PHYSIOLOGY
HAYAT BATCH

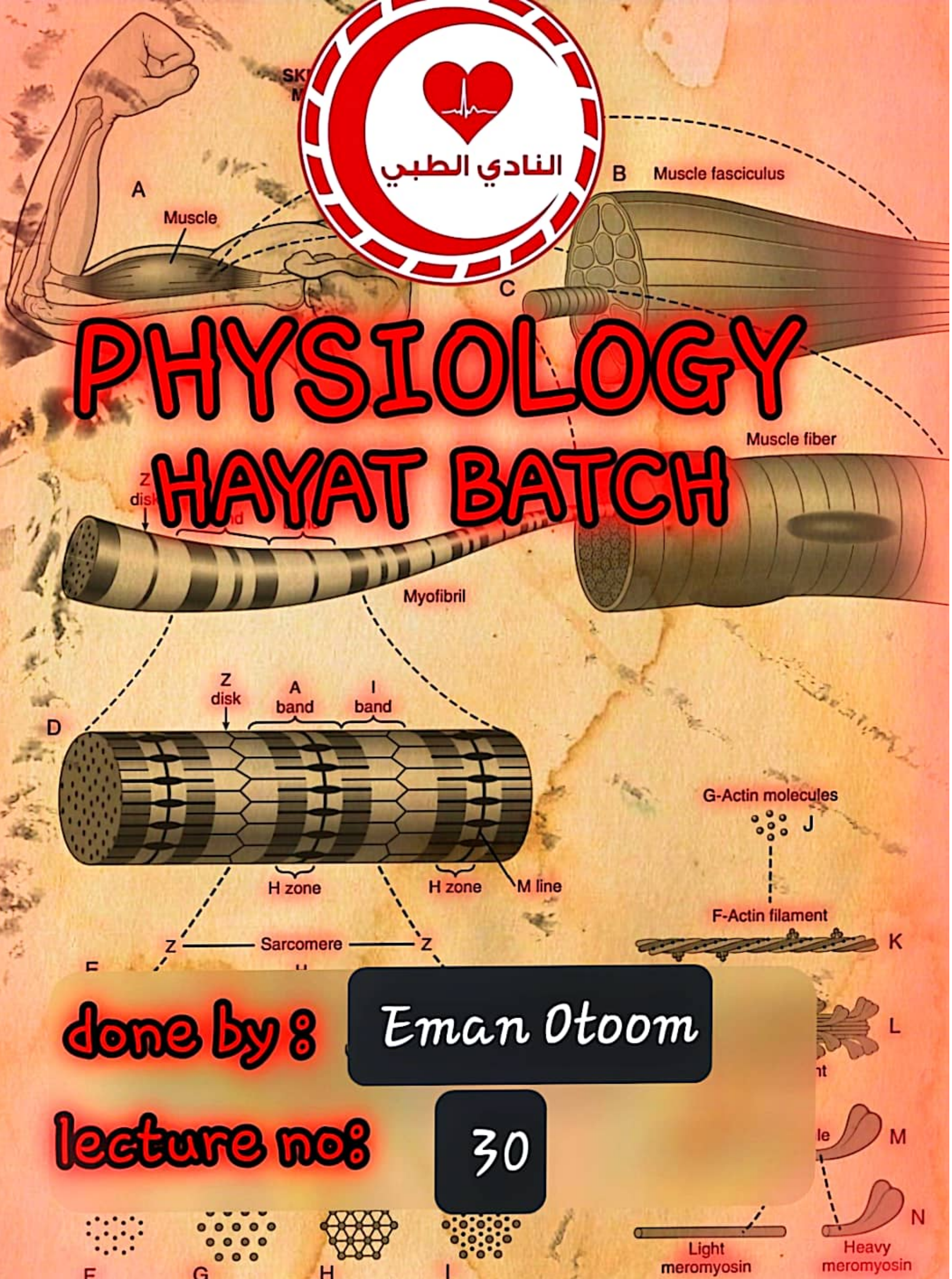


Figure 6-1. Organization of skeletal muscle, from the gross to the molecular level. *F, G, H,* and *I* are cross sections at the levels indic

done by : Eman Otoom

lecture no: 30

General physiology
Second semester 2022-2023
lecture 30
Skeletal Muscle Mechanics

Zuheir A Hasan Professor of Physiology

Department of anatomy , physiology and biochemistry

College of medicine

HU

Lecture objectives

- Define muscle twitch and relate the electrical and mechanical activity of the muscle
- Describe what happens during an isotonic and isometric contraction .
- Define preload and after load and their effect on muscle mechanics
- Explain the length–tension relationship in sarcomere and hole skeletal muscle and cardiac muscles
- Explain the length–tension relationship in sarcomere and hole skeletal muscle and cardiac muscles
- Explain the force–velocity relationship in skeletal muscle; explain the basis for the *V*max. And How does the load affect
- shortening and velocity of shortening?
- Define motor unit and describe the relation of the size of the motor unit to affects the type of skeletal muscle movement
- Explain how whole muscle strength of contraction can be graded
- Define motor unit recruitment and frequency summation
- Define the phenomena of tetany and treppe
- Compare and contrast of different properties of fast and slow muscle

بدنا نحكي اليوم بالمحاضرة عن ال mechanical Response

Usually the interaction of actin and myosin and the generation of tension will involve a mechanical response

يعني مثلا : اذا صار عندي excitation في ال biceps بصير عندي tension

If it was one stimulus -→ بحرك ايدي مرة وحدة

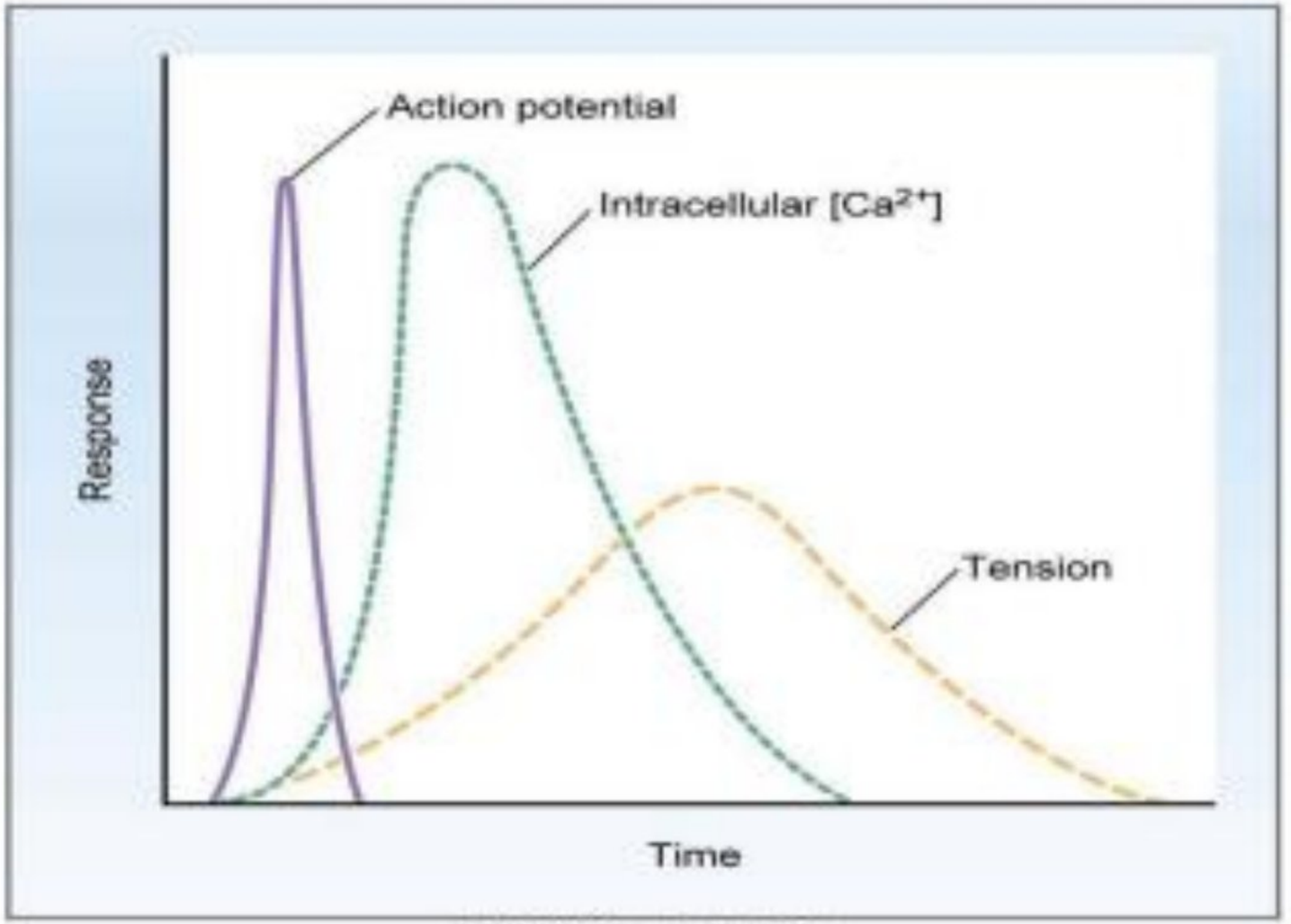
If I record the tension of the muscle or the mechanical Response to a muscle (to a single stimulus) I will get a mechanical response to muscle (muscle Twitch)

