MUSCULAR CONTROL OF MOVEMENT

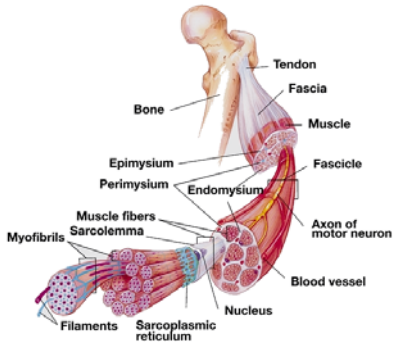
Types of Muscles

Smooth
- Involuntary muscle; controlled unconsciously
- In the walls of blood vessels and internal organs

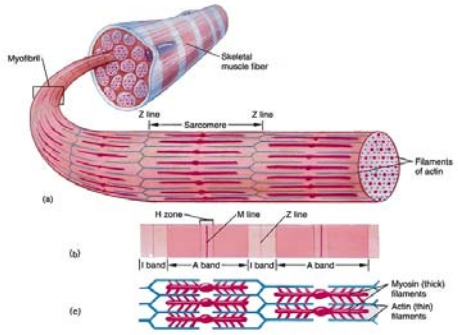
Cardiac
- Controls itself with help from nervous and endocrine systems
- Only in the heart

Skeletal
- Voluntary muscle; controlled consciously
- Over 600 throughout the body

SKELETAL MUSCLE STRUCTURE



A MUSCLE FIBER



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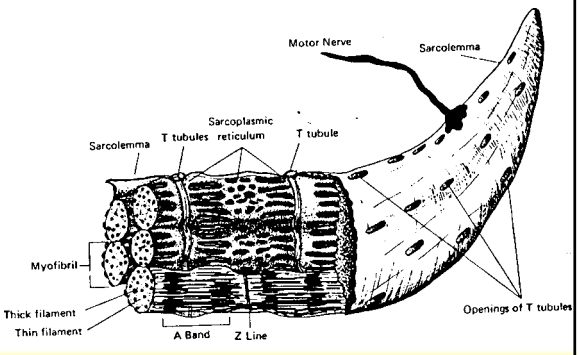

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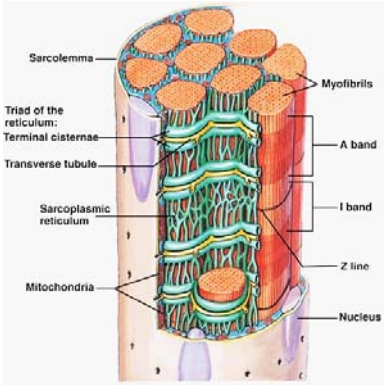

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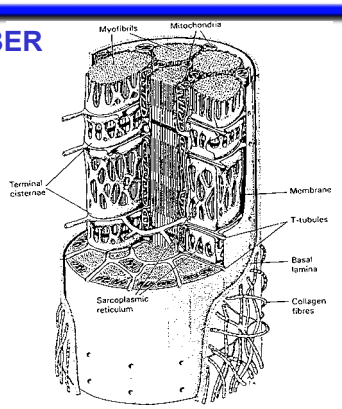

