Muscle and Exercise Physiology

Lecture 1.1 – Functional Properties of Skeletal Muscle

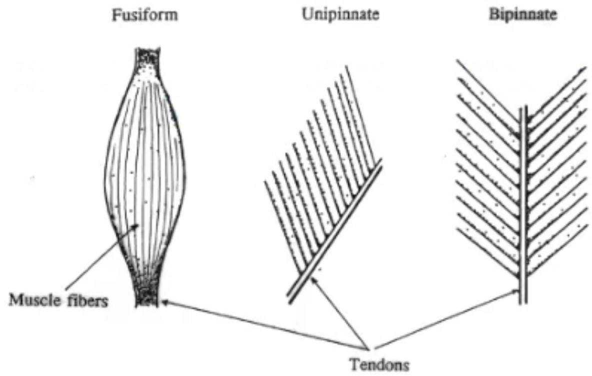
***Review the Neuromuscular Junction**

Muscles for Purpose

- Muscles have different architectures depending on their purpose
- Muscle fibres are rarely ever the same as the muscle length – most fibres tend to insert themselves on angles
- Muscles that have their fibres inserted obliquely (the angle on which they are oriented is called a 'pinnation') tend to have a greater cross sectional area as more fibres can be packed in

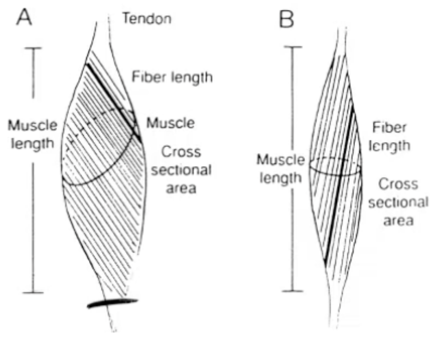
Types of Muscle Architectures

- *Fusiform:* fibre length is the same as the muscle length – runs from tendon to tendon in a straight line
- *Unipinnate:* fibres inserted obliquely from a central tendon
- *Bipinnate:* when fibres are inserted obliquely from a central tendon on both sides
- The greater cross –sectional area is illustrated in muscle A – as it has obliquely inserted muscle fibres
- Muscle A has much shorter fibres than muscle B
- This would make the cross sectional area for muscle A greater than that of muscle B



Muscle Force ∝ Cross Sectional Area

- These different architectures tend to have significance because muscles have different and specific functions – this is termed architectural specialisation
- Some muscles may be designed for fine control e.g. muscles in eyelids, while others may be designed for force and power output e.g. quadriceps



Types of Muscle Actions

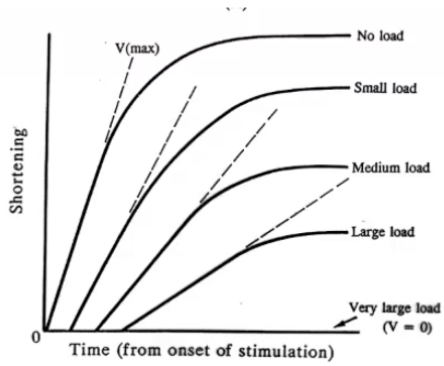
- Muscles will always aim to move towards the 'midline' when shortening
- *Isometric:* length stays fixed, the muscle attempts to shorten but it can't, therefore there is no change, force = load
- *Concentric/Miometric:* is the shortening of a muscle, force > load
- *Eccentric/Pliometric:* is the lengthening of a muscle, load > force

Length-Tension Relationship

- This describes the relationship between actin and myosin filament overlap and isometric force
- Maximally stimulate muscle at a number of discrete lengths
- Optimum force generation is when there is perfect binding between actin filaments and myosin heads (all binding sites are occupied) – sufficient force is required

