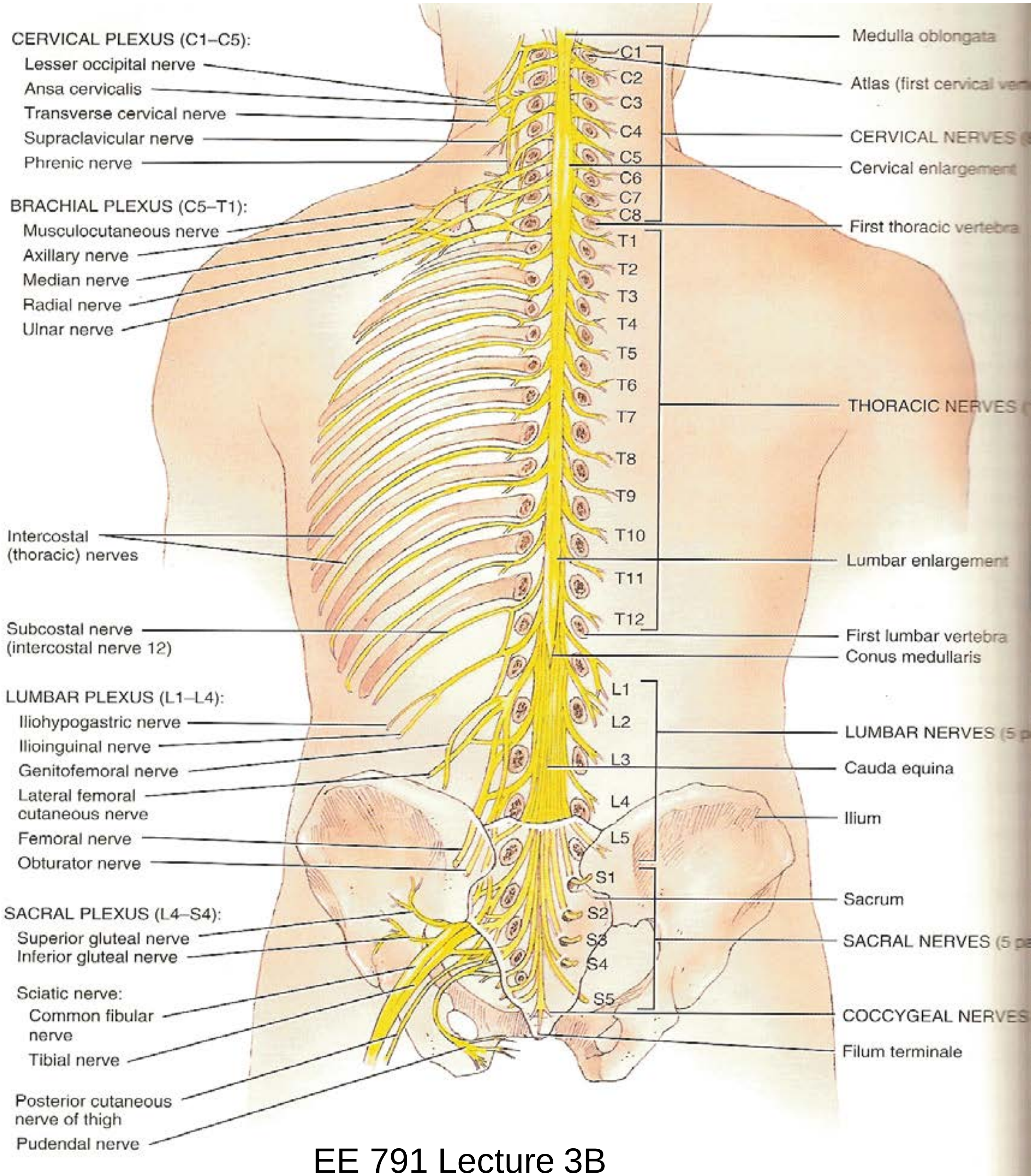
EE 791 Lecture 3B

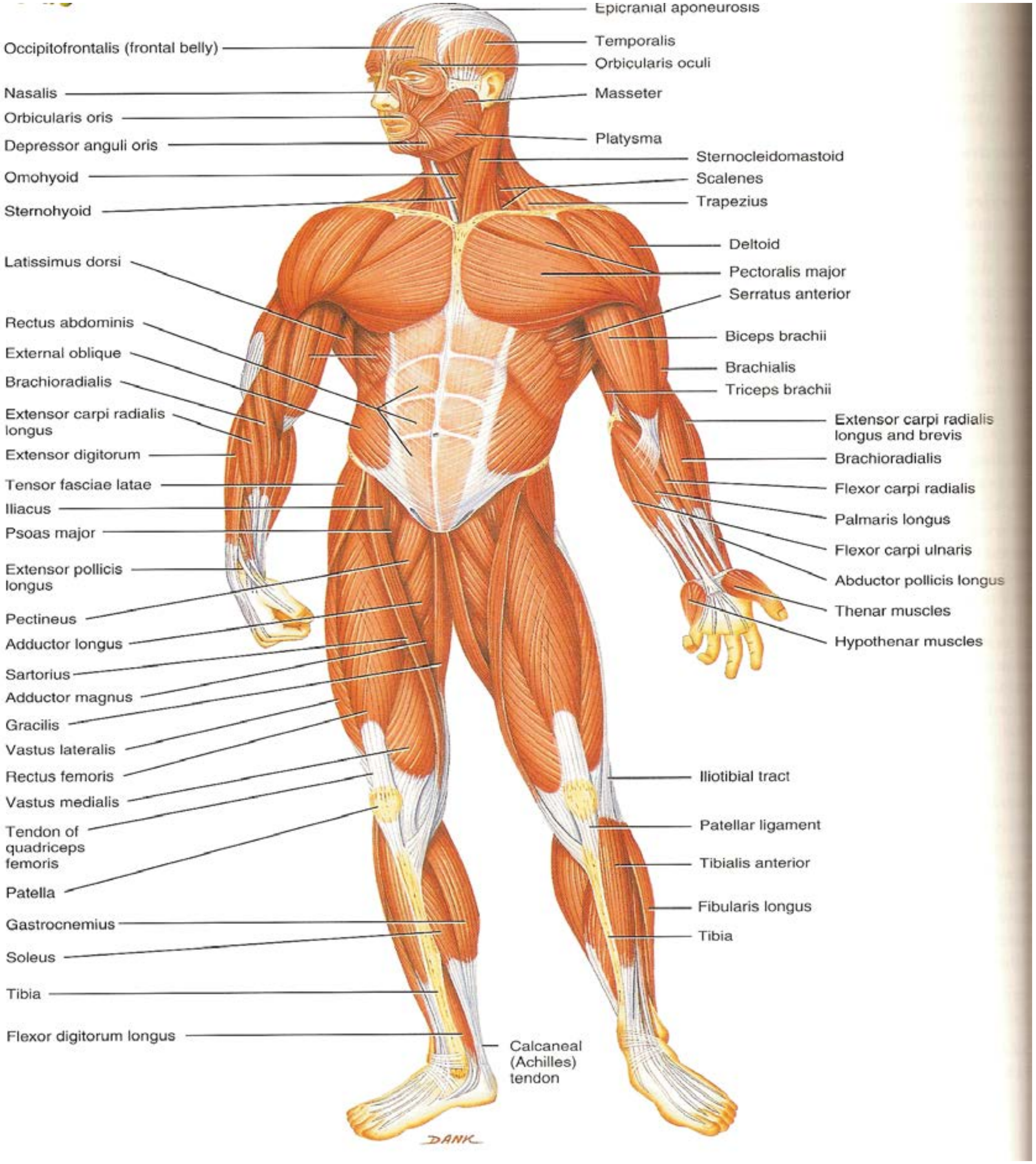
Muscle

January 19, 2015

Peripheral Nerves



Skeletal Muscles



3.2 Muscle biomechanics

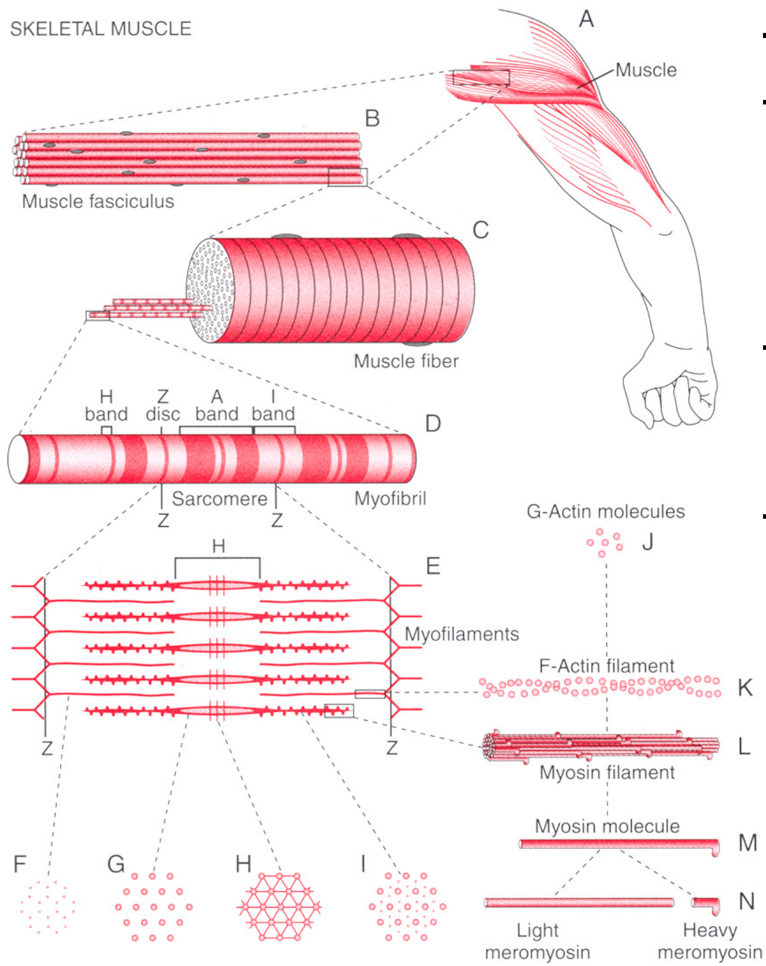


FIGURE 6–1

Organization of skeletal muscle, from the gross to the molecular level. *F*, *G*, *H*, and *I* are cross sections at the levels indicated. (Drawing by Sylvia Colard Keene. Modified from Fawcett DW: Bloom and Fawcett: A Textbook of Histology. Philadelphia: WB Saunders Co, 1986.)