طيب شو هي ال muscle twitch؟؟

عبارة عن mechanical response ب single stimulation

Which of course reaches to molecular mechanism of contraction

Temporal sequence of events in excitation-contraction coupling in skeletal



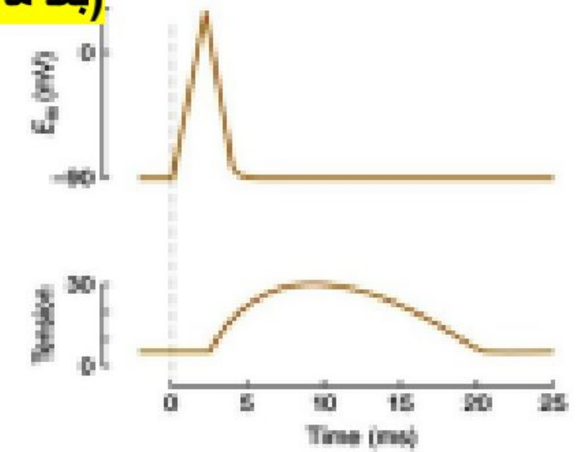
The electrical and mechanical responses of a mammalian skeletal muscle

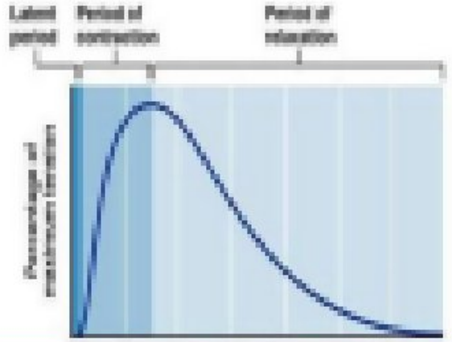
Muscle twitch الها 2 phases

1-contraction phase

2-Relaxation phase (بعد ما يرجع الكالسيوم لمكانه ويفك الرابطه بين الأكتين والميوسين)

- A single action potential causes a brief contraction followed by relaxation.
- **Latency 2 msec**
- duration of the twitch varies with the type of muscle being tested.
- "Fast" muscle fibers, primarily those concerned with fine, rapid, precise movement, have twitch durations as short as 7.5 ms.
- "Slow" muscle fibers, principally those involved in strong, gross, sustained movements, have twitch durations up to 100 ms.





Slow and fast muscle fibers تبعا لاختلاف العضلة ووظيفتها وومكانها

Latency : فيه شوية وقت مش كلهن بصيرن بنفس اللحظة (the time between the electrical stimulation and the mechinicail response)

Mechanical properties of muscle contraction

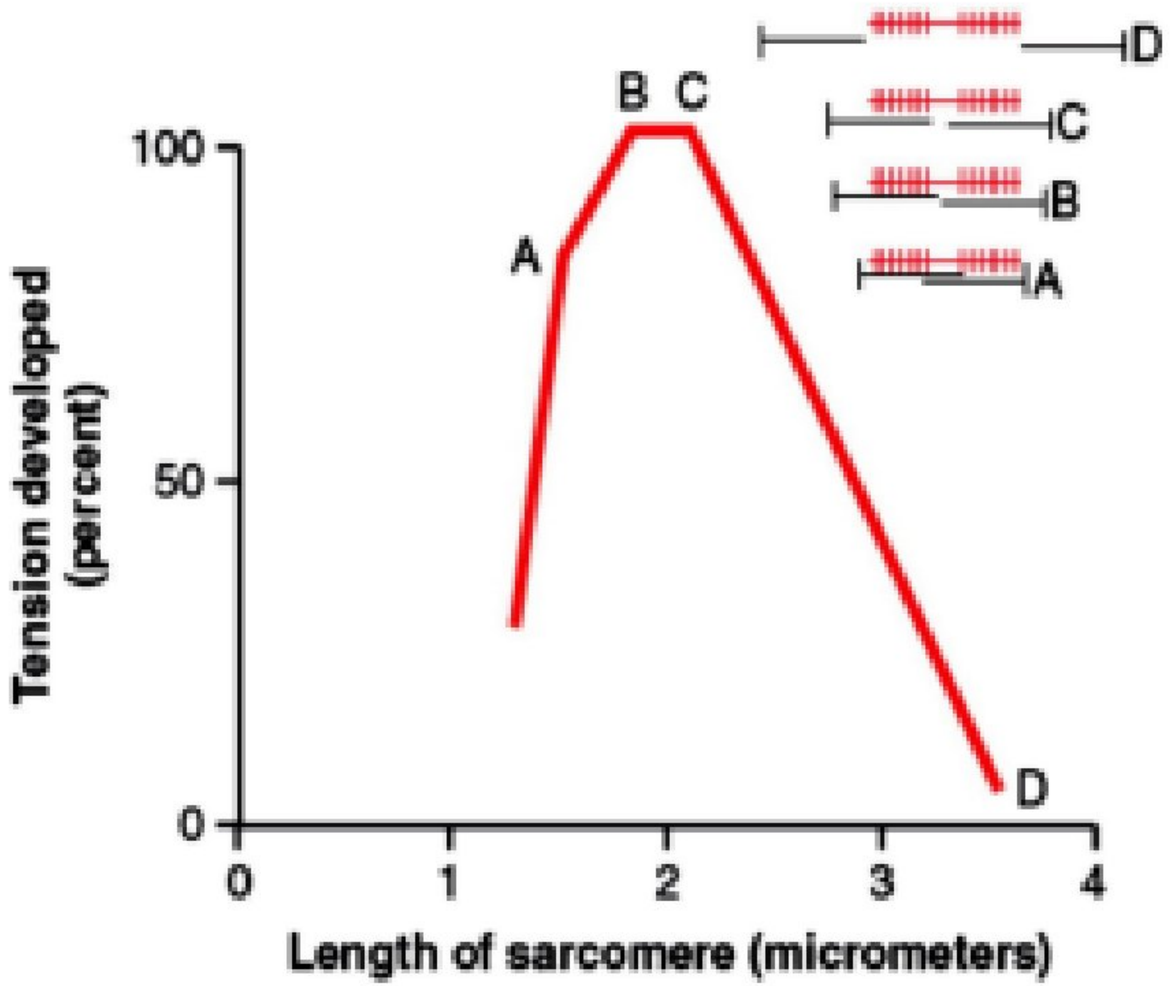
Length tension relationship

الشرح عن الصورة رح يكون بالسلايد الي بعده

A length-tension diagram for a single fully contracted Sarcomere It shows the effect of sarcomere length and the amount of myosin- actin filament overlap on the active tension developed by a contracting muscle fiber

Maximum strength of contraction when the sarcomere is 2.0 to 2.2 micrometers in length.

At the upper right are the relative positions of the actin and myosin filaments at different sarcomere lengths from point *A* to point *D*.



