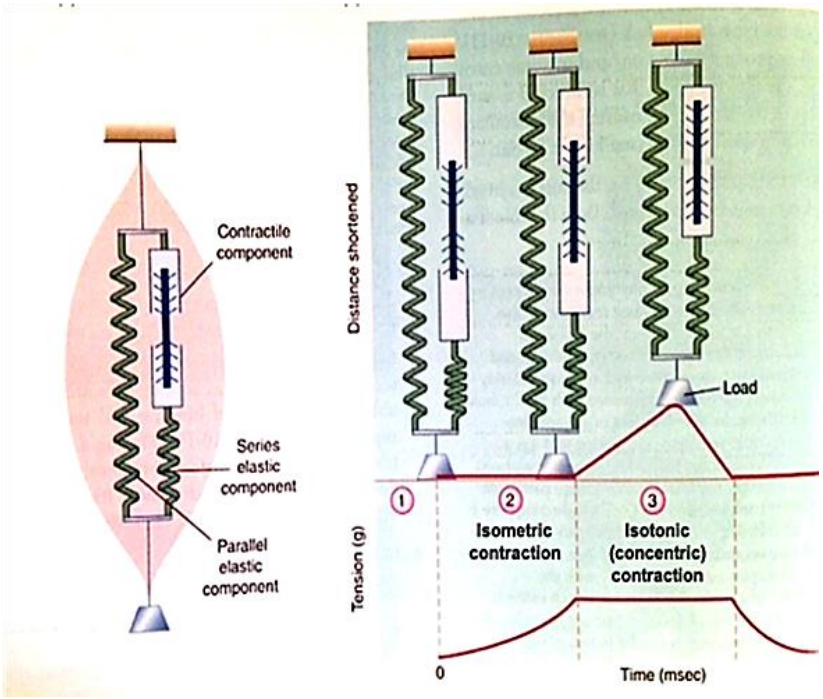
❑ **Isotonic contraction.**

- **Normal muscle activity is a combination of isometric and isotonic contractions.**



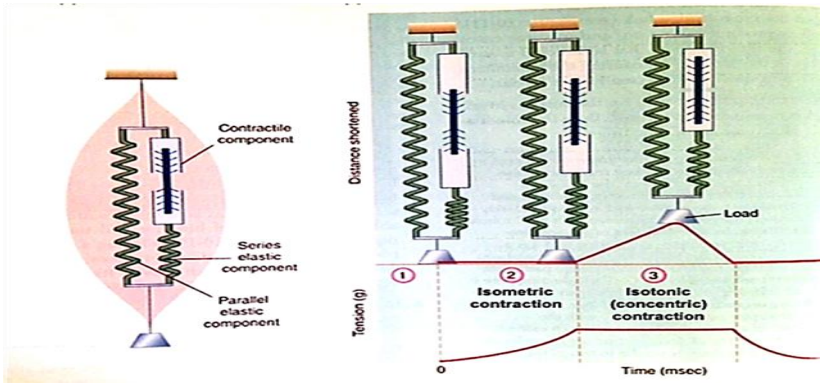
In addition to the contractile element (CE) in skeletal muscles, there are also TWO elastic elements: one parallel (PE) to CE and the other in series with it (SE). The element that mainly stretches during contraction is the SE.