Organization:

- skeletal muscle is made up of *muscle fibers*
- each fiber is a single cell
- the contraction of a fiber is achieved by the *motor proteins actin & myosin*

(from Guyton and Hall, 10th Edition)

Fiber orientation:

– muscles that undergo large length changes or high velocities usually have long fibers running lengthwise e.g. biceps brachii

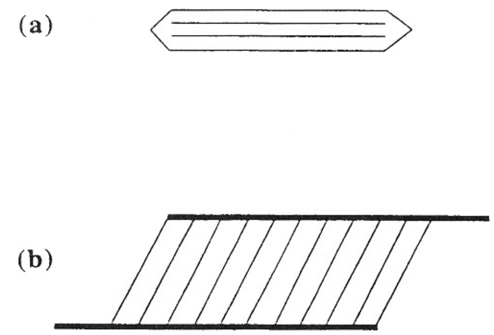
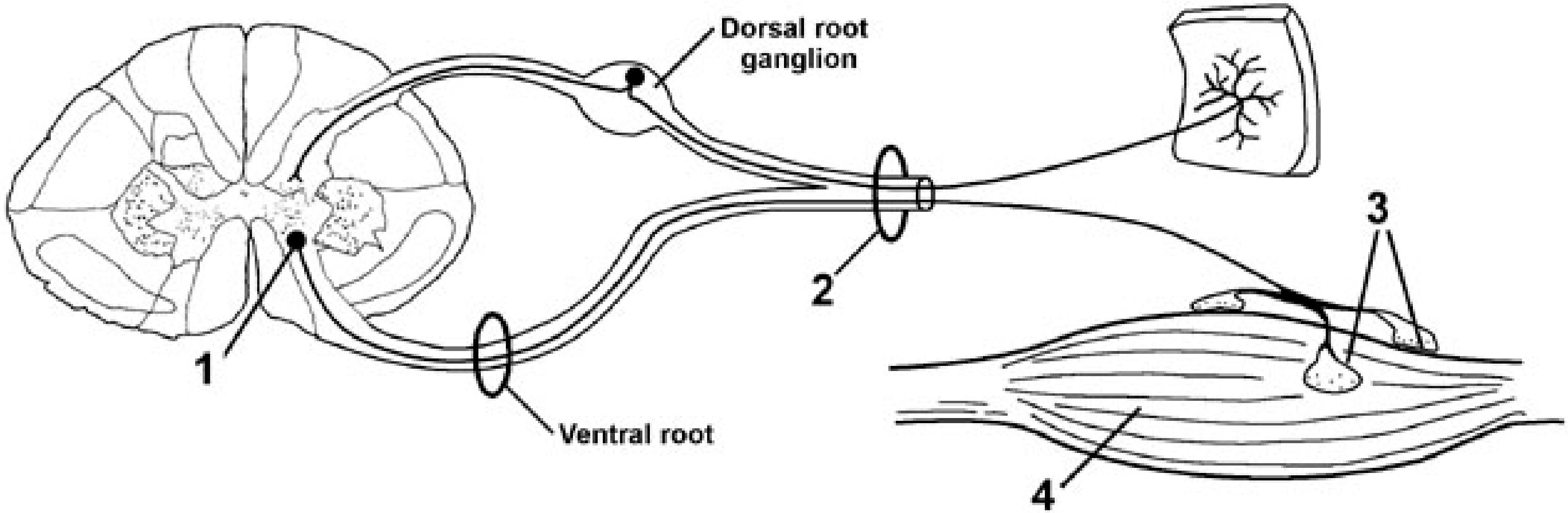


Fig. 10.14 Two common arrangements of fibers within a muscle. In the fusiform arrangement (a), fibers run the length of the muscle. The pennate structure (b) has fibers attached to tendon (bold) at an angle, like the pinna of a feather to its shaft.

– muscles that undergo only small length changes but are required to produce large forces or stiffness have fibers arranged at an angle to the tendons to which they are attached e.g. flexor carpi radialis

Muscle fiber innervation:

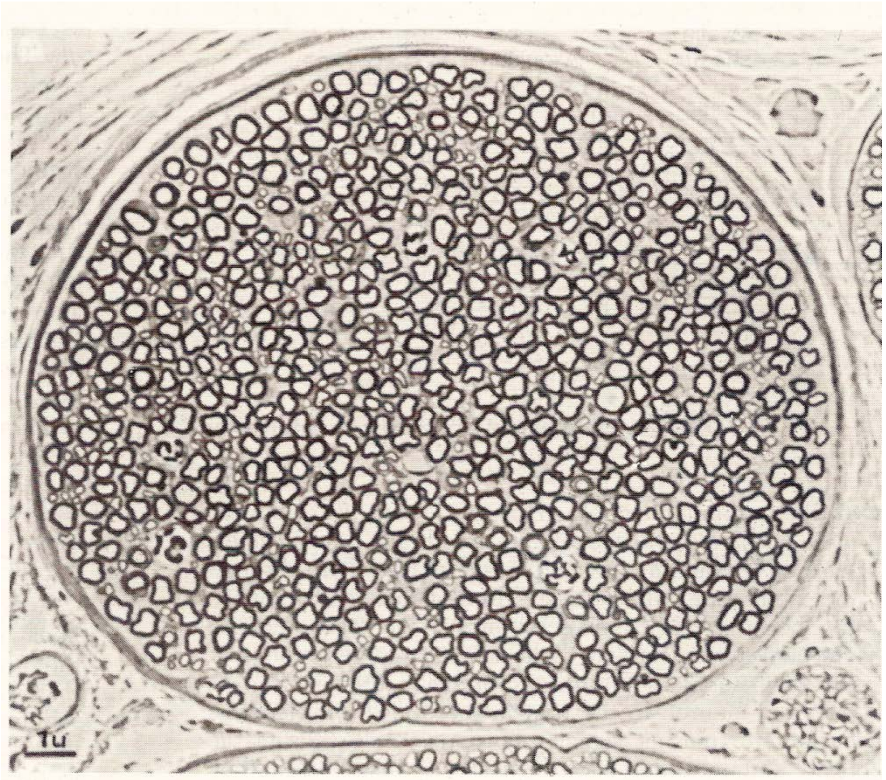


1. Motor neuron
2. Peripheral nerve
3. Neuromuscular junction
4. Muscle

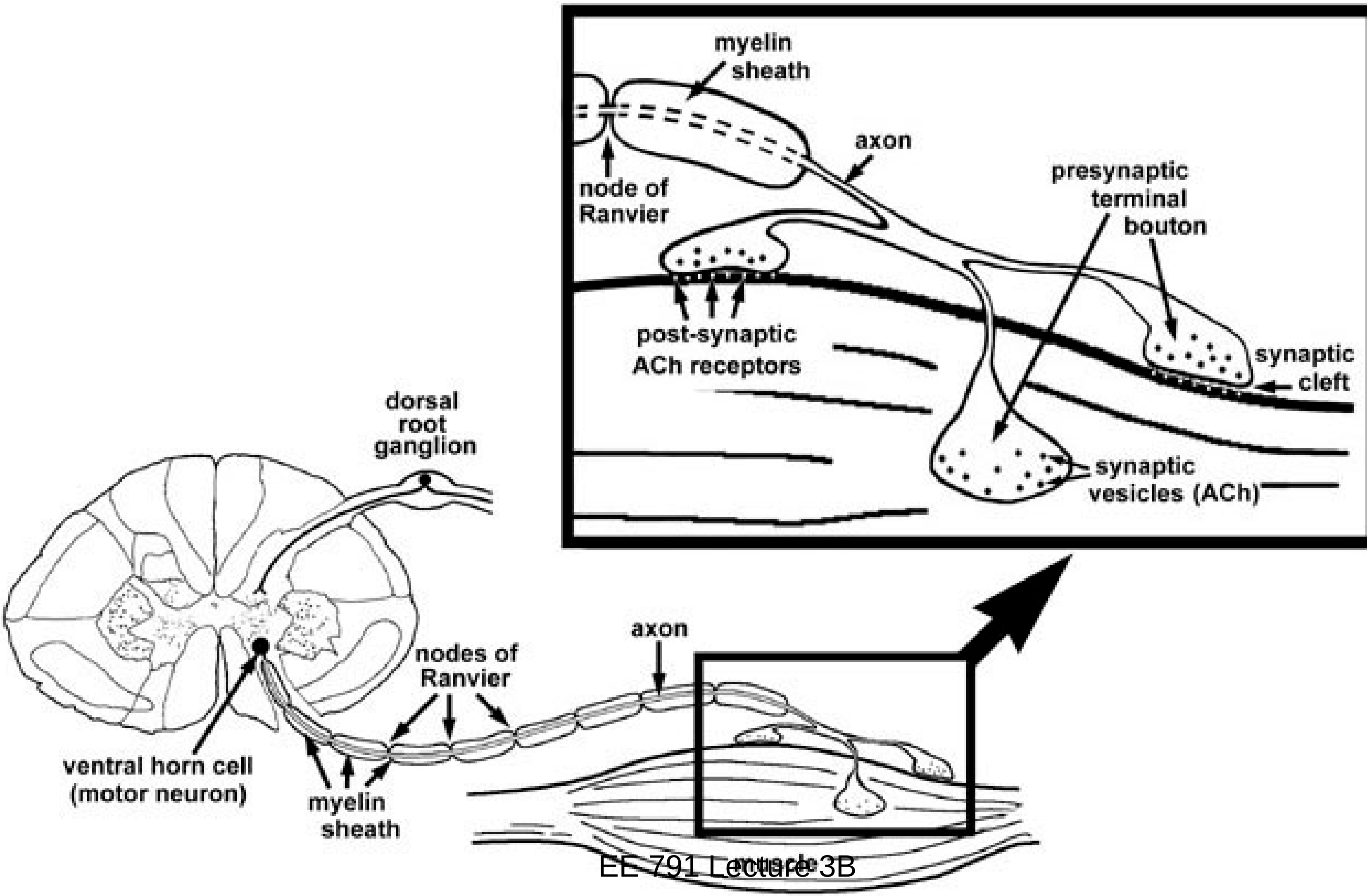
Motor unit:

A *motor unit* is defined as an individual motor neuron plus all the muscle fibers that are innervated by that neuron.