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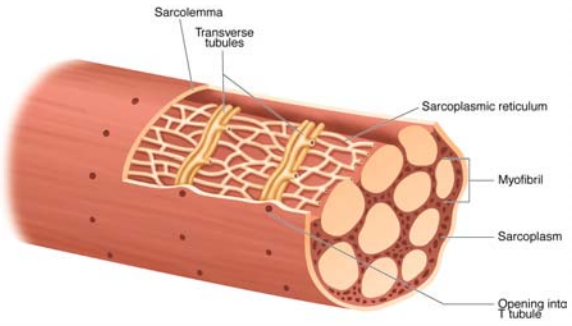
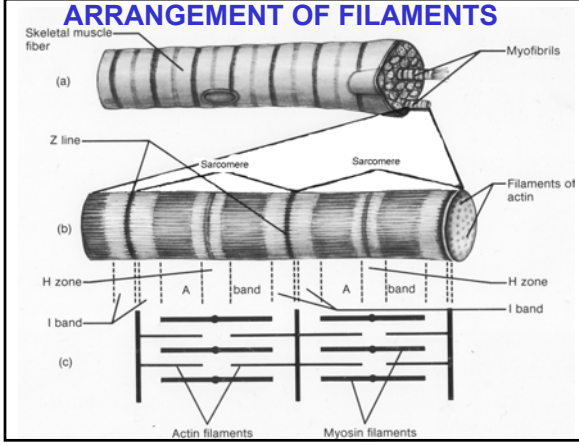
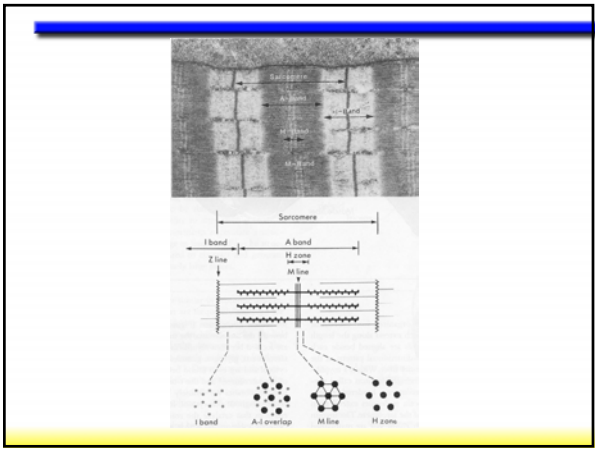
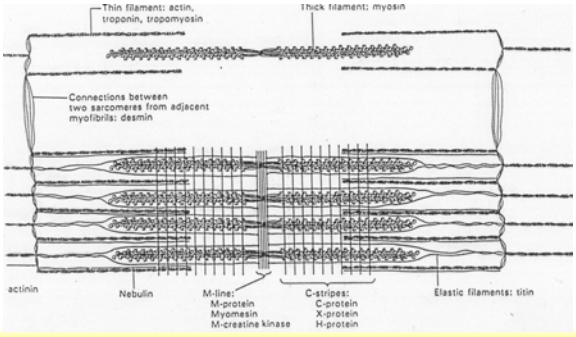