ISOMETRIC CONTRACTION

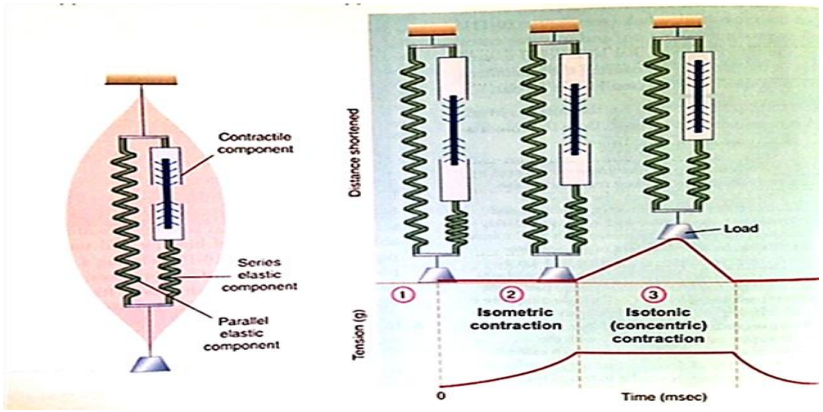
- Involves the **development of tension without** any **change in length (constant length).**
- The muscle **contract without shortening** but the **tension is much increased.**
- **Mechanism**: The muscle fibers are formed of **contractile** parts (CE) and elastic tissue (SE). When the contractile part (sarcomere) is shortened → **pull** on the elastic tissue which is markedly **stretched (because the load is not moved)→** so that the **total length** of the muscle fiber **doesn't** change (i.e. length is constant **but** tension is increased).