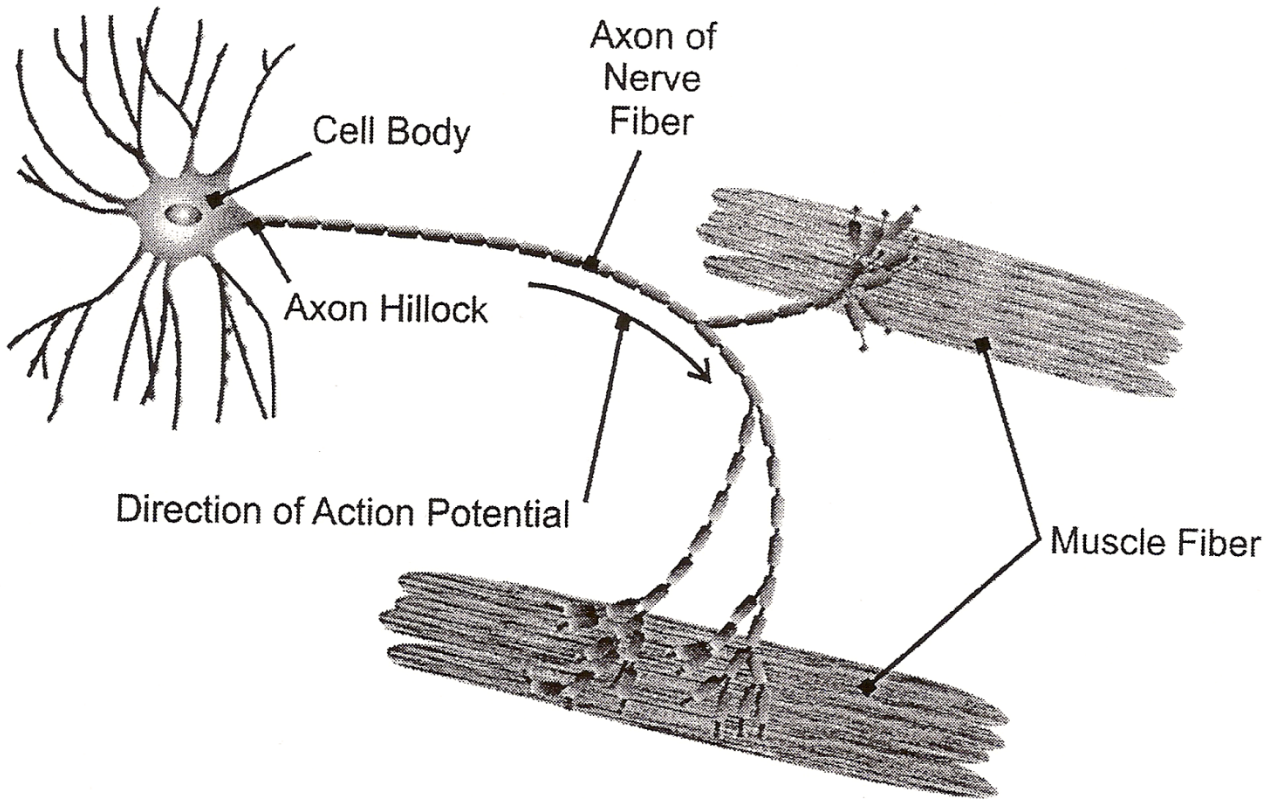
Peripheral Nerve



Neuromuscular junction:



The Motor Unit



Steps in muscle fiber contraction

1. Motor neuron action potential
2. Action potential propagation along motor axon (myelinated fiber)
3. Transmission of *acetylcholine* (ACh) at neuromuscular junctions (synapses)
4. Action potential generation in muscle fiber
5. Release of Ca^{2+} from *sarcoplasmic reticulum* initiates attractive forces between actin & myosin filaments, causing them to slide alongside each other) muscle contraction
6. Return of Ca^{2+} to sarcoplasmic reticulum, ending muscle contraction

Muscle structure (cont.):

Each fibril is surrounded by:

- a *sarcoplasmic reticulum* (SR), which stores Ca^{2+} for triggering muscle fiber contraction, and
- the *transverse tubules system* (TTS), which ensures that action potentials propagate deep into the fiber.