احنا عنا بالجسم العضلات بتكون بطريقة معينة بحيث انه طول ال sarcomere تقريبا 2.2 وعندها تقريبا يكون ال tensionاعلى ما يمكن وهذا مهم لما الواحد بده يعمل اشي زي مثلا لما يجي ينط

When the sarcomere is about 2.2 micrometer if you record the tension or measure the tension generated by this sarcomere you will find that the muscle tension is maximum so there is defined length of the sarcomere which is determine by the muscle length eventually

في حالة : D

الأكتين والميوسن بعاد عن بعض طول ال sarcomere كبير واكبر من 2.2 ال tensionصار قليل لانه قلت فرصة انه يصير في عنا bridgeو interactionبين الأكتين والميوسين

في حالة :A

قراب على بعض بس ما فيه فرصة انه يصير continuous cyclingيعمل crosss bridge

****العلاقة ال بين ال tension and the length of sarcomere مهمه

Optimal length is (2-2.22)

اكثر من هاي القيمة او اقل بتقل ال tension

Effect of Muscle Length on Force of Contraction in the Whole Intact isolated Muscle
Relation of muscle length to tension in the isolated muscle both before and during muscle contraction

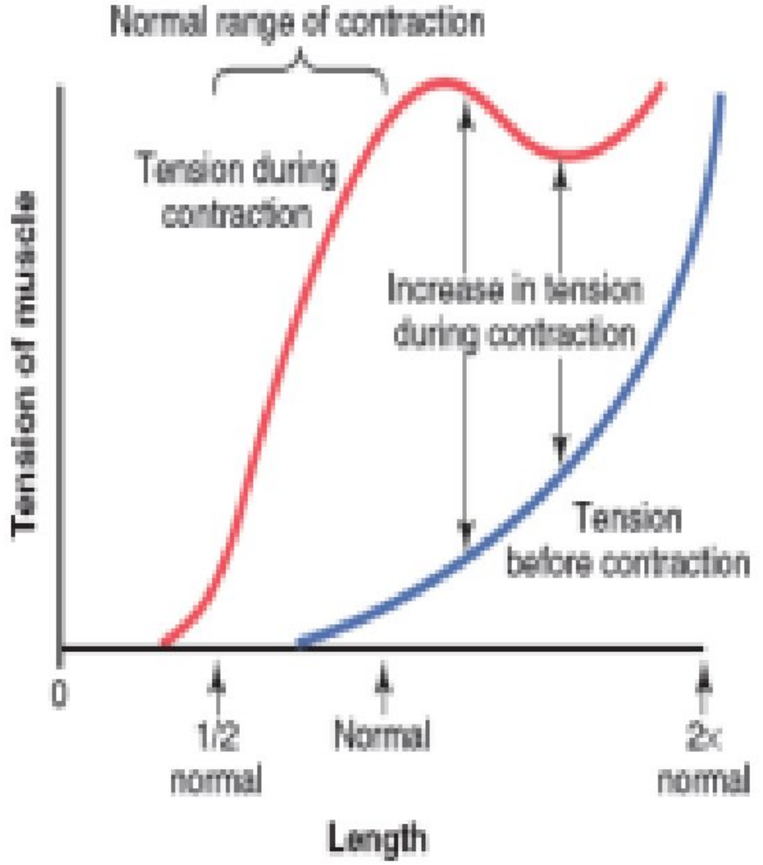
Active tension cannot be measured directly What can be measured?

(1) passive tension - *tension required to extend a resting muscle*

(2) (2) total tension - *active tension and passive combined*

The active or developed tension is the difference between the total tension and the passive tension. It is the tension that the muscle produces during the contraction. At the
muscle is at the optimum length to give the
greatest tension— maximum isometric tension.

Note that active tension falls away linearly with increasing resting length



كل ما مطينا العضله وعملنا muscle tension by the whole muscle للrecord رح نلاقي ال muscle tensionرح يقل
وكل ما قصرناها برضو كمان رح يقل ال tension
لكن لما تكون ال muscle موجودة بال resting length رح يكون ال tension is maximum

In the muscle we have :

1-Active tension : the tension generated by the interaction between actin and myosin during the process of cross – bridges formation

-by the contractile elements of the muscle when they interact with each others

2-Passive tension :

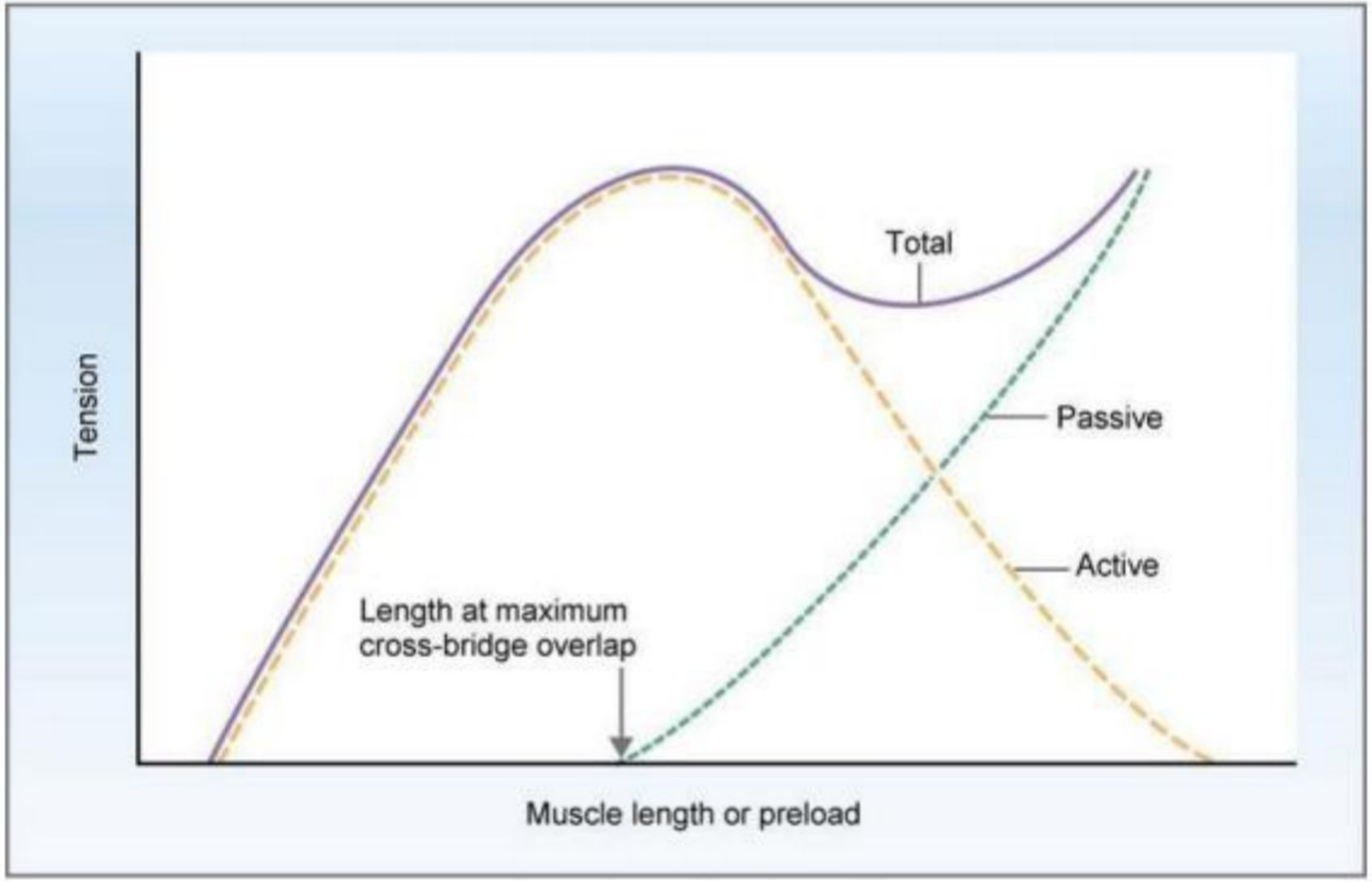
العضلة فيها elastic tissue يعني فيها elasticity يعني بتقدر تمط
كل ما مطينا العضلة وبالتالي ال tension ---- > which is related to how much is the muscle is strength
او زدنا طول العضلة ال passive tension رح يزيد
في اللحظة الي بنزيد فيها ال passive tension شو رح يصير ؟؟
رح يزيد طول ال sarcomere وقاعدين احنا بنبعد ال actinعن ال myosinوبالتالي ال tensionبقل
ما فيه طريقة لحتى نقيس ال active tension بس بنقدر نحسب ال total

When the passive tension is = to zero the muscle will be at resting optimal length -→ Active tension will be the maximum