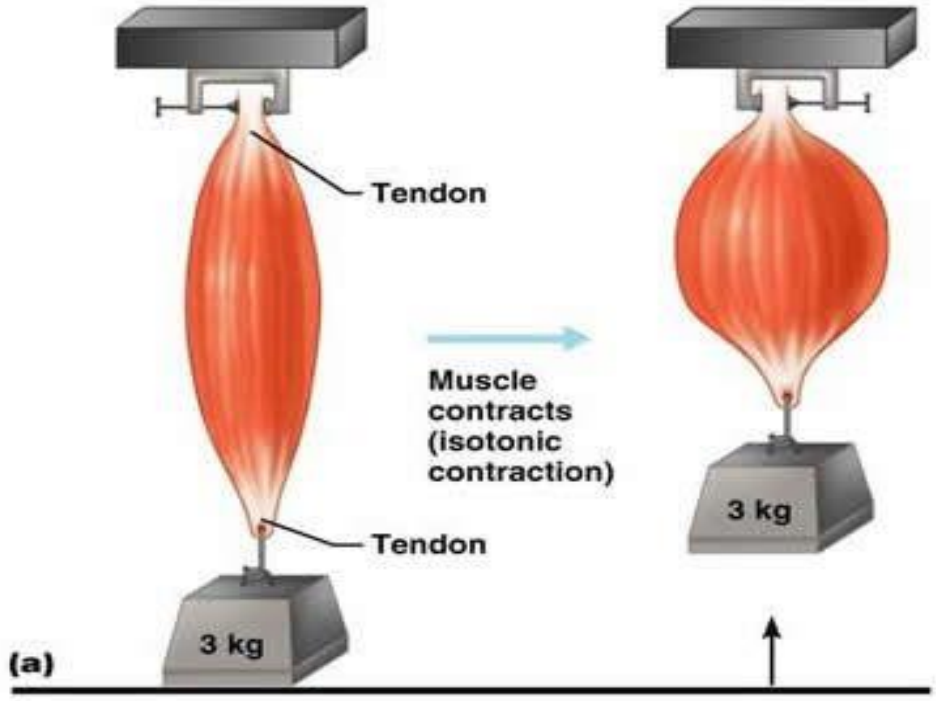


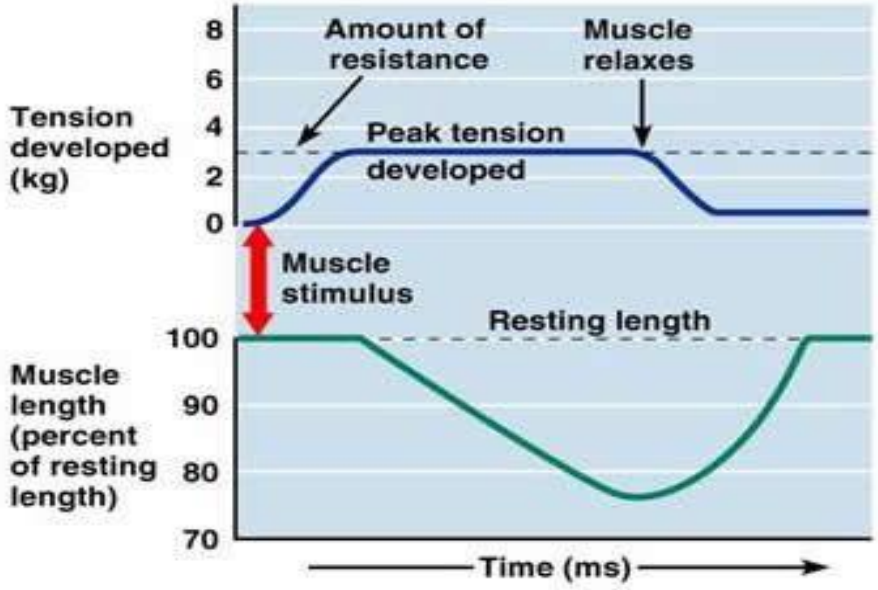
ISOTONIC CONTRACTION

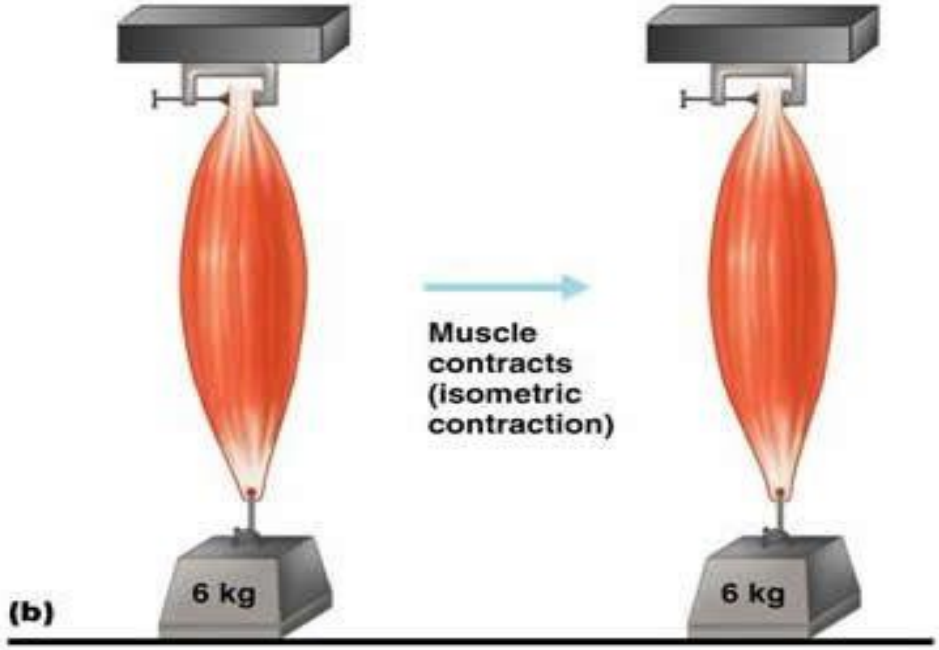
- Involves the **change in length without any change in tension (constant tension).**
- The muscle **shortens** and carries a weight (i.e. **mechanical work is done**) **without change in tension**.
- **Mechanism:**

