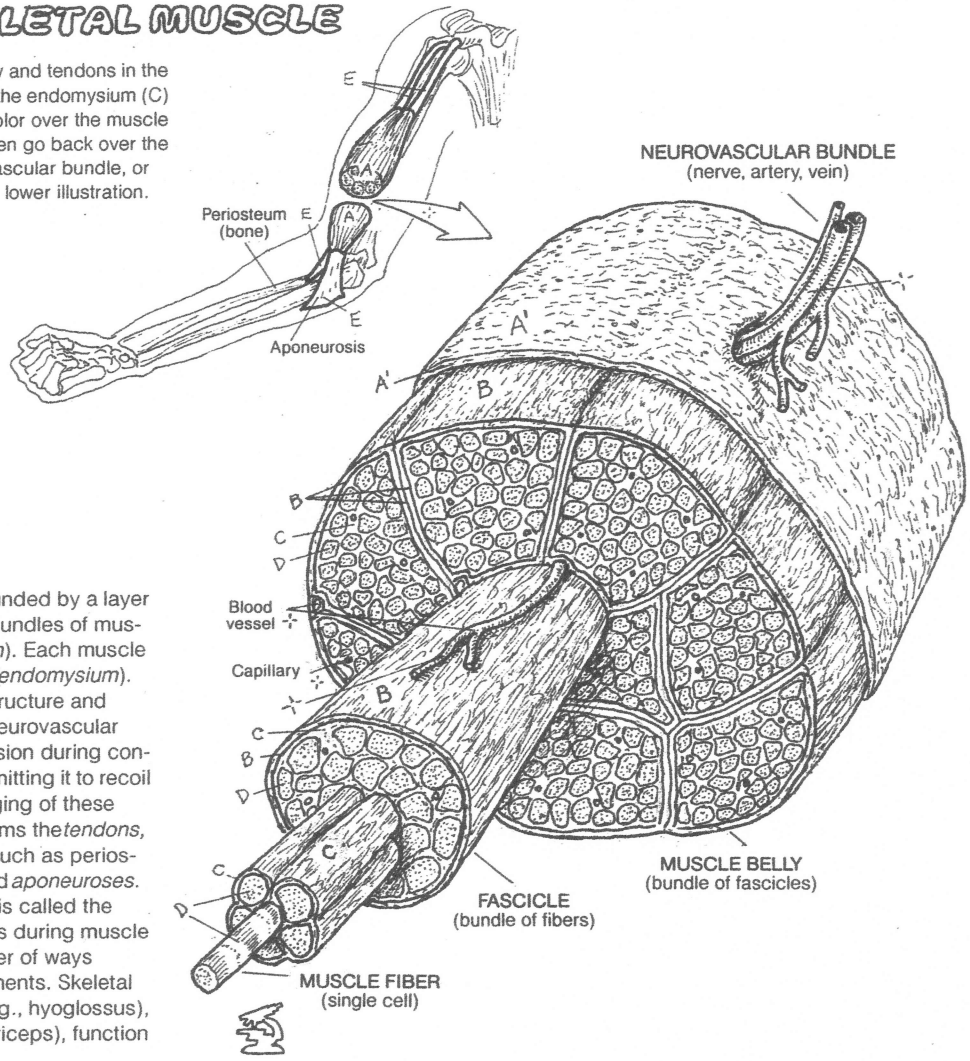
INTRODUCTION TO SKELETAL MUSCLE

CN: Use light colors for A–E. (1) Begin with the muscle belly and tendons in the upper illustration. (2) When coloring the narrow borders of the endomysium (C) in the enlarged section, it is recommended that you also color over the muscle fiber ends (D) with the very light endomysium color, and then go back over the fiber ends with a darker color (D). Do not color the neurovascular bundle, or the cut ends of blood vessels and capillaries. (3) Color the lower illustration.



SKELETAL MUSCLE

- BELLY (A)
  - FASCIA:
    - EPIMYSIUM (A')
    - PERIMYSIUM (B)
    - ENDOMYSIUM (C)
  - MUSCLE FIBER (CELL) (D)
- TENDON (E)

A **named skeletal muscle** (e.g., biceps brachii), surrounded by a layer of deep fascia (*epimysium*), consists of fascicles or bundles of muscle fibers enveloped in thin fibrous tissue (*perimysium*). Each muscle fiber is surrounded by a thin sheath of fibrous tissue (*endomysium*). Each of these fibrous layers is important to muscle structure and function, providing support for nerves and vessels (neurovascular bundles), ensuring uniform distribution of muscle tension during contraction, and maintaining the elasticity of muscle, permitting it to recoil to its resting length following stretching. It is the merging of these fibrous layers at the ends of the muscle fibers that forms the *tendons,* which integrate the muscle to its attachment site(s), such as periosteum or another tendon. Broad, flat tendons are called *aponeuroses.* The mass of the fasciae-enveloped contractile fibers is called the *belly* of the muscle. It is the muscle belly that shortens during muscle contraction. The belly may be shaped one of a number of ways depending on its tendinous arrangement and attachments. Skeletal muscles are named in relation to their attachments (e.g., hyoglossus), shape (e.g., trapezius), number of heads (e.g., quadriceps), function (e.g., adductor magnus), or position (e.g., brachialis).