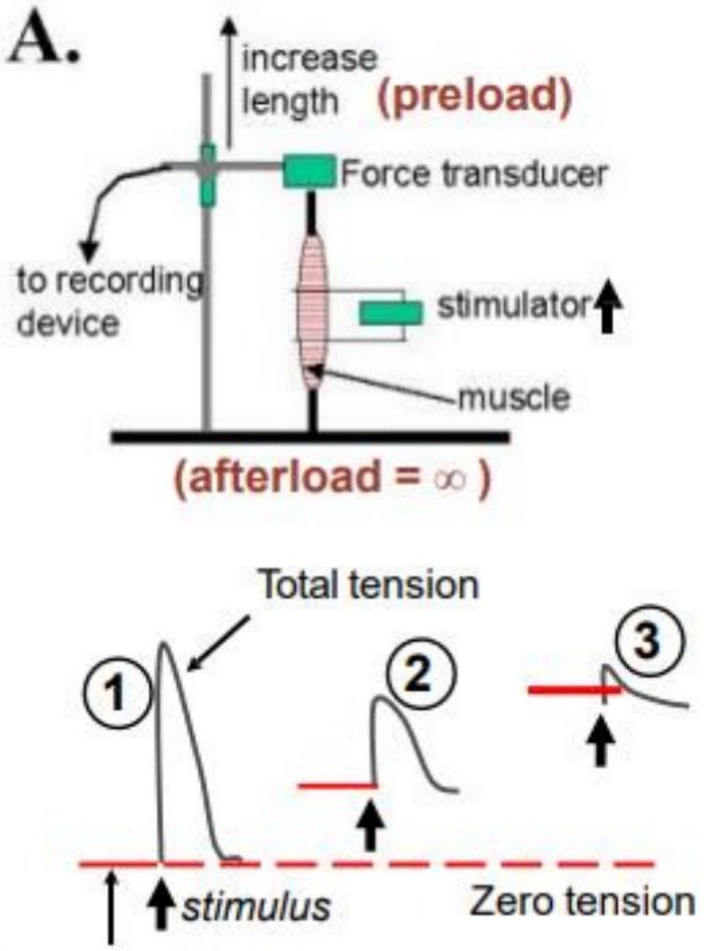
في حال زادت ال passive tension--> رح يزيد طول العضلة ----> بس ال total tension will decreased***

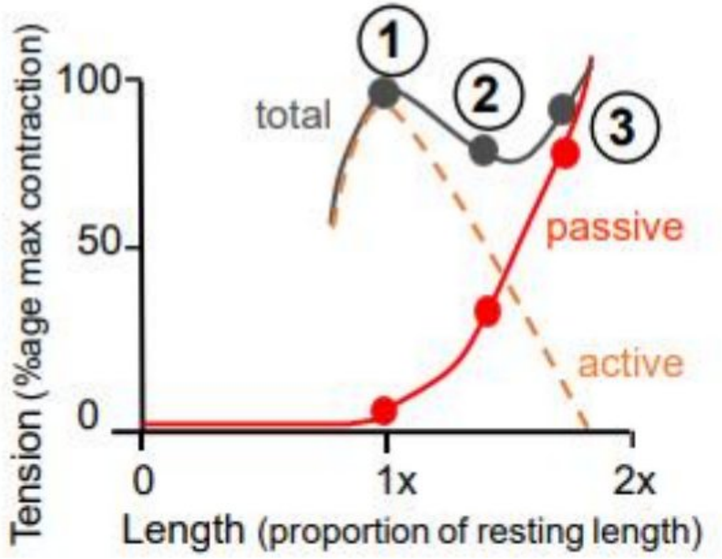
Passive tension basically is determinate the resting length of the muscle
Stretching the muscle will increase the passive tension

Length-tension relationship in whole intact skeletal muscle



Length-tension relation – the experiment

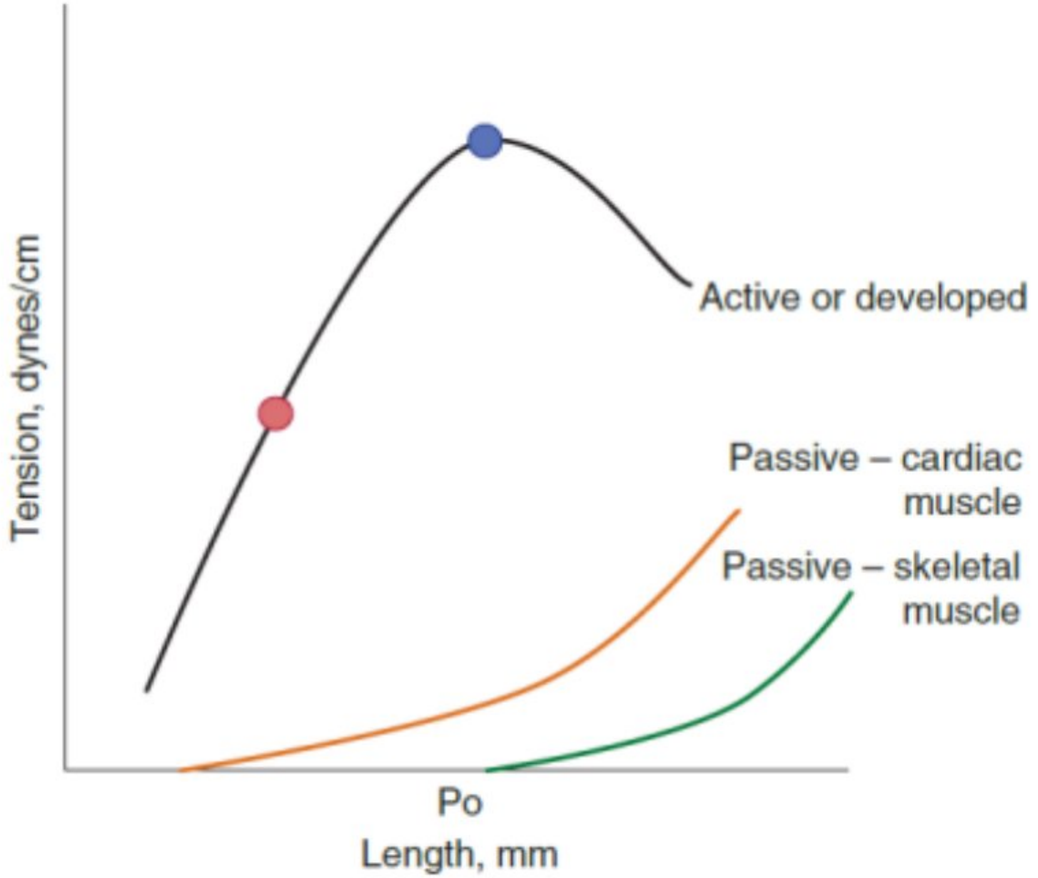




Comparison of the length tension relationship of skeletal and cardiac muscle

Note that in skeletal muscle, the fibers are usually operating at the blue point—resting length is optimum because most skeletal muscle
is held in place by the bones and resting length cannot vary greatly.

Cardiac muscle normally operates at lower (red point) than optimum length and therefore has reserve capacity to increase tension development, that is, have stronger contractions, when resting length is increased



The length tension relationship in cardiac muscle and skeletal muscle

- **Differences are primarily due to the presence of passive tension at shorter length in cardiac due to**
- Anatomic differences in structure of skeletal muscle (all of the fibers in parallel) and cardiac muscle (fibers exist in a basket weave-type pattern)
- The properties of the noncontractile components in skeletal muscle versus cardiac muscle.
  - in skeletal muscle, the fibers are usually operating at an optimal resting length because most skeletal muscle is held in place by the bones and resting length cannot vary greatly.
- Cardiac muscle normally operates at lower than optimum length and therefore has reserve capacity to increase tension development, that is, have stronger contractions, when resting length is increased.
- In the intact heart, cardiac cell resting length is set by the volume in the ventricle(EDV) at the end of diastole (the relaxed state of cardiac muscle).