Force-Velocity Relationship

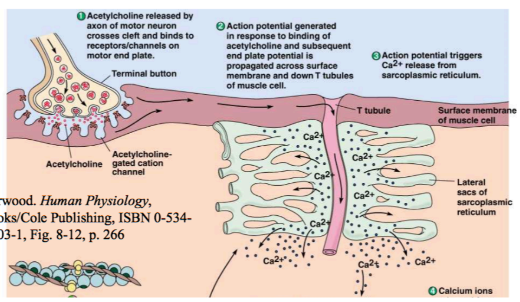
- Demonstrates the power output that can be generated by a muscle
- When the load is heavier, the lift is slower (decrease in velocity)
- There is a latent period (which increases with load) where the muscle is contracting isometrically until sufficient tension has been produced to equal the load
- Not only is the rate of shortening reduced for heavy loads, the amount of shortening also decreases
- $\mathbf{V_{max}}$: maximum velocity of shortening – related to muscle fibre type distribution and muscle architecture
- Muscle *power* will be zero when there is no load on the muscle and when the load is so heavy it cannot be moved at all



Power = Load x Velocity

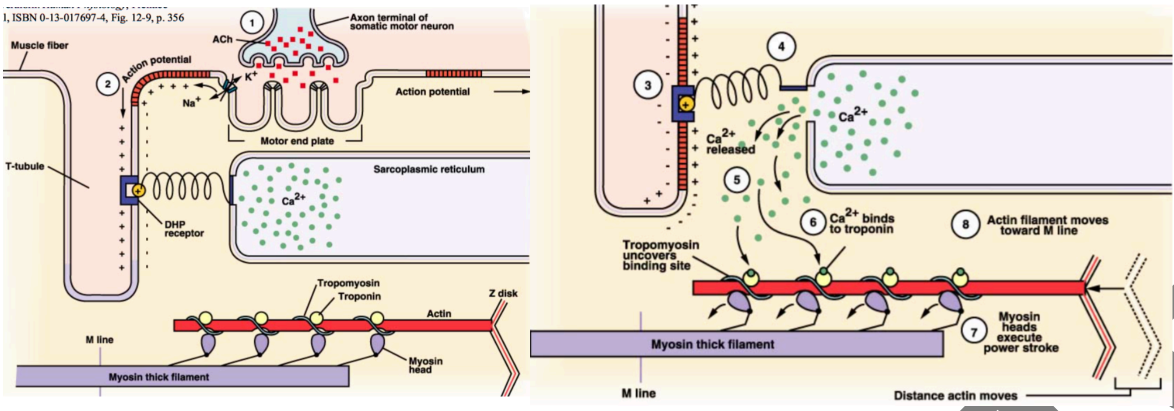
Muscle Contractions

- At the neuromuscular junction, there is action potential generation, which travels down the t-tubule, causing release of Ca^{2+} from sarcoplasmic reticulum and its subsequent binding to troponin
- The change in voltage in the t-tubules is detected by Dihydropyridine receptor (DHPR), which couples to ryanodine receptors, popping open the sarcoplasmic reticulum and releasing calcium ions
- Influx of Ca^{2+}, triggers the exposure of binding sites on actin as it moves



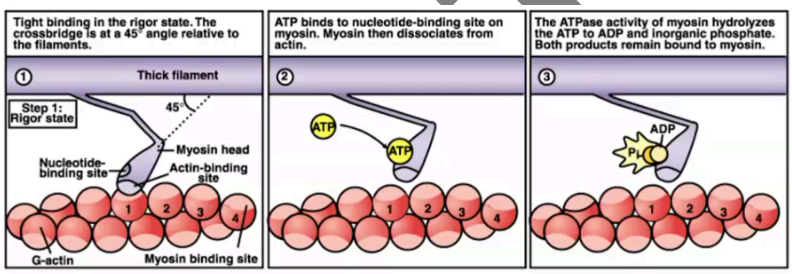
Sherwood. *Human Physiology*, Brooks/Cole Publishing, ISBN 0-534-39503-1, Fig. 8-12, p. 266

tropomyosin out of the way
- Following this, the binding of myosin and actin occurs