MECHANICS OF MOVEMENT

- FULCRUM (F) (JOINT) (F')
- EFFORT (A) (MUSCLE) (A)
- RESISTANCE (G) (WEIGHT) (G')

Skeletal muscles employ simple machines, such as levers, to increase the efficiency of their contractile work about a joint. Mechanically, the degree of *muscular effort* required to overcome resistance to movement at a *joint* (*fulcrum*) depends upon the force of that resistance (*weight*); the relative distances from the anatomical fulcrum to the anatomical sites of *muscular effort*; and the anatomical sites of *resistance* (joints). The position of the joint relative to the site of muscle pull and the site of imposed load determines the class of the lever system in use.

1ST CLASS LEVER

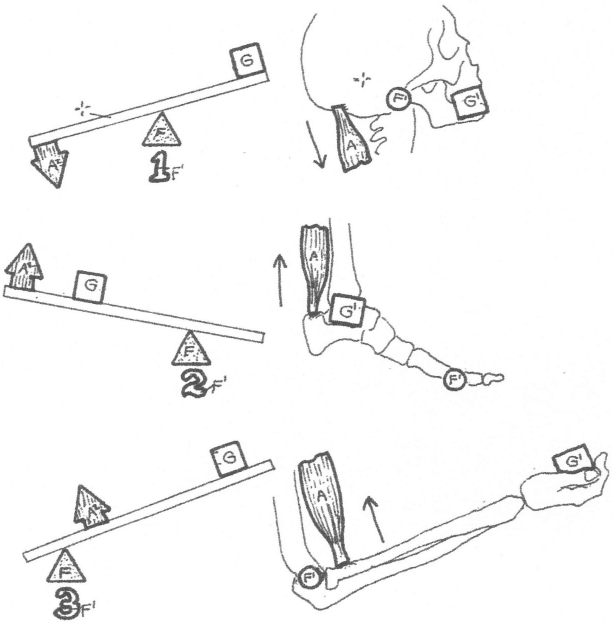
In a **1st class lever,** the joint lies between the muscle and the load. This is the most efficient class of lever. By flexing the neck and posturing the head forward and downward, the load (G^1) is appreciably increased (due to gravity), and the muscular effort (A) to hold that posture may induce muscle pain and stiffness/tightness (overuse).