ARRANGEMENT OF FILAMENTS

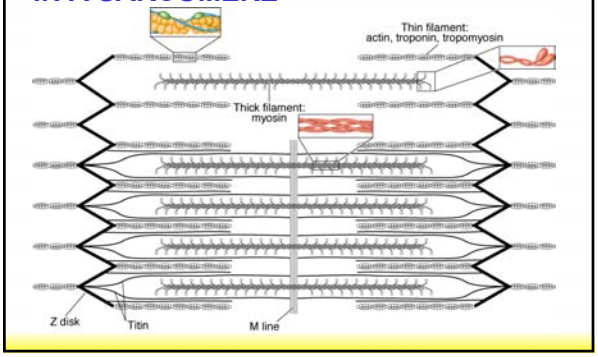




ARRANGEMENT OF FILAMENTS IN A SARCOMERE

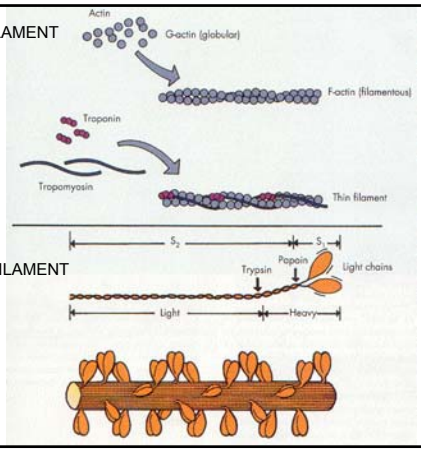


ARRANGEMENT OF FILAMENTS IN A SARCOMERE

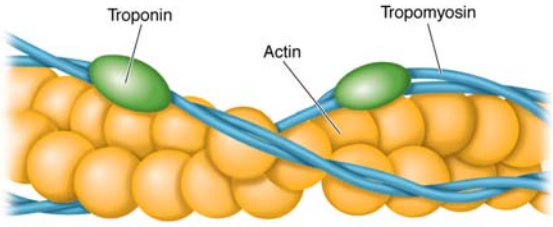


ACTIN FILAMENT

MYOSIN FILAMENT



AN ACTIN FILAMENT



Key Points

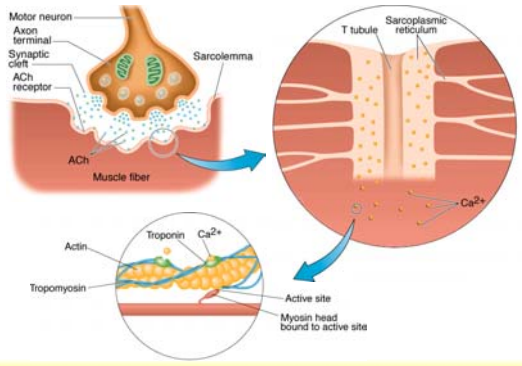
The Myofibril

- Myofibrils are made up of sarcomeres, the smallest functional units of a muscle.
- A sarcomere is composed of filaments of two proteins, myosin and actin, which are responsible for muscle contraction.
- Myosin is a thick filament with a globular head at one end.
- An actin filament—composed of actin, tropomyosin, and troponin—is attached to a Z disk.

Events Leading to Muscle Fiber Action

1. A motor neuron releases acetylcholine (ACh).
2. ACh binds to receptors on the sarcolemma.
3. The action potential triggers release of Ca^{2+}.
4. The Ca^{2+} binds to troponin on the actin filament, and the troponin pulls tropomyosin off the active sites, allowing myosin heads to attach to the actin filament.

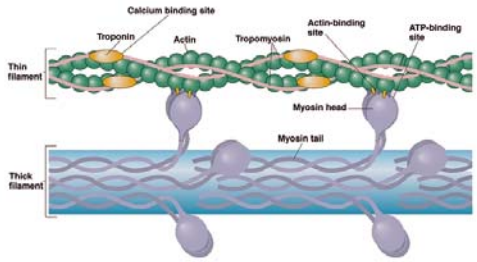
EVENTS LEADING TO MUSCLE ACTION



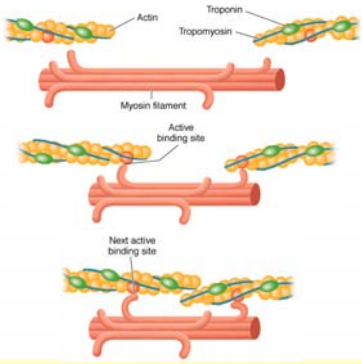
The Sliding Filament Theory

- When myosin cross-bridges are activated, they bind strongly with actin, resulting in a change in the cross-bridge.
- The change in the cross-bridge causes the myosin head to tilt toward the arm of the cross-bridge and drag the actin and myosin filaments in opposite directions.
- The tilt of the myosin head is known as a *power stroke*.
- The pulling of the actin filament past the myosin results in muscle shortening and generation of muscle force.

ACTIN AND MYOSIN BINDING



CONTRACTING MUSCLE FIBER



Key Points

Muscle Fiber Action

- Muscle action is initiated by a nerve impulse.
- The nerve releases ACh, which allows sodium to enter and depolarize the cell. If the cell is sufficiently depolarized, an action potential occurs which releases stored Ca^{2+} ions.
- Ca^{2+} ions bind with troponin, which lifts the tropomyosin molecules off the active sites on the actin filament. These open sites allow the myosin heads to bind to them.