Isometric and isotonic contractions

Isotonic contraction :

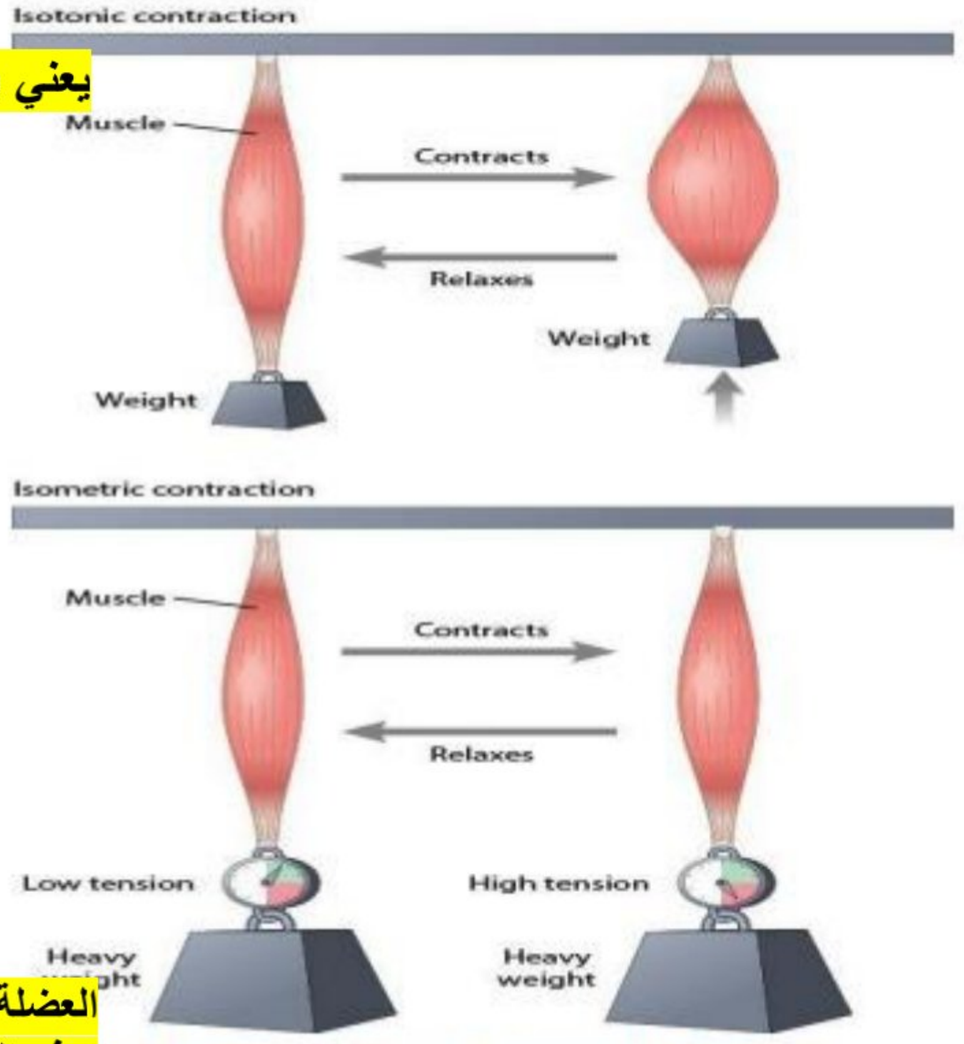
يعني بدي ارفع هاي الطاولة وقدرت ارفعها والعضله عندي طولها قصر

.Isotonic contraction occurs when the force of the muscle contraction is greater than the load and the tension on the muscle remains constant during the contraction; when the muscle contracts, it shortens and moves the load.

Isometric contraction occurs when the load is greater than the force of the muscle contraction; the muscle creates tension when it contracts, but the overall length of the muscle does not change.

1-Isometric contraction :

العضلة حاملة وزن هلأ العضله will contract بس لأنه الوزنه ثقيله ما قدرت ترفع الوزنه فبالتالي ضل طول العضلة ثابت



and isometric systems for recording muscle contractions

Isometric and isotonic contractions

- Isotonic: muscle shortens.
  Important for:

لما بنمشي

1. For body movements
2. Moving external objects

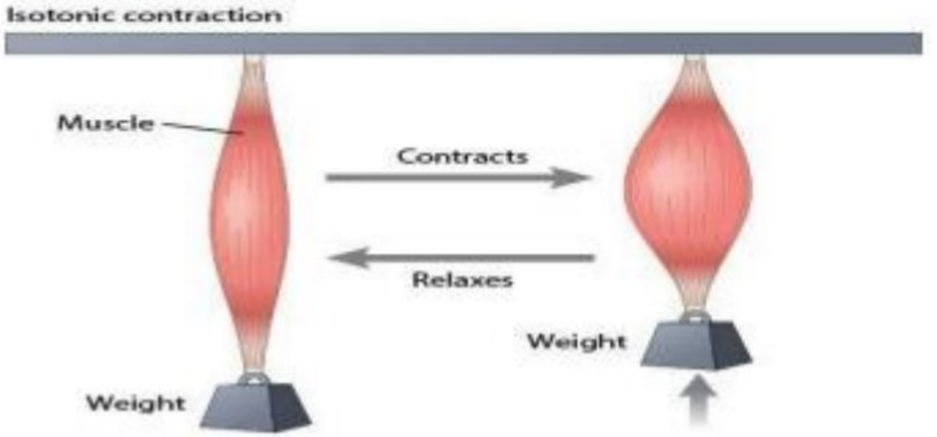
- Isometric: no muscle shortening.
  Important for:

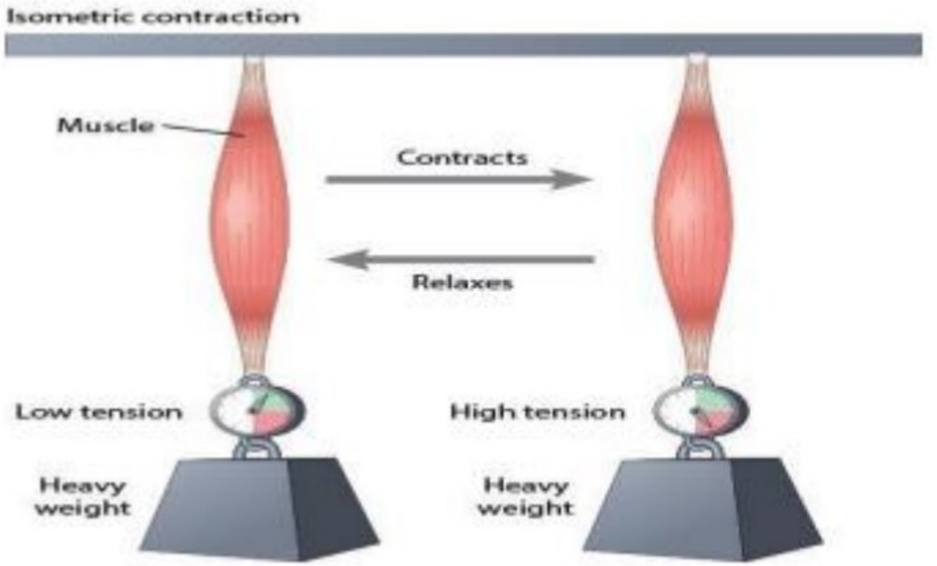
فيش داعي اعمل shorten

1. Maintaining posture (keep legs stiff while standing)
2. Supporting objects in a fixed place

لما احط ايدي اثبت شغله

في امثله كمان بس هذول شوي منهم بشكل عام





Force and velocity (how fast a muscle contract)

If the load increased (الوزنه) velocity will decreased

Where as if you contract a muscle it maximal will occure -→ لما بتكون حامل اشي

بدي اعطيكم إياها من الآخر: هسا اذا بدي ارفع وزنه بايدي واحركها إياها اسرع ؟؟

لما تكون ايدي مش حامله اشي ولا لما أكون حامل وزن ؟؟اكيد لما تكون مش حامل اشي

لما يكون ال load المرفوع كبيير بتكون ال velocityاقل

الشرح موجود بالسلايد السابق

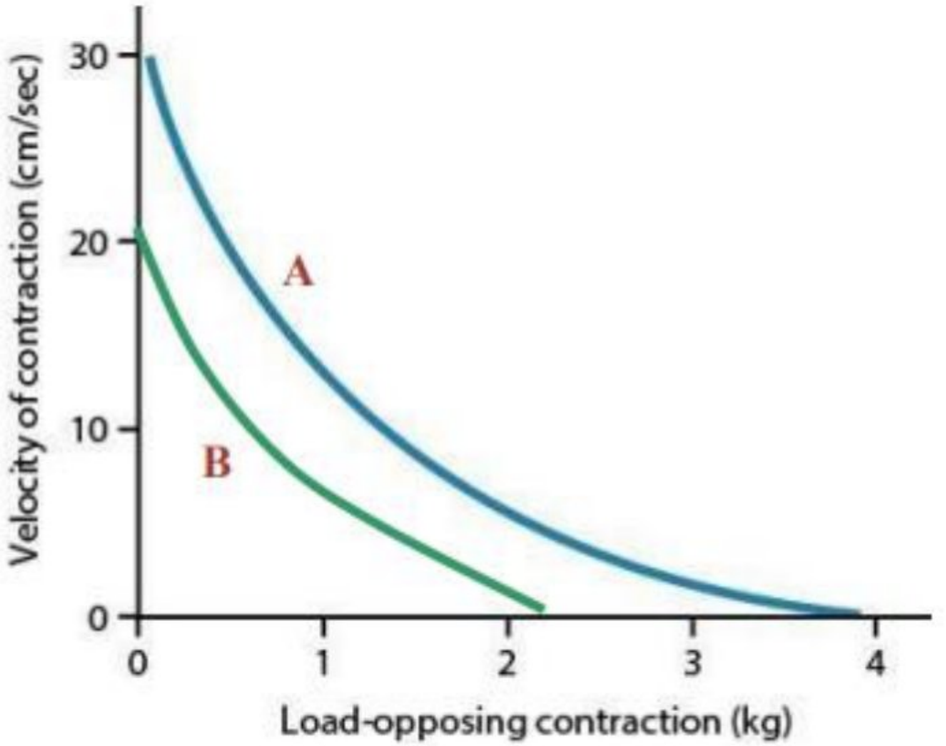
Relationship of Contraction Velocity to Load