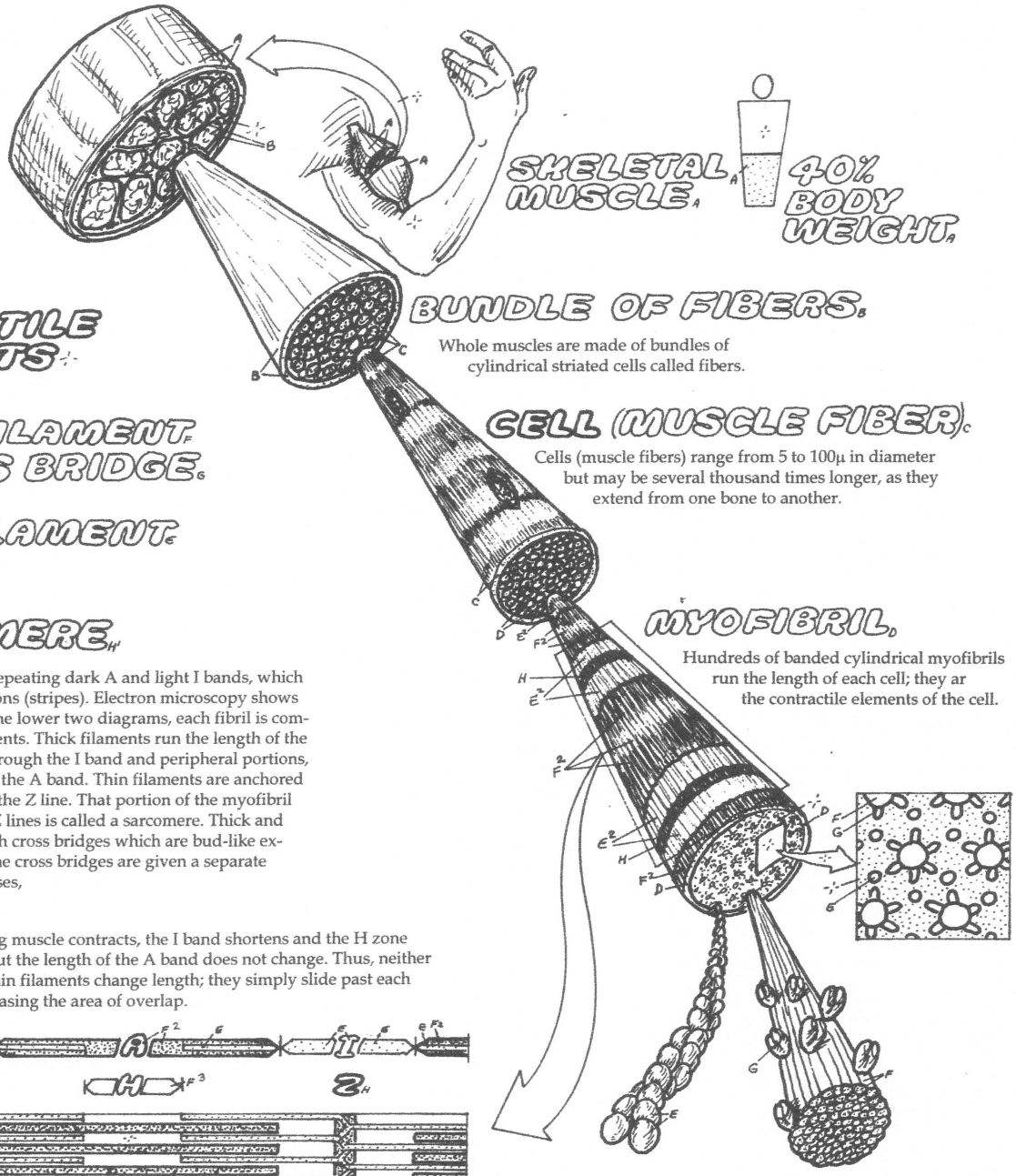
2ND CLASS LEVER

In a **2nd class lever,** the load lies between the joint and the pulling muscle. This lever system operates in lifting a wheelbarrow (the wheel is the fulcrum) as well as lifting a 75 kg (165 lb) body onto the metatarsal heads at the metatarsophalangeal joints. This is a relatively easy task for the strong calf (triceps surae) muscles; but try standing on the heads of your middle phalanges (increasing the distance F^1–G^1)!

3RD CLASS LEVER

In a **3rd class lever,** the muscle lies between the joint and the load and has a poor mechanical advantage here. Consider the difference in muscular effort required to carry a 45 kg (100 lb) bag of cement in your hands with flexed elbows (elbow joint: 3rd class lever) and carrying your 75 kg (165 lb) body on the heads of your metatarsals (2nd class lever at the metatarsophalangeal joints). It is all a matter of leverage.



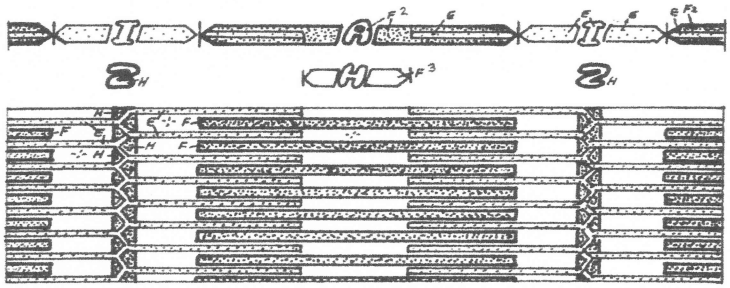


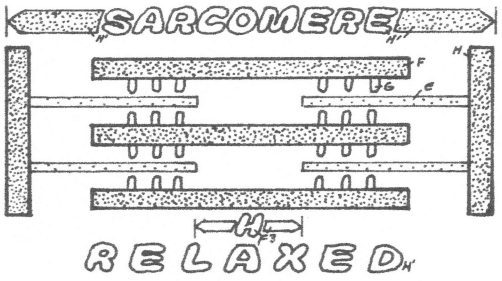
CONTRACTILE ELEMENTS

A BAND F2
THICK FILAMENT F
CROSS BRIDGE G
I BAND E2
THIN FILAMENT E
H ZONE F3
Z LINE H
SARCOMERE H'