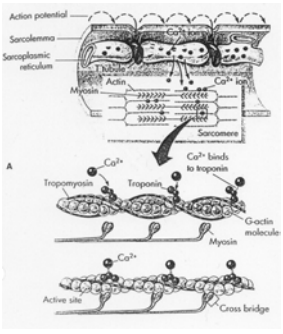
(continued)

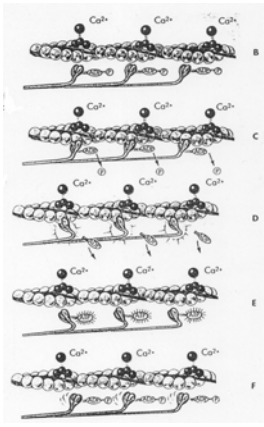
Key Points

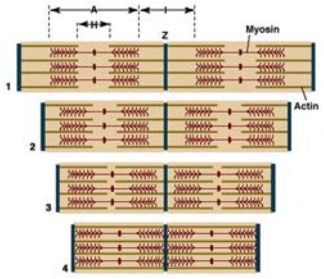
Muscle Fiber Action

- Once myosin binds with actin, the myosin head tilts and pulls the actin filament so they slide across each other.
- Muscle action ends when calcium is pumped out of the sarcoplasm to the sarcoplasmic reticulum for storage.
- Energy for muscle action is provided when the myosin head binds to ATP. ATPase on the myosin head splits the ATP into a usable energy source.

CONTRACTING MUSCLE FIBER



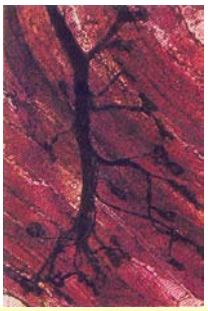


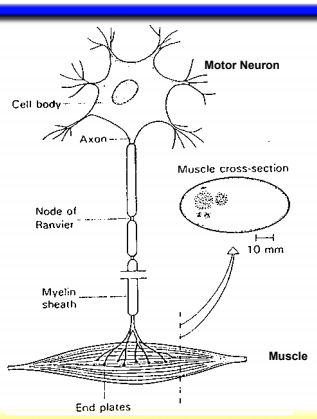


CONTRACTING MUSCLE FIBER

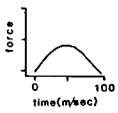
Motor Unit

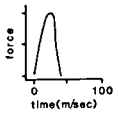
A motor neuron and the muscle fibers that it innervates





TWITCH RESPONSE

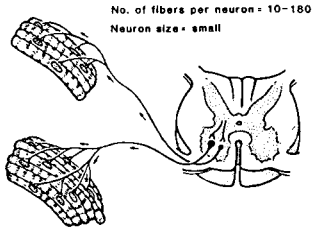




TYPE I FIBERS

No. of fibers per neuron = 10–180

Neuron size = small



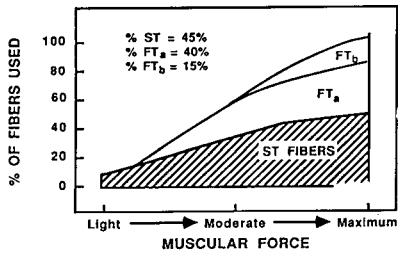
TYPE II FIBERS

No. of fibers per neuron = 300–800

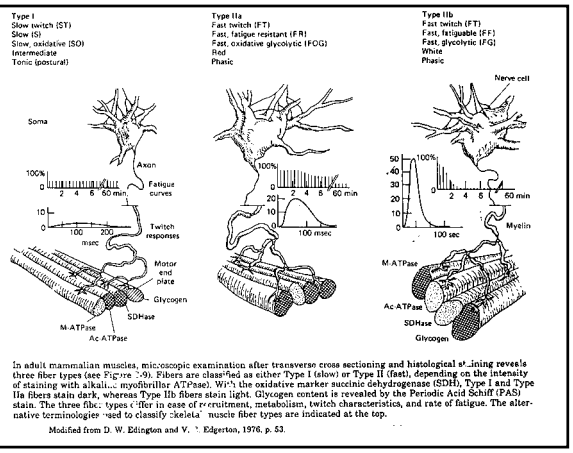
Neuron size = large

Characteristics of the type I (slow-twitch) and type II (fast-twitch) motor units. Each motor unit consists of a nerve cell and the muscle fibers it innervates. Note the difference between the duration and height of a muscle twitch for the type I and II motor units (from Costill, 1986).