The force–velocity curve is generated from the study of isolated muscle during isotonic contractions

no afterload: →
- maximum velocity at minimum load

increased afterload: →
- contraction velocity decreases

contraction velocity is zero → when afterload = max force of contraction



A: larger, faster muscle (white muscle)
B: smaller, slower muscle (red muscle)

Types of skeletal muscle

السرعة تبعت الانقباض برضو بتختلف من عضلة لعضلة

- speed of twitch contraction -

ماشي الحال
سرعة العضلات تبعت العين سريعة (حركة العين سريعة) وبالتالي العضله بتنقبض اسرع

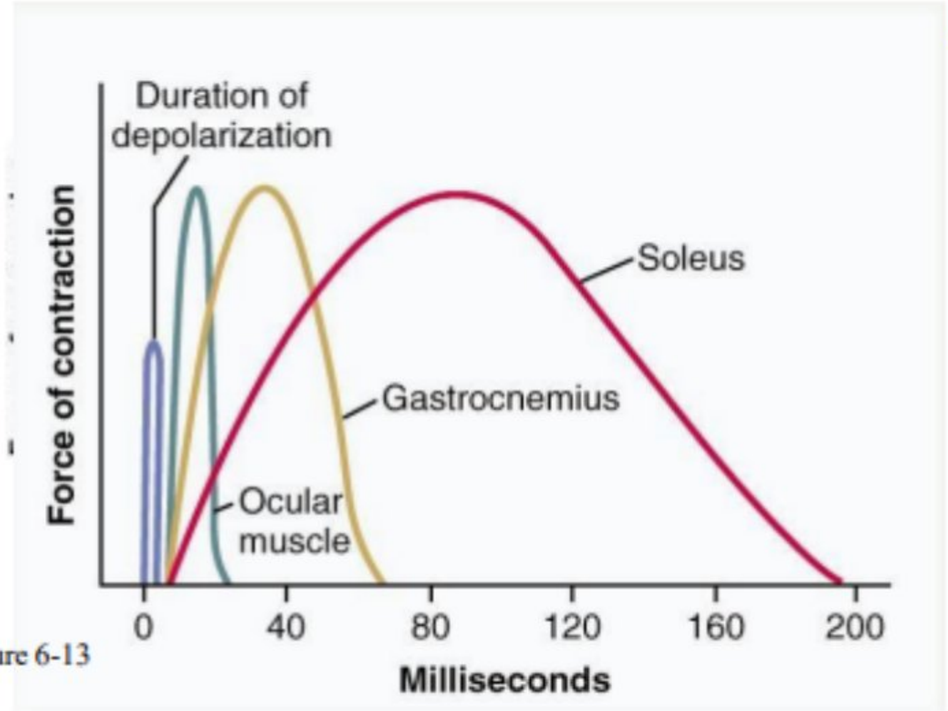


Figure 6-13

- Speed of contraction determined by V_{max} of myosin ATPase.
  - High V_{max} *(fast, white)*
    - rapid cross bridge cycling
    - *rapid rate of shortening (fast fiber)*
  - Low V_{max} *(slow, red)*
    - slow cross bridge cycling
    - slow rate of shortening (slow fiber)
- Most muscles contain both types of fiber, but proportions differ
- All fibers in a particular motor unit will be of the same type, i.e., fast or slow.

The duration of isometric contractions for different types of mammalian skeletal muscles, showing a latent period between the action potential (depolarization) and muscle contraction

so the muscle twitch duration, the speed of contraction, the Vmax
Depending on muscle function and its slow, fast or white , red

Resistance of fatigue :

Slow :

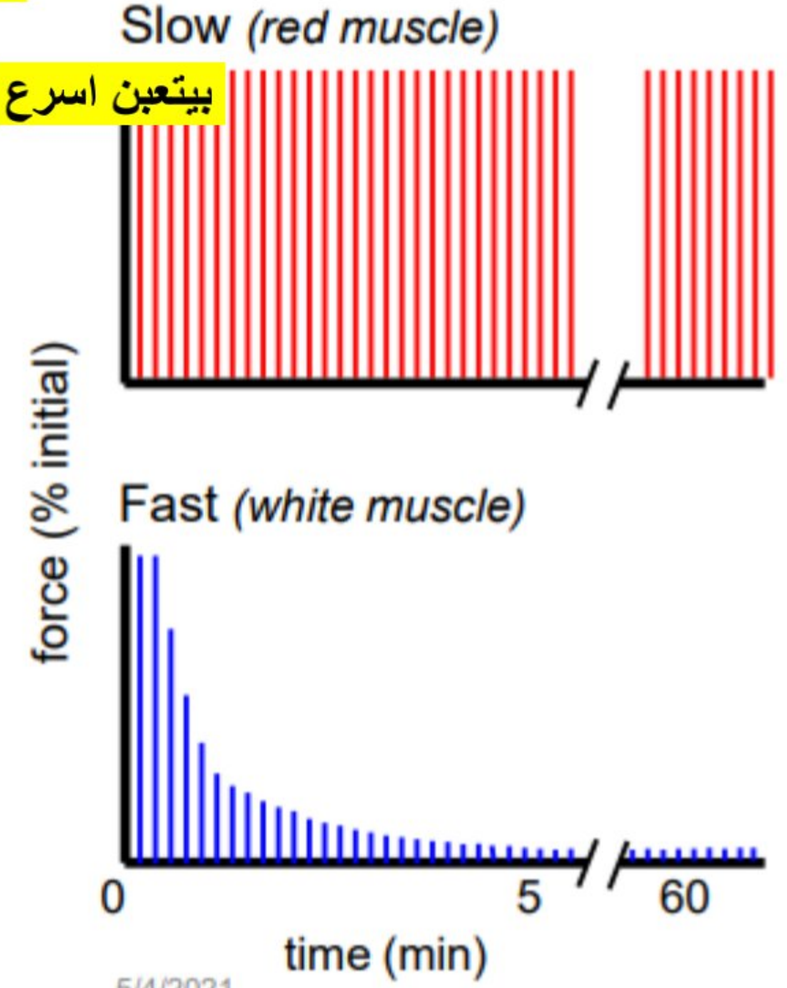
ما بيتعبن بسرعة مشان هيك الواحد بيقدر يوقف بالساعات

Fast :

more fatigable بيتعبن اسرع

Types of Skeletal Muscle

- resistance to fatigue -



- Fast and slow fibbers show different resistance to fatigue
- **Slow fibbers (Type I)**
  - oxidative
    - innervated by smaller nerve fibers.
    - high myoglobin content
    - high capillary density and extensive blood supply
    - many mitochondria to support high levels of oxidative metabolism
    - low glycolytic enzyme content
- **Fast fibers (Type II)**
  - Glycolytic
    - large diameter
    - low myoglobin content (white appearance)
    - low capillary density
    - few mitochondria
    - high glycolytic enzyme content

Fast and slow fibers types

- **Slow Fibers (Type 1, Red Muscle).**

- :1. Slow fibers are smaller than fast fibers.
- 2. Slow fibers are also innervated by smaller nerve fibers.
- 3. Compared with fast fibers, slow fibers have a more
- extensive blood vessel system and more capillaries to supply extra amounts of oxygen.
- 4. Slow fibers have greatly increased numbers of mitochondria to support high levels of oxidative metabolism.
- Slow fibers contain large amounts of myoglobin