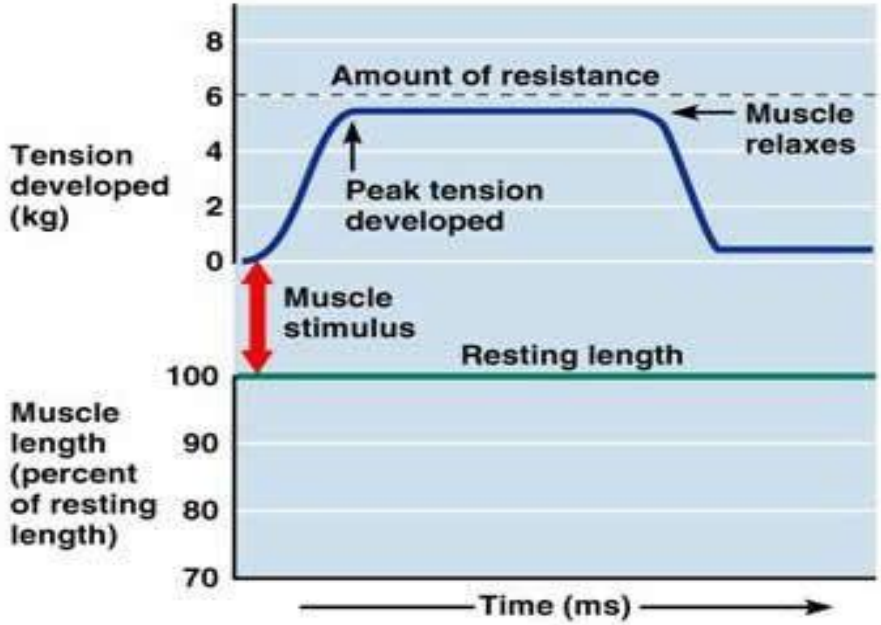
The CE shortens and SE is not markedly stretched (because load is moved)→ the whole muscle is shortened and tension remains constant.




Tendon
Muscle contracts (isotonic contraction)
3 kg
Tendon
3 kg
(a)


Amount of resistance
Muscle relaxes
Tension developed (kg)
8
6
4
2
0
Peak tension developed
Muscle stimulus
Resting length
100
90
80
70
Muscle length (percent of resting length)
Time (ms)


Muscle contracts (isometric contraction)
6 kg
6 kg
(b)


Amount of resistance
Muscle relaxes
Tension developed (kg)
8
6
4
2
0
Peak tension developed
Muscle stimulus
Resting length
100
90
80
70
Muscle length (percent of resting length)
Time (ms)

Types of Skeletal Muscle Contraction

Item	Isotonic	Isometric
Length of muscle	Decreases; the muscle shortens	Constant length
Tension	Constant	Much increased
Work	The muscle performs external work	No work is done
Mechanical efficiency	20-25% The rest of energy production is released as heat	Zero Though energy is consumed
Example	Carrying a weight against gravity	Carrying a weight that is too heavy to be carried

Length-Tension Relationship

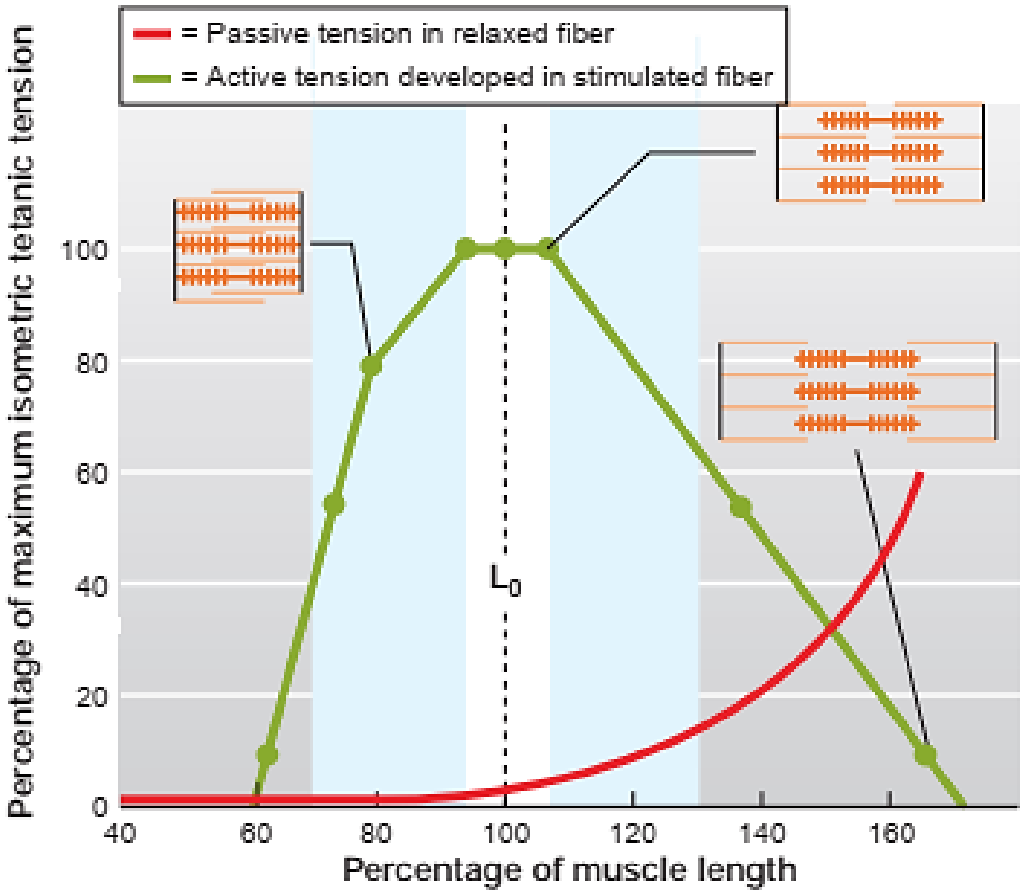
The **length-tension relationship in muscle refers** to the **effect of muscle fiber length on the amount of tension the fiber can develop**.