RAMPLIKE RECRUITMENT OF FIBERS

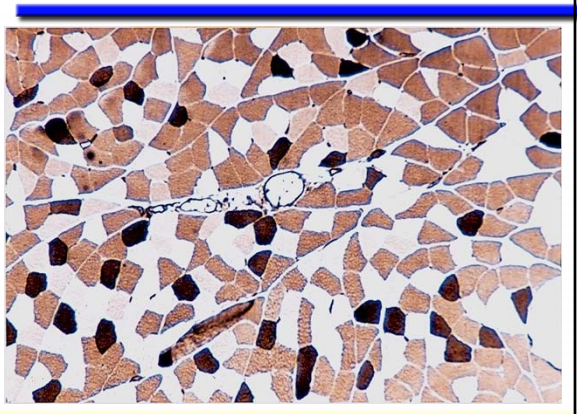


The ramp-like recruitment of muscle fibers in varied levels of muscular effort. Whereas light force requirements only use the slow-twitch fibers, heavy loads on the muscle will result in the recruitment of all three types of muscle fibers.



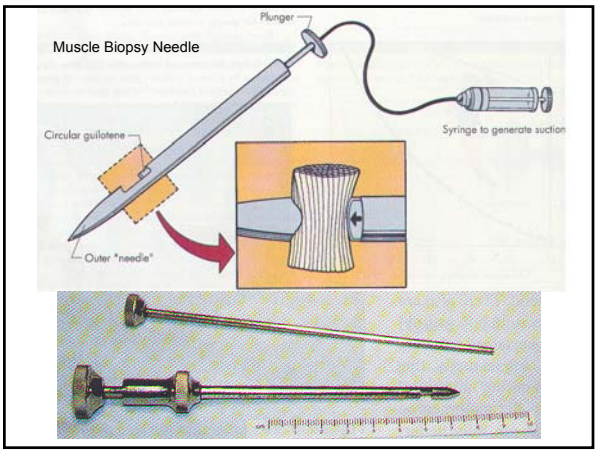
In adult mammalian muscles, microscopic examination after transverse cross sectioning and histological staining reveals three fiber types (see Figure 7-9). Fibers are classified as either Type I (slow) or Type II (fast), depending on the intensity of staining with alkali... myofibrillar ATPase). With the oxidative marker succinic dehydrogenase (SDH), Type I and Type IIa fibers stain dark, whereas Type IIb fibers stain light. Glycogen content is revealed by the Periodic Acid Schiff (PAS) stain. The three fiber types differ in ease of recruitment, metabolism, twitch characteristics, and rate of fatigue. The alternative terminologies used to classify skeletal muscle fiber types are indicated at the top.

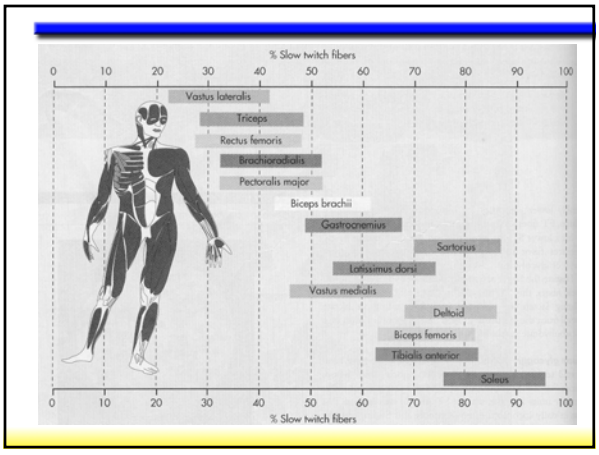
Modified from D. W. Edington and V. R. Edgerton, 1976, p. 53.