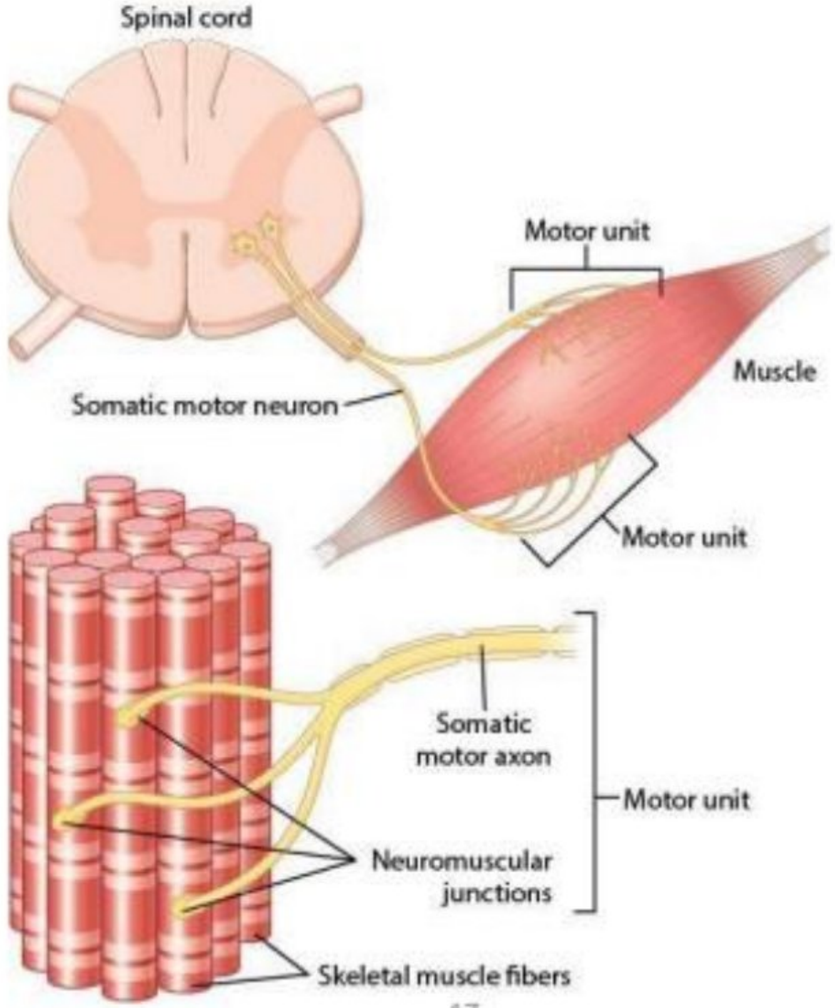
Fast fibers Type , white muscles

- Are large for great strength of contraction.
- 2. have an extensive sarcoplasmic reticulum is present for rapid release of calcium ions to initiate contraction.
- 3. Have Large amounts of glycolytic enzymes are present for rapid release of energy by the glycolytic process.
- 4. Have less extensive blood supply than do slow fibers because oxidative metabolism is of secondary importance.
- 5. have fewer mitochondria than do slow fibers, also because oxidative metabolism is secondary.
- A deficit of red myoglobin in fast muscle
- gives it the name *white muscle.*

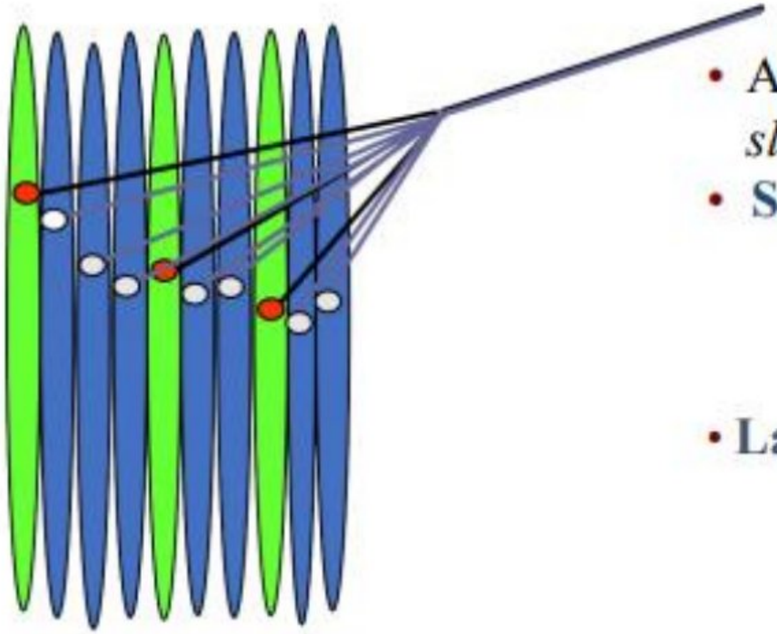
Motor Unit

A collection of muscle fibers innervated by a single motor neuron

A motor unit consists of a motor neuron and the group of skeletal muscle fibers it innervates. A single motor axon may branch to innervate several muscle fibers that function together as a group. Although each muscle fiber is innervated by a single motor neuron, an entire muscle may receive input from hundreds of different motor neurons.



Motor Unit (cont.)



- All fibers are same type *(fast or slow)* in a given motor unit
- **Small motor units** *(e.g., larnyx, extraocular)*
  - as few as 10 fibers/unit
  - precise control
  - rapid reacting
- **Large motor units** *(e.g., quadriceps muscles)*
  - as many as 1000 fibers/unit
  - coarse control
  - slower reacting
- Motor units overlap, which provides coordination
-

Muscle Contractions of Different Force.
Force Summation.

- *Summation* means the adding together of individual twitch contractions to increase the intensity of overall muscle contraction.

- Summation occurs in two ways:

كيف بدنا نزيد ال muscle contraction ؟؟
من خلال 2&1
الشرح بالسلايد الي بعده

- (1) Recruitment of motor units by : increasing the number of motor units contracting simultaneously, which is called *multiple fiber summation*

- 2) by increasing the frequency of contraction, which is called *frequency summation* and can lead to *tetanization*

عندي طريقتين :

الأولى : اعمل stimulation for more than one motor unit بشبه ال spatial summation الي كان بصير بال synapse

الثانية : عن طريق زيادة ال frequency of contraction

Muscle contraction – *force summation*

Force summation:
increase in contraction intensity as a result of the additive effect of individual twitch contractions

(1) Multiple fiber summation:

- results from an ***increase in the number of motor units*** contracting simultaneously (fiber recruitment)
- **Size principle**