- It is the **relationship between muscle length and active tension**.
- **The active tension:**

- The amount of **tension** is determined for a muscle undergoing an **isometric contraction**.
- It is **proportional to the number of cross-bridges that cycle**.
- The **active tension is maximal** when there is **maximal overlap (attachment) of thick and thin filaments and maximal possible cross-bridges**.
- When the **muscle is stretched to longer lengths**, the number of possible crossbridges is reduced **and active tension is reduced**.

- When **muscle length is decreased**, the thin filaments collide with each other in the center of the sarcomere, reducing the number of possible crossbridges and **reducing active tension**.

N.B. For skeletal muscle→ The resting length is the optimal length (L_O) → maximal amount of tension that can be developed during contraction.


= Passive tension in relaxed fiber
= Active tension developed in stimulated fiber
Percentage of maximum isometric tetanic tension
0
20
40
60
80
100
40
60
80
100
120
140
160
Percentage of muscle length
L_0

Load–Velocity Relation

- **A load** on a contracting muscle is **a reverse force** that opposes the contractile force caused by muscle contraction.
- As the load increases → Velocity of shortening is decreased.
- **At zero load**, the muscle contracts with **a maximal velocity of shortening**.
- **A heavy load that cannot be lifted** doesn't allow shortening of the muscle → **isometric contraction**.

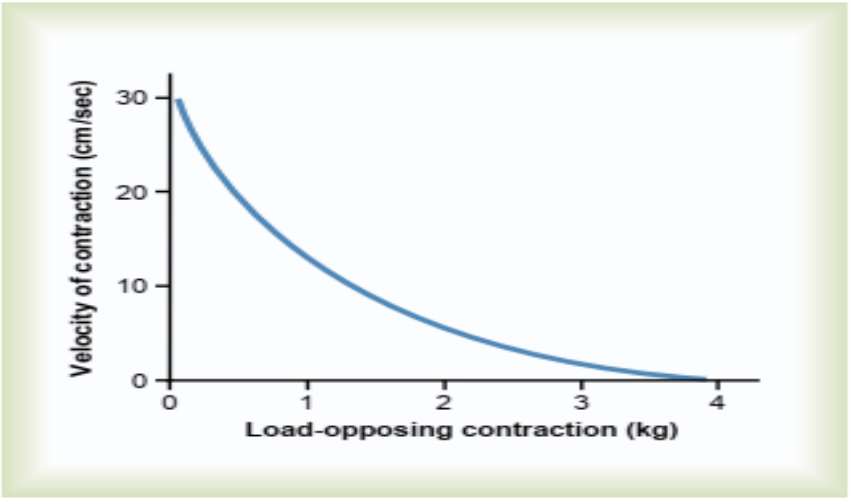
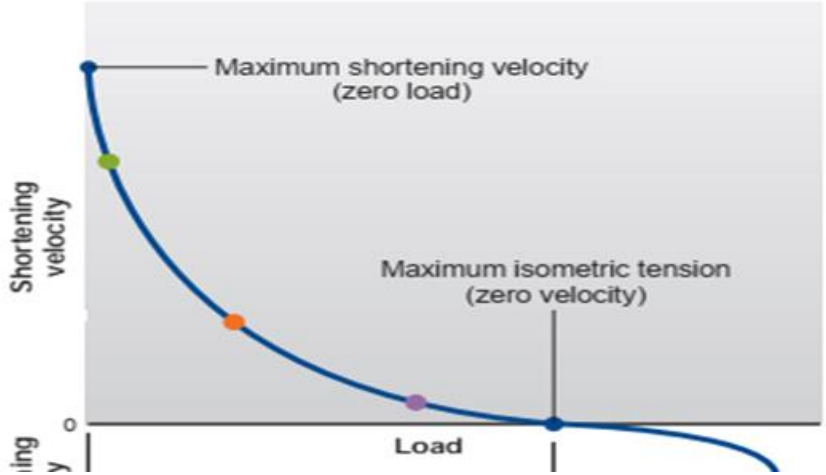