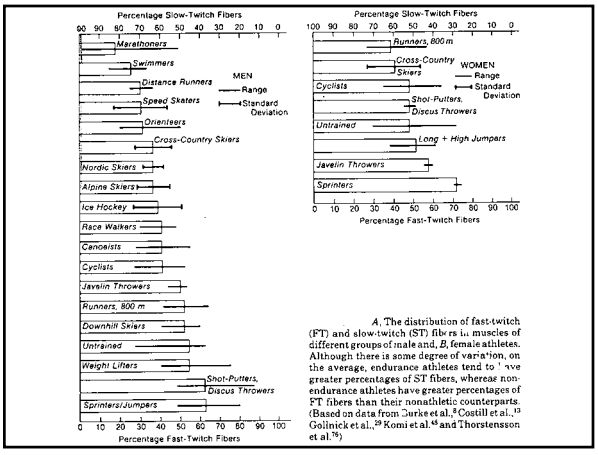


Structural and Functional Characteristics of Slow Twitch and Fast Twitch Type A and B Skeletal Muscle Fibers

Characteristics	Fiber Type ST	FT_A	FT_B
NEURAL ASPECTS			
Motoneuron size	Small	Large	Large
Motoneuron recruitment threshold	Low	High	High
Motor nerve conduction velocity	Slow	Fast	Fast
STRUCTURAL ASPECTS			
Muscle fiber diameter	Small	Large	Large
Sarcoplasmic reticulum development	Less	More	More
Mitochondrial density	High	High	Low
Capillary density	High	Medium	Low
Myoglobin content	High	Medium	Low
ENERGY SUBSTRATES			
Phosphocreatine stores	Low	High	High
Glycogen stores	Low	High	High
Triglyceride stores	High	Medium	Low
ENZYMATIC ASPECTS			
Myosin-ATPase activity	Low	High	High
Glycolytic enzyme activity	Low	High	High
Oxidative enzyme activity	High	High	Low
FUNCTIONAL ASPECTS			
Twitch (contraction) time	Slow	Fast	Fast
Relaxation time	Slow	Fast	Fast
Force production	Low	High	High
Energy efficiency, "economy"	High	Low	Low
Fatigue resistance	High	Low	Low
Elasticity	Low	High	High







A, The distribution of fast-twitch (FT) and slow-twitch (ST) fibers in muscles of different groups of male and, *B*, female athletes. Although there is some degree of variation, on the average, endurance athletes tend to have greater percentages of ST fibers, whereas non-endurance athletes have greater percentages of FT fibers than their nonathletic counterparts. (Based on data from Burke et al.,[8] Costill et al.,[13] Gollnick et al.,[29] Komi et al.[45] and Thorstensson et al.[76])

SKELETAL MUSCLE

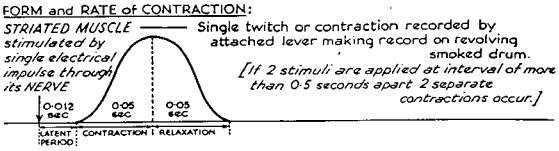
Skeletal (or Striated) muscle is found in the muscles which can be moved VOLUNTARILY. Its PHYSIOLOGICAL BEHAVIOUR can be studied in FROG muscle — ISOLATED from the body but with its motor nerve attached. (It is kept bathed in a watery fluid of roughly the same osmotic pressure and electrolytic composition as Body Fluid.)

PROPERTIES of Striated Muscle are shown in this way:-

FORM and RATE of CONTRACTION:

STRIATED MUSCLE stimulated by single electrical impulse through its NERVE ——— Single twitch or contraction recorded by attached lever making record on revolving smoked drum.

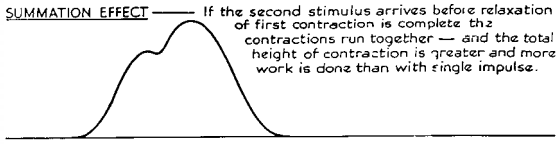
[If 2 stimuli are applied at interval of more than 0·5 seconds apart 2 separate contractions occur.]