انه اخلي ال tension
في مختلف ال motor unitsيصير وبالتالي ال
Tensionبزيد

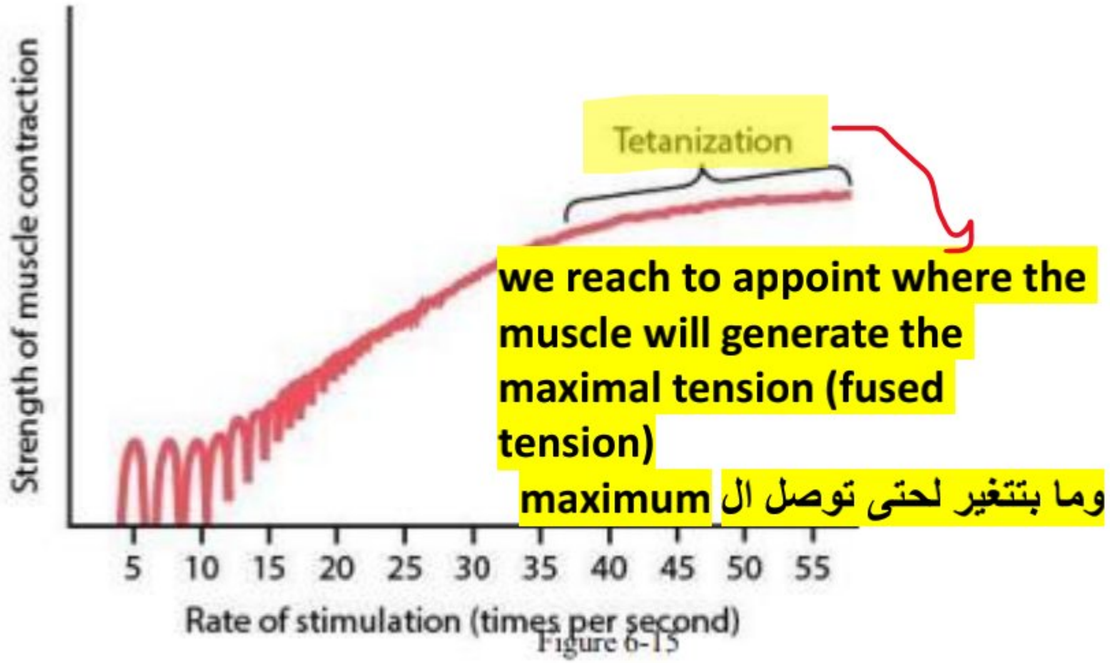


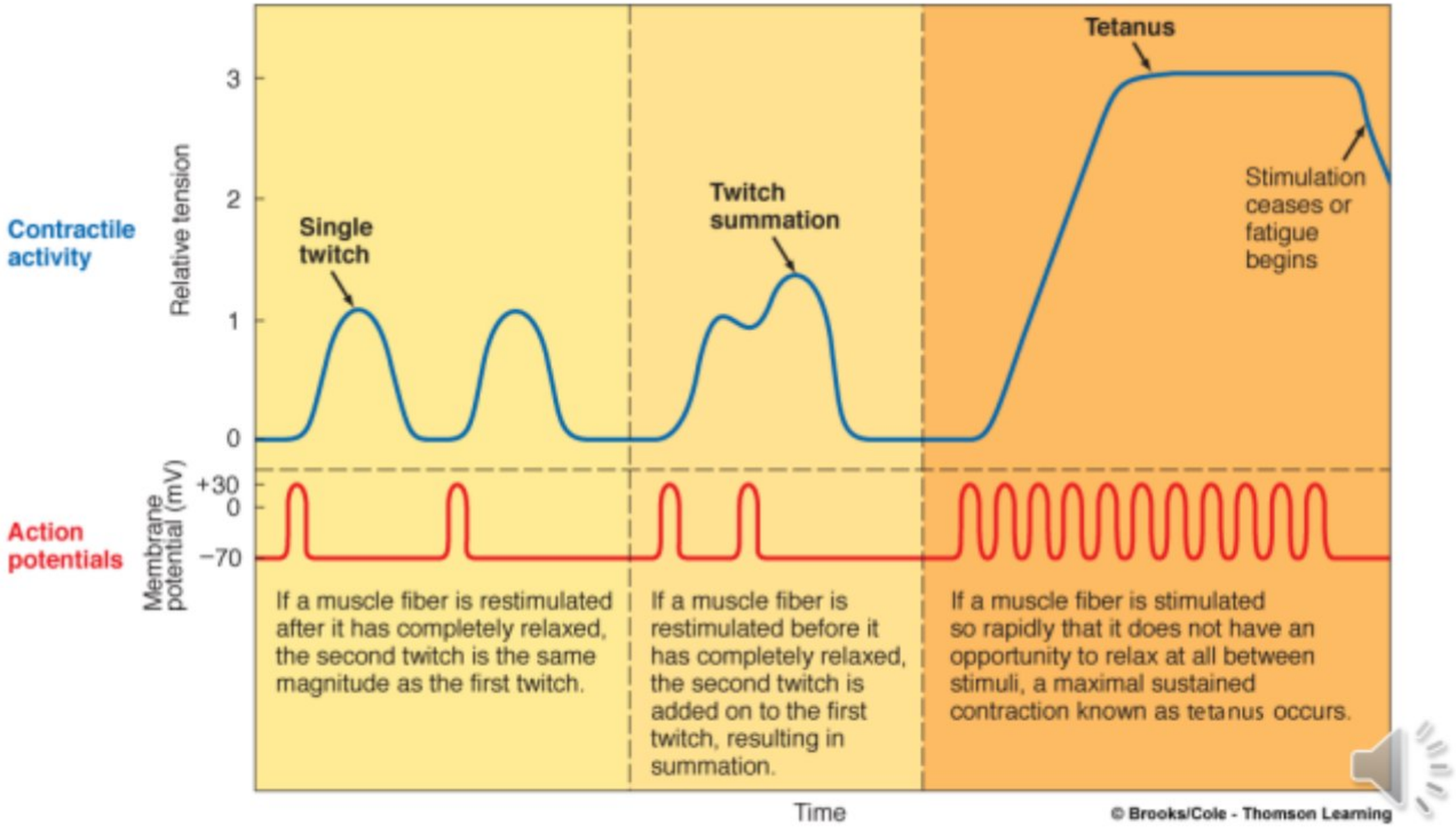
Figure 6-15

we reach to appoint where the muscle will generate the maximal tension (fused tension)
وما بتتغير لحتى توصل ال maximum

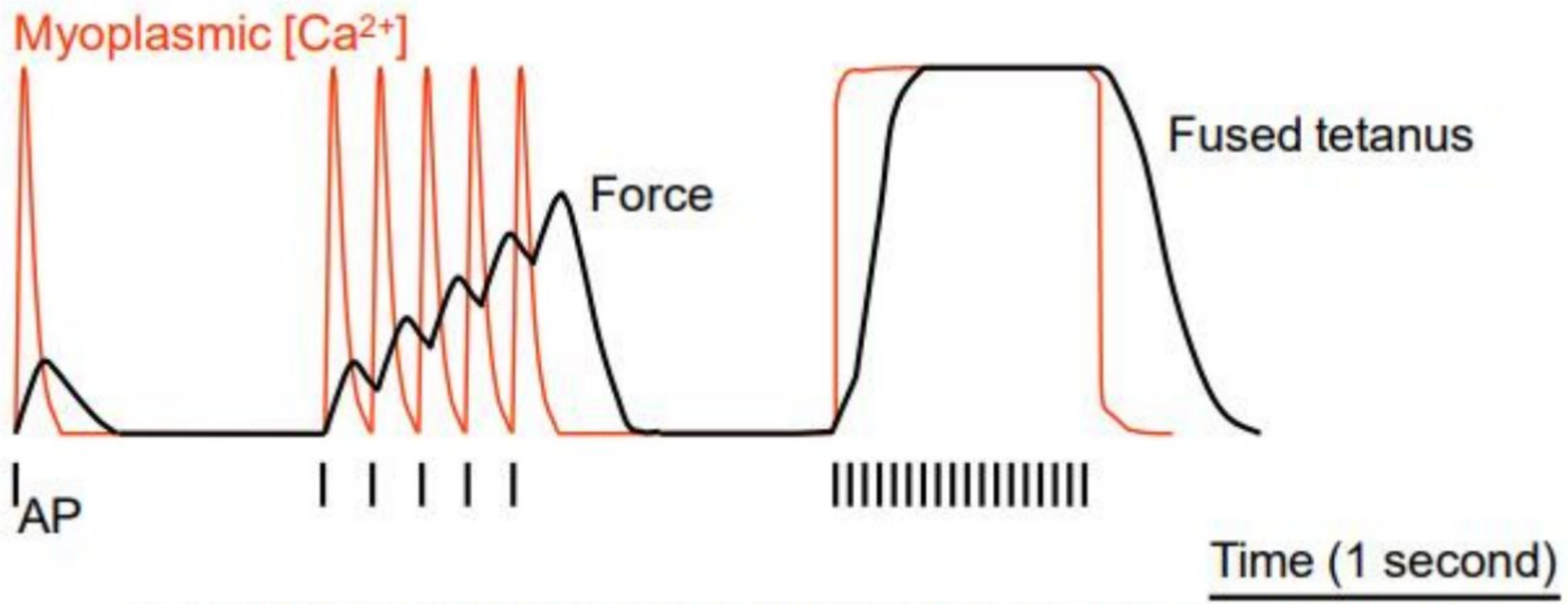
(2) Frequency summation: results from an ***increase in the frequency of contraction*** of a single motor unit

بحيث انه تزيد كمية ال Ach وبالتالي ال forceرح تزيد
قبل ما تخلص الأولى بتصير الثانية وهكذا ...

High frequency stimulation Tetany and summation



Frequency summation of twitches and tetanus



- Myoplasmic Ca^{2+} falls (initiating relaxation) before development of maximal contractile force
- If the muscle is stimulated before complete relaxation has occurred the new twitch will sum with the previous one, etc.
- If action potential frequency is sufficiently high, the individual contractions are not resolved and a 'fused tetanus' contraction is recorded.

Summary

Determinants of Whole-Muscle Tension in Skeletal Muscle

- **Number of Fibers Contracting**
- Number of motor units recruited*
- Number of muscle fibers per motor unit
- Number of muscle fibers available to contract (size of muscle)
- **Tension Developed by Each Contracting Fiber**
- Frequency of stimulation (twitch summation and tetanus)*
- Length of fiber at onset of contraction (length–tension relationship)
- Extent of fatigue
- Type of fiber (fatigue-resistant oxidative or fatigue-prone glycolytic)
- Thickness of fiber (strength training and testosterone)

(وقل ربِّ زدني علما)