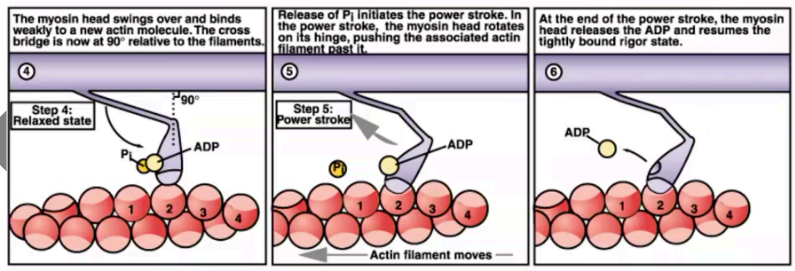


Cross Bridge Cycling

- The myosin heads are attached to the actin filaments in the rigor state – this is at an angle of 45 degrees
- If there is no ATP around, the myosin head remains attached to the actin filament
- The hydrolysis of and dephosphorylation ATP (ADP + Pi) which leads to the re-energising and re-positioning of the crossbridge to the next actin binding site using its characteristic hinge
- The myosin head swings over and binds to a new actin molecule – at a 90-degree angle
- The power stroke of the crossbridge that causes the sliding of the thin filaments
- The binding of ATP to the crossbridge, which results in the crossbridge disconnecting from actin
- After cross bridge cycling, the Ca^{2+} is taken back up into the sarcoplasmic reticulum and tropomyosin moves back into place and the muscle relaxes

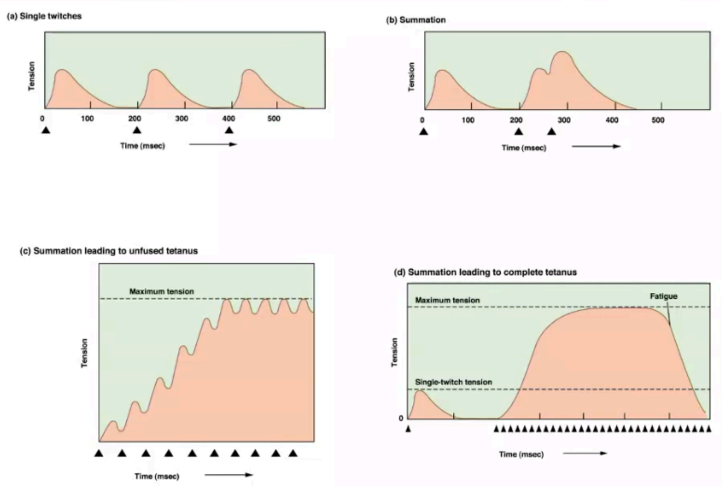


Silverthorn. *Human Physiology*, Prentice-Hall, ISBN 0-13-017697-4, Fig. 12-8, p. 355



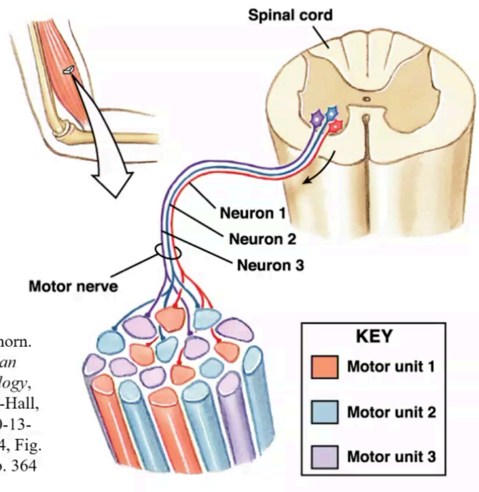
Muscle Force, Contraction and Tetanus

- An isometric twitch is a response to a single electrical stimulus
- The optimum muscle length is the length at which maximum twitch is recorded
- *Summation:* staircase effect whereby twitch responses add together in response to repeated electrical stimulation recruitment o motor units or the frequency-force relationship
- *Tetanus:* the muscle response following stimulation frequency sufficient enough to cause fusion
- *Frequency-Force Relationship:* plot of summation frequency vs isometric force response
- *Maximum Isometric Force:* Maximum tetanic force response taken from the plateau of the frequency-force relationship