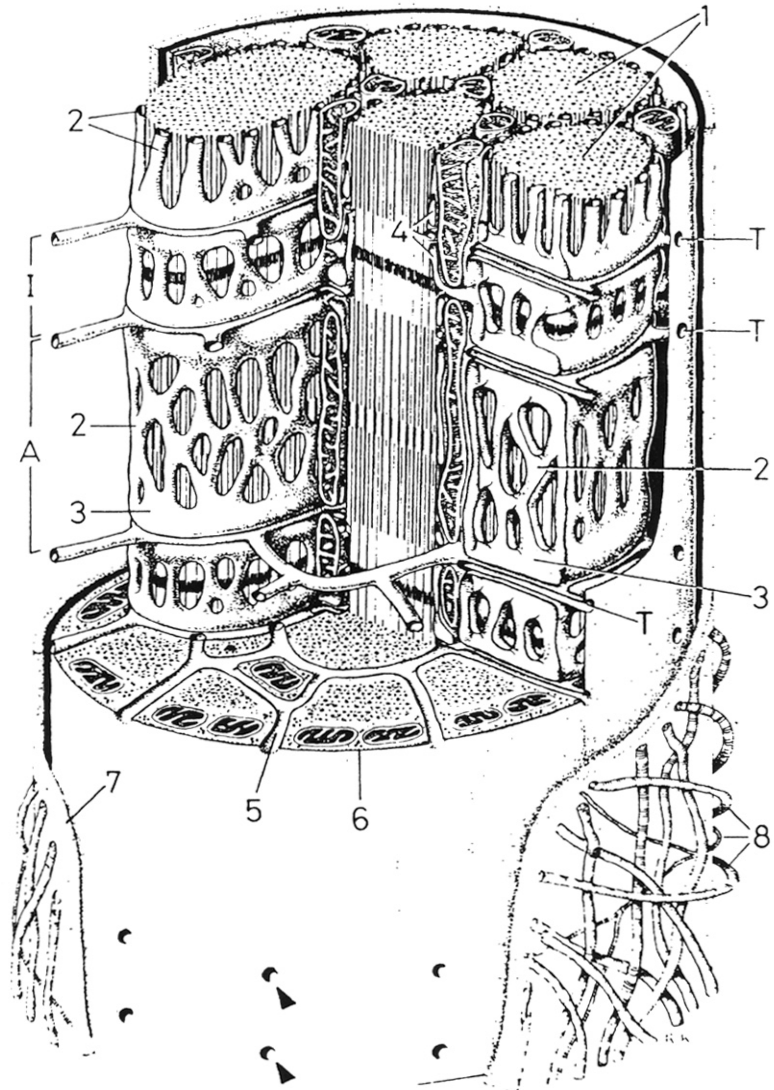


Figure 11.2. A magnified view of the structure of a single muscle fiber with a cutaway view of the myofibrillar structure. Each fibril is surrounded by a sarcoplasmic reticulum (SR) and by the transverse tubules system (TTS) which opens to the exterior of the fiber. [From R. V. Krstić, *Ultrastructure of the Mammalian Cell*, Springer-Verlag, Berlin, Heidelberg, New York, 1970 with permission.]

Actin & myosin filament movement:

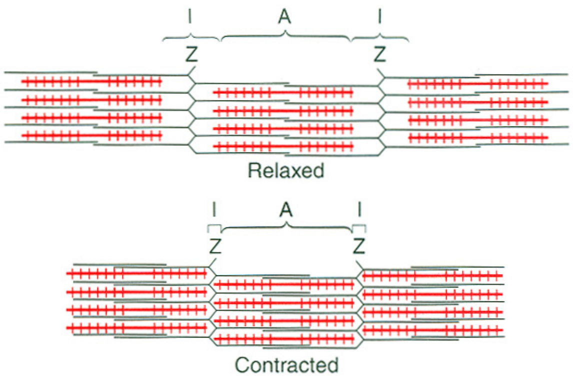


FIGURE 6 – 4

Relaxed and contracted states of a myofibril showing (*top*) sliding of the actin filaments (*black*) into the spaces between the myosin filaments (*red*), and (*bottom*) pulling of the Z membranes toward each other.

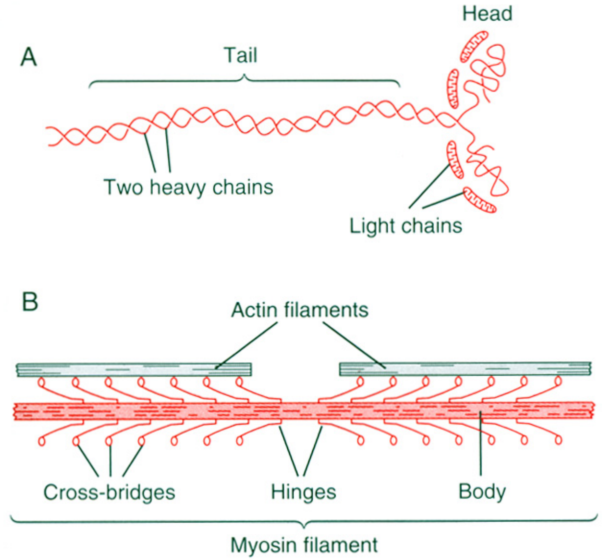


FIGURE 6 – 5

A, Myosin molecule. *B*, Combination of many myosin molecules to form a myosin filament. Also shown are the cross-bridges and interaction between the heads of the cross-bridges and adjacent actin filaments.

(from Guyton and Hall, 10th Edition)

Myofibril

- Muscle fibres 10 – 80 μm
- Each fibre has several hundred to several thousand myofibrils
- Each myofibril has 1500 myosin filaments and 3000 actin filaments
- Z-band (attachment of actin filaments) across the myofibril and between myofibrils

Sliding filament theory:

The sliding filament theory suggests that contraction is generated by movement of the myosin filaments against the actin filaments.