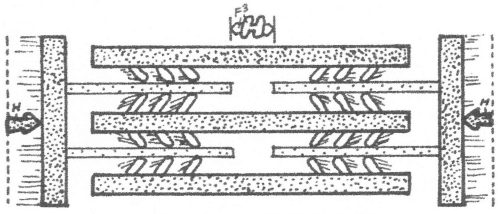
Myofibrils are composed of repeating dark A and light I bands, which are responsible for the striations (stripes). Electron microscopy shows finer detail; as illustrated in the lower two diagrams, each fibril is composed of thick and thin filaments. Thick filaments run the length of the A band; thin filaments run through the I band and peripheral portions, but not the central H zone, of the A band. Thin filaments are anchored in the center of the I band by the Z line. That portion of the myofibril (2.5μ long) between the two Z lines is called a sarcomere. Thick and thin filaments interact through cross bridges which are bud-like extensions of thick filaments. The cross bridges are given a separate color for identification purposes,

When living muscle contracts, the I band shortens and the H zone shortens, but the length of the A band does not change. Thus, neither thick nor thin filaments change length; they simply slide past each other, increasing the area of overlap.





RELAXED H'



CONTRACTED H'

ACTIN FILAMENT (THIN) E

Thin filaments are highly ordered assemblies of protein molecules called actin.

MYOSIN FILAMENT (THICK) F

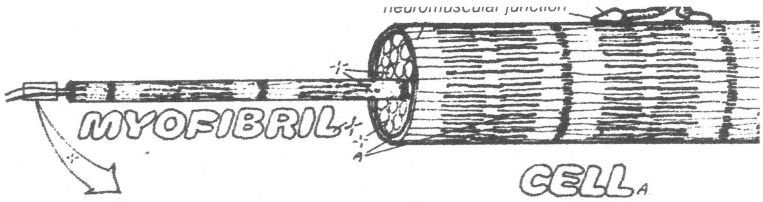
Thick filaments are highly ordered assemblies of protein molecules called myosin.

ACTIN MOLECULE E

Actin molecules are pear-shaped (approx. 4nm in diameter). In thin filaments they are joined together like two strings of beads intertwined at regular intervals. (Note: Thin filaments also contain other proteins in addition to actin).

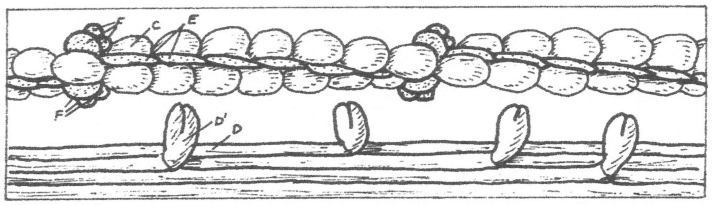
MYOSIN MOLECULE F'

Myosin molecules have long (160nm) rod-shaped tails with globular heads. The heads form cross bridges between thick and thin filaments.