Velocity of contraction (cm/sec)
30
20
10
0
0
1
2
3
4
Load-opposing contraction (kg)

Figure 6–10


Maximum shortening velocity
(zero load)
Shortening
velocity
Maximum isometric tension
(zero velocity)
0
Load

Types of Skeletal Muscle Fibers

Three principal types of skeletal muscle fibers can be distinguished:

1. Slow-oxidative fibers (type I).

2. Fast-oxidative-glycolytic fibers (type IIA).

3. Fast-glycolytic fibers (type IIB).

	Type I	Type IIB
Other names	Slow – Oxidative (SO)	Fast – Glycolytic (FG)
Myosin ATPase activity	Slow	Fast
Contraction Velocity	Slow	Fast
Sarcoplasmic Reticulum	Less extensive	More extensive for rapid release of calcium ions to initiate contraction.
Color	Red	Pale (white)
Myoglobin content	High	Low
Primary source of ATP Production	Oxidative Phosphorylation	Glycolysis
Glycolytic Capacity	Low	High
Glycogen content	Low	High
Examples	Muscles of the back and leg	Extraocular and hand muscles
Rate of Fatigue	Slow (Resistant to fatigue)	Fast (Fatigue rapidly)
Fiber diameter	Small	Large

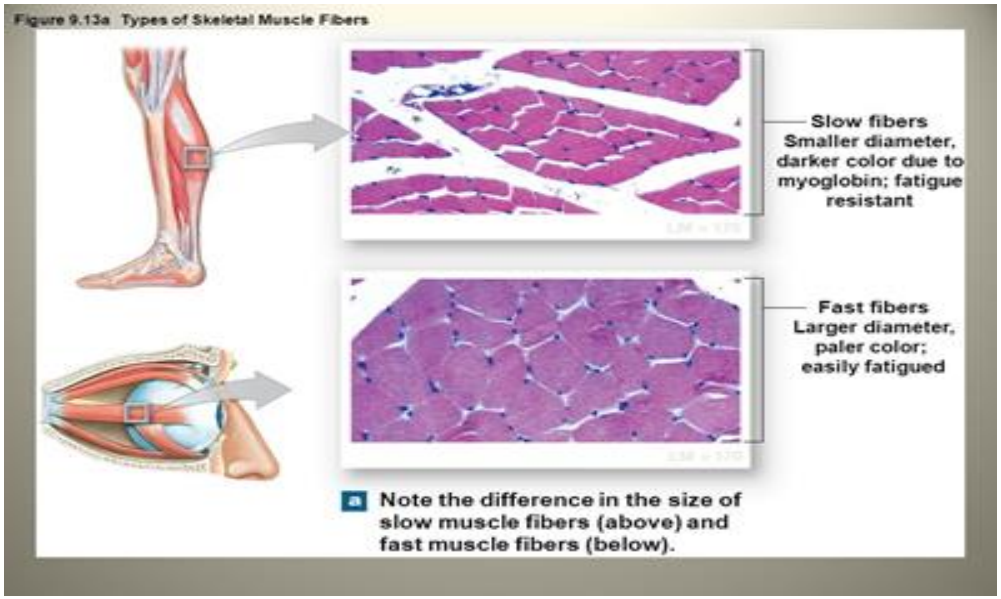
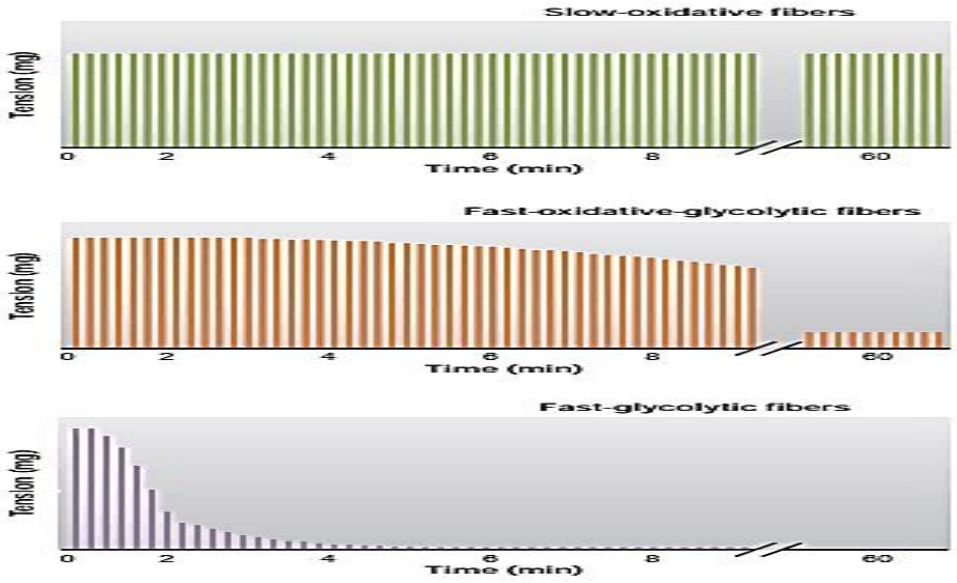


Figure 9.13a Types of Skeletal Muscle Fibers
Slow fibers
Smaller diameter, darker color due to myoglobin; fatigue resistant
Fast fibers
Larger diameter, paler color; easily fatigued
a Note the difference in the size of slow muscle fibers (above) and fast muscle fibers (below).


Slow-oxidative fibers
Tension (mg)
0
2
4
6
8
60
Time (min)
Fast-oxidative-glycolytic fibers
Tension (mg)
0
2
4
6
8
60
Time (min)
Fast-glycolytic fibers
Tension (mg)
0
2
4
6
8
60
Time (min)

THE MOTOR UNIT

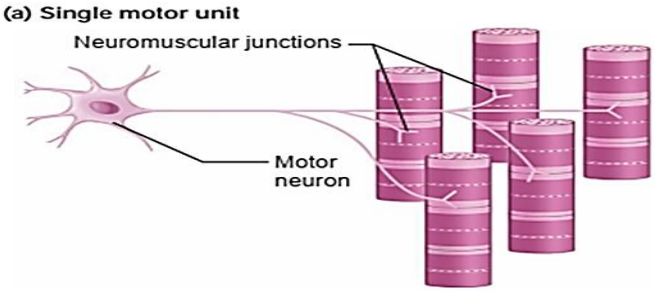
✓ **Definition:**

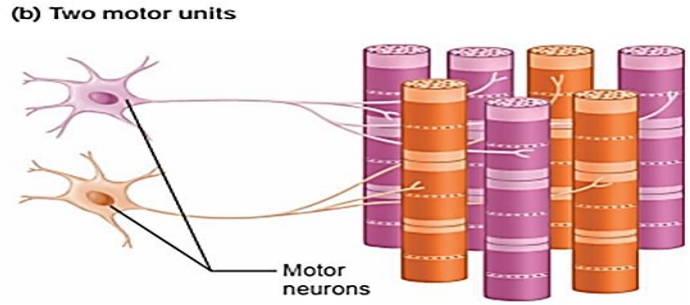
The **motor unit** is formed of the **motor neuron plus the muscle fibers it innervates**.