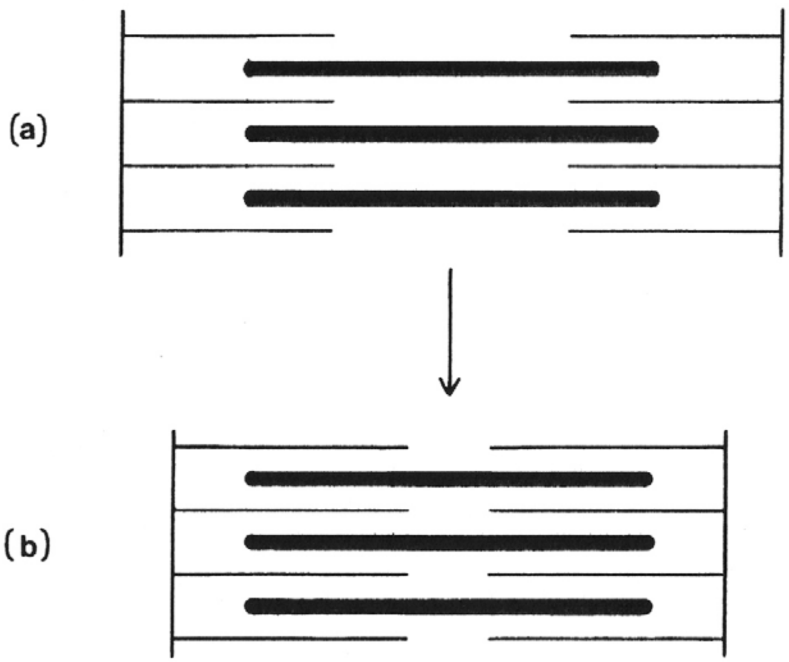


Figure 11.11. The figure illustrates the sliding-filament model. In (a) the muscle is elongated and in (b) it is contracted; in each case the lengths of the thick and thin filaments are unchanged.

Sliding filament theory (cont.):

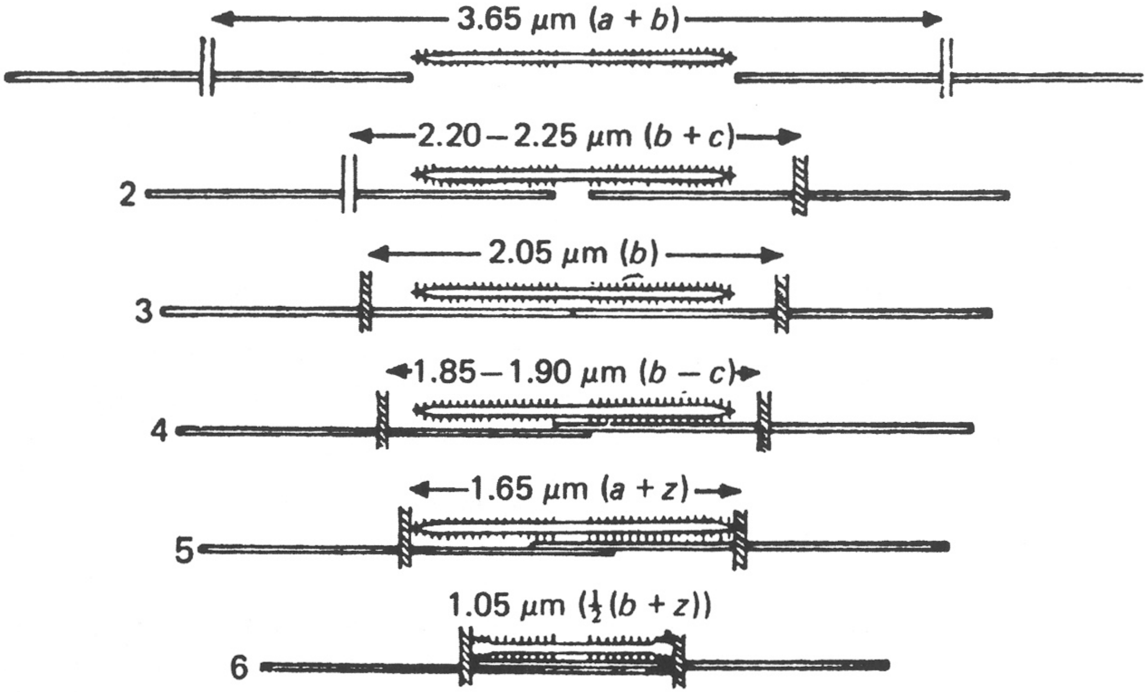


Figure 11.13. Myofilament arrangements at different lengths. The numbers are the positions corresponding to the curve given in Fig. 11.12. *a* = thick filament length (1.6 μm); *b* = thin filament length including *z* line (2.05 μm); *c* = thick filament region base of projections (0.15 μm); and *z* = *z* line width (0.05 μm). [From A. M. Gordon, A. F. Huxley, and F. J. Julian, The variation in isometric tension with sarcomere length in vertebrate muscle fibers, *J. Physiol.* **184**:170–192 (1966). Redrawn by D. J. Aidley, *The Physiology of Excitable Cells*, Cambridge University Press, 1978.]

Sliding filament theory (cont.):

The sliding filament theory is consistent with the tension versus length relationship of muscle undergoing isometric contraction.