REFRACTORY PERIOD — This is the period after stimulation during which a muscle does not respond to a second stimulus. This interval is very short in skeletal muscle — 0·002 second.

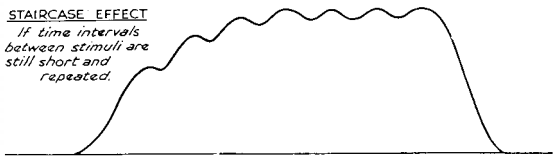
SKELETAL MUSCLE

SUMMATION EFFECT ——— If the second stimulus arrives before relaxation of first contraction is complete the contractions run together — and the total height of contraction is greater and more work is done than with single impulse.



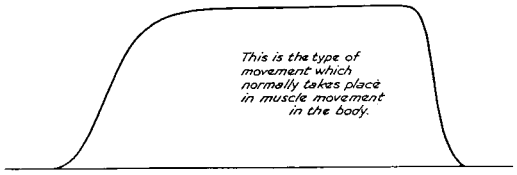
STAIRCASE EFFECT

If time intervals between stimuli are still short and repeated.



SKELETAL MUSCLE

TETANUS ——— If time interval is further shortened (e.g. 300 stimuli/second) smooth sustained contraction results



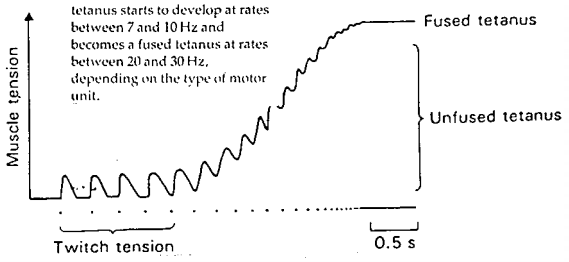
Each individual muscle cell obeys the 'ALL-or-NONE' law. i.e. Each muscle fibre, if it responds at all to a stimulus, will respond to the maximum extent — unless fatigued or partially shortened before stimulation.

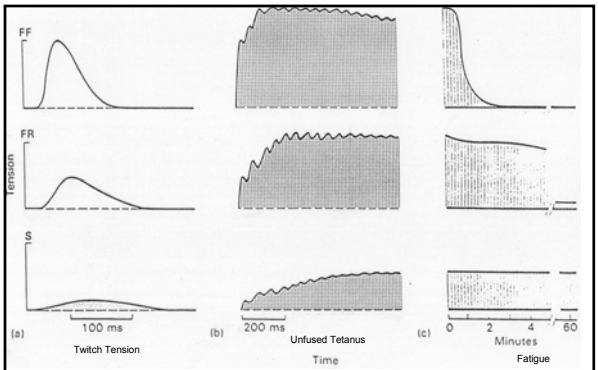
Even if stimulus is increased in strength, the strength of contraction will remain the same.

The summation effects are due to an increase in the number of individual muscle fibres in the muscle being stimulated.

MAXIMAL CONTRACTION occurs when all fibres making up a muscle are stimulated.

Rate coding of muscle force. Isometric force development of a motor fibre during electrical stimulation at progressively increasing rate. At low rates of stimulation, single twitches are evoked. Unfused tetanus starts to develop at rates between 7 and 10 Hz and becomes a fused tetanus at rates between 20 and 30 Hz, depending on the type of motor unit.





Graphs of typical isometric tension development of the three types of motor unit (FF, FR, S) as found in the cat gastrocnemius muscle. (a) Twitch tension; (b) unfused tetanus evoked by stimulus train of 20 s^{-1}; (c) curve of isometric maxima obtained by train of stimulation at 40 s^{-1}, lasting 330 ms and repeated every 1 s. Note large twitch force in the FF unit, slow build-up of tetanic force in the S unit and rapid decline in tension within 2 mm in the FF unit. The FR unit behaves in an intermediate fashion.

Motor Unit

A motor neuron and the muscle fibers that it innervates