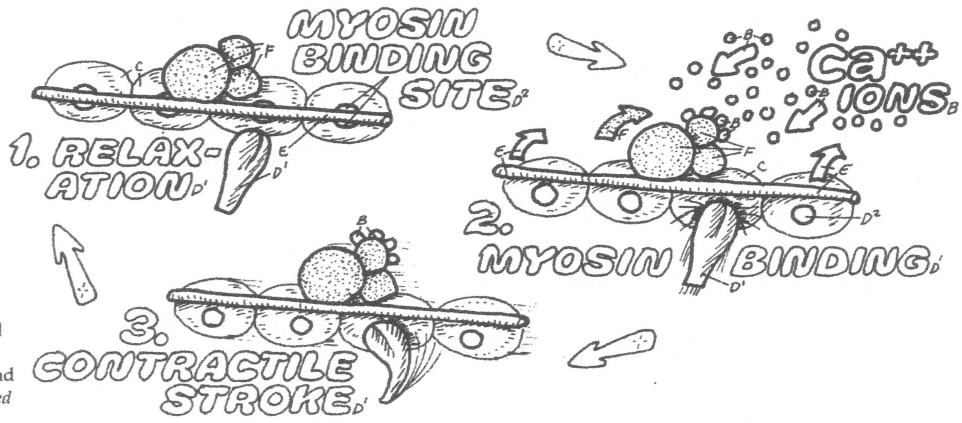


FREE CALCIUM TRIGGERS CONTRACTION

ACTIN
MYOSIN
CROSS BRIDGE
TROPOMYOSIN
TROPONIN



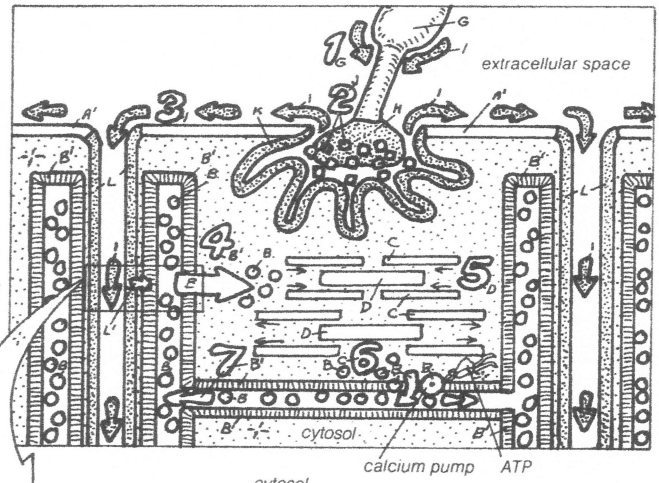
Tropomyosin is a long, two-stranded helical protein aligned almost parallel to the axis of the thin actin filaments. Troponin is a protein complex of three globular subunits, located at regular intervals (spaced approximately seven actin molecules apart) along the thin filament. One of the subunits attaches to tropomyosin, another to actin, and the third subunit can bind Ca^{++} ions

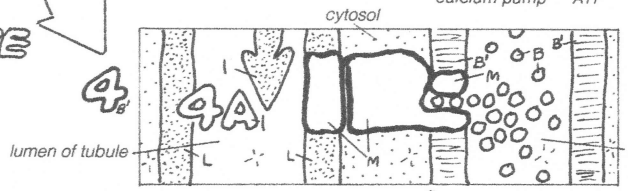


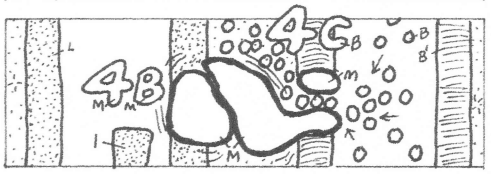
1. Relaxation: *Myosin cross bridges* cannot attach to thin filament because the site of attachment is blocked by *tropomyosin*. **2. Myosin binding:** *Ca^{++} ions appear* on the scene. Four Ca^{++} bind to each troponin and the complex moves the tropomyosin away from the binding sites. Myosin can now bind to *actin*. **3. Contractile stroke:** Once *energized myosin* binds to actin, the head tilts and propels the thin filament.

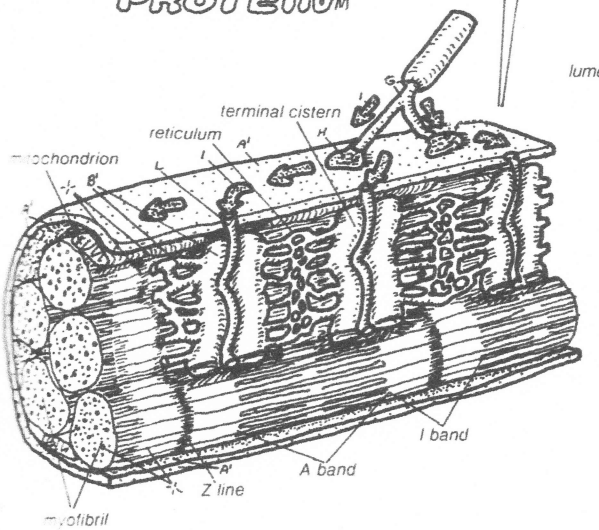
SARCOPLASMIC RETICULUM & Ca^{++} STORAGE

AXON
AXON TERMINAL
ACTION POTENTIAL
ACETYLCHOLINE
MOTOR END PLATE
CELL MEMBRANE
T TUBULE
VOLTAGE-SENSITIVE PROTEIN









Relaxation: Ca^{++} is trapped within the sarcoplasmic reticulum (SR) and cannot bind to troponin to trigger contraction **Contraction** (1, 2, 3): An action potential on the surface of the cell invades the interior via T tubules and comes in close contact with the SR. (4) Depolarization produced by the advancing action potential (4A in the lower enlargement) changes the conformation of a voltage-sensitive tubule membrane protein (*dihydropyridine* or *DHP* receptor). The changed shape of this protein forces the SR channels open (4B), releasing Ca^{++} into the cytosol (4C). (5) Ca^{++} ions bind to troponin and expose binding sites for myosin. Contraction follows. **Relaxation** (6, 7): An ATP-driven Ca^{++}pump actively transports Ca^{++} back into the SR. The cytoplasmic Ca^{++} level falls and relaxation follows.