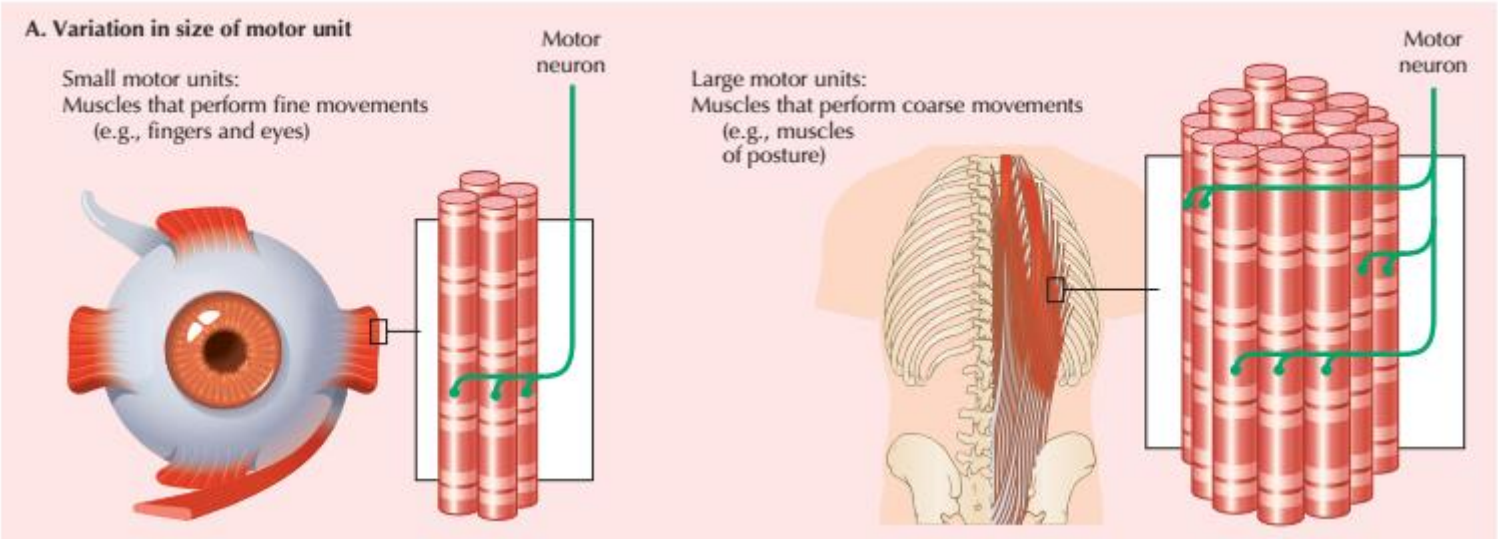
✓ **Types of Motor Units:**

- **Small motor units:** such as in the muscles concerned with **fine movements** e.g. muscles of the hands and extraocular muscles have **few** muscle fibers/motor unit to **allow gradation of contraction**.
- **Large motor units:** such as in the muscles concerned with **gross movements** e.g. large muscles of the back and leg have **large number of** muscle fibers/motor unit to **allow maintained strong postural contractions**.

✓ **All the muscle fibers in a motor unit are of the same type.**


(a) Single motor unit
Neuromuscular junctions
Motor neuron


(b) Two motor units
Motor neurons


A. Variation in size of motor unit
Small motor units:
Muscles that perform fine movements
(e.g., fingers and eyes)
Motor neuron
Large motor units:
Muscles that perform coarse movements
(e.g., muscles of posture)
Motor neuron

Thank You