Motor Units

- A motor unit is a motor neuron and all the muscle fibres it contracts
- With increased age, there is a decrease in motor neurons and therefore a decrease in motor units
- The fibre to nerve ratio is defined as (F:N ratio)
- Eye muscles perform fine movements and may have as few as one muscle fibre per motor unit (low F: N) vs. quadriceps (which have a higher force) have many muscle fibres per motor unit (high F: N) but are less precise
- More fibres mean there is less precision
- All muscle fibres in a MU are innervated by the same motor neuron, therefore an AP in that neuron causes all the muscle fibres in the MU to contract synchronously
- All the fibres in a MU are of the same fibre type (sensory or motor)



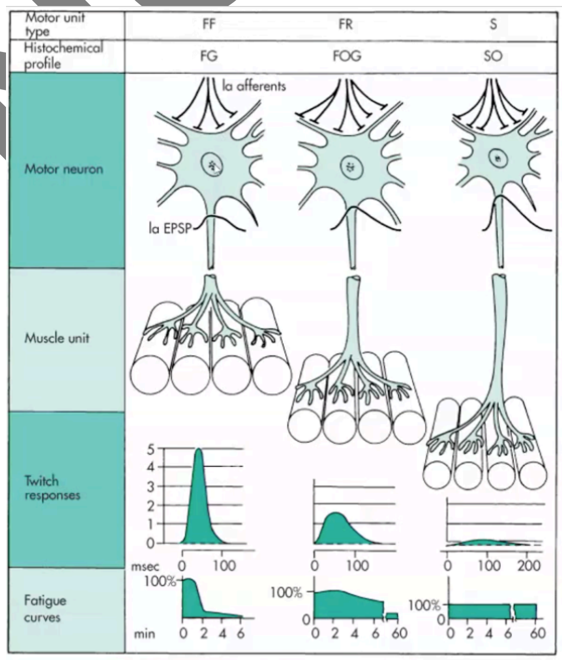
Silverthorn. *Human Physiology*, Prentice-Hall, ISBN 0-13-017697-4, Fig. 12-16, p. 364

Physiological and Biochemical Properties of Motor Units

- Motor units differ from each other in terms of: size, biochemical and physiological properties of their muscle fibres
- Skeletal Muscle fibres possess a wide spectrum of morphologic, contractile and metabolic properties
  - Contractile Properties: fast/slow rate of contractility or velocity
  - Enzyme histochemistry: mATPases

Fibre Types

- *Fast Fatigueable (FF):* fast, glycolytic fibres, which contract and relax quickly. They are considered sprinters are they cannot sustain force. These fibres have poor capillarisation and low mitochondrial enzymes
- *Fast Fatigue Resistant (FR):* fast, oxidative and glycolytic fibres which contract quickly. They can produce decent force which they are able to sustain. These fibres are a combination of both slow and fast twitch fibres
- *Slow Oxidative (S):* are considered marathoners as they contract and relax slowly. They don't produce that much force, but they are able to sustain the force for long periods of time as they are fatigue resistant. They have low glycogen, high mitochondrial enzymes, rich capillarisation and are suited for prolonged activity.
- Everyone has different proportions of muscle fibres
- Highly oxidative units are those that are used most
- Maximal efforts in which fast motor units are also recruited cannot be sustained because of rapid glycogen depletion
- When viewed under a microscope, the darker cells have a greater amount of mitochondrial cells, and have lower ATPase activity



***Henneman's Size Principle:* during physical tasks, the small, slow motor units are recruited first. With exercise intensity, the faster and larger motor units are recruited. This is dependent on the number of fibres and size of the motor neuron itself