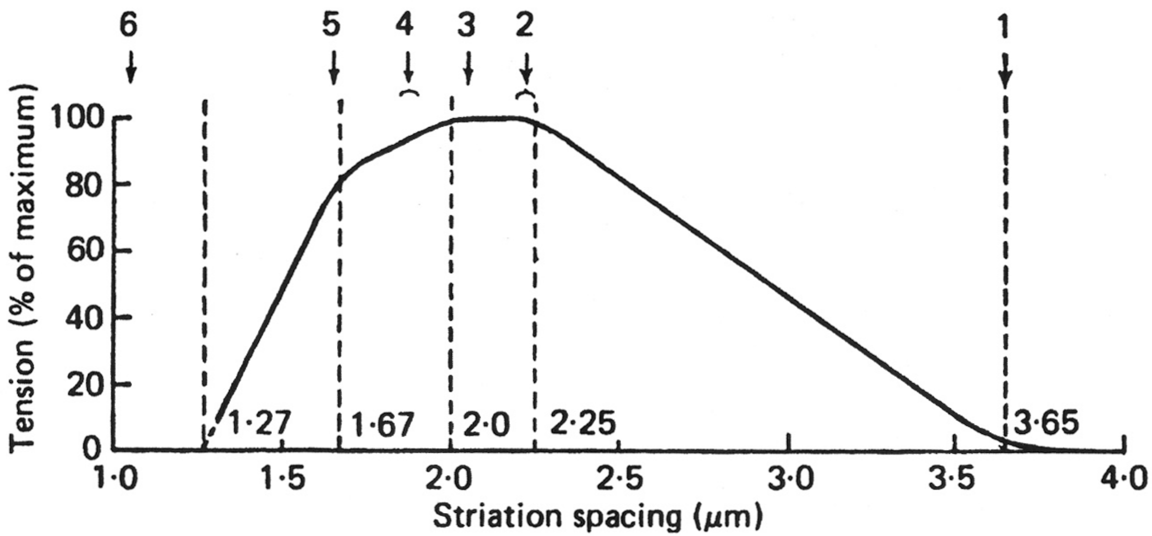


Figure 11.12. The isometric tension of a frog muscle fiber, measured as a percentage of its maximum value at different sarcomere lengths. The numbers 1–6 refer to the myofilament positions illustrated in Fig. 11.13. Note that the general shape is anticipated in Fig. 11.13. [From A. M. Gordon, A. F. Huxley, and F. J. Julian, The variation in isometric tension with sarcomere length in vertebrate muscle fibers, *J. Physiol.* **184**:170–192 (1966). Redrawn by D. J. Aidley, *The Physiology of Excitable Cells*, Cambridge University Press, 1978.]

Fiber types

1. Fast twitch

   – large fibers, for greater contraction strength

   – extensive sarcoplasmic reticulum for rapid release of Ca^{2+}

   – large amounts of glycolytic enzymes

   – less extensive blood supply

   – fewer mitochondria

Force versus fiber length:

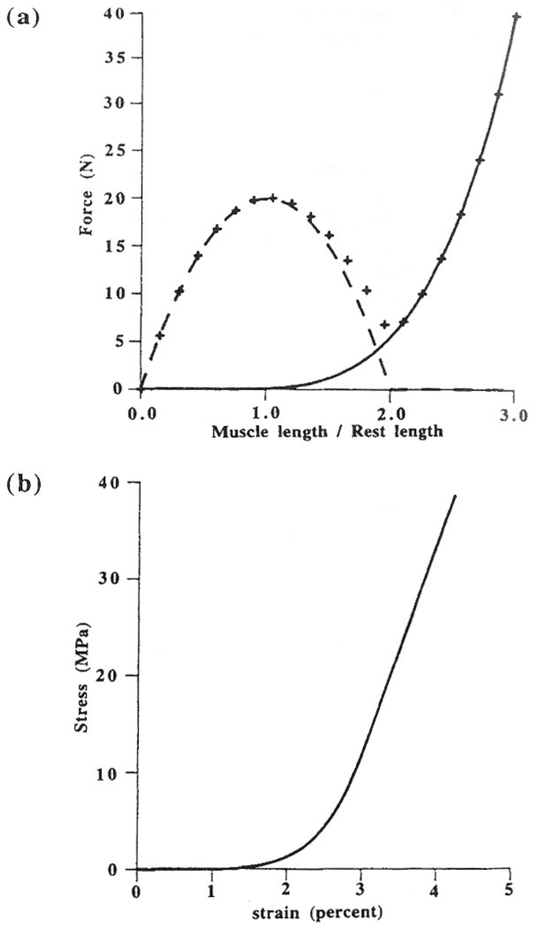


Fig. 10.16 (a) The relationship between length and force for a passive muscle (solid curve), and for an active muscle (+). At each length, the tension developed by active muscle is thought to be the sum of that produced by the passive muscle and the tension produced by the interaction of the sliding filaments (dashed curve). (b) Stress–strain characteristic for a tendon. The characteristic is similar to that for passive muscle, but the tendon is much stiffer.

Force versus fiber length (cont.):

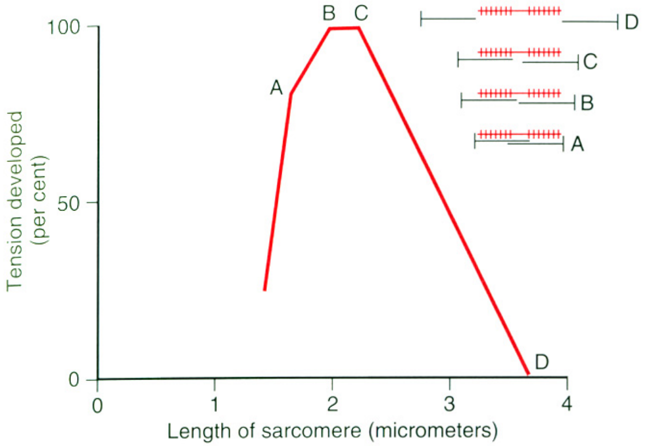


FIGURE 6 – 8

Length-tension diagram for a single sarcomere showing maximum strength of contraction when the sarcomere is 2.0 to 2.2 micrometers in length. At the upper right are shown the relative positions of the actin and myosin filaments at different sarcomere lengths from point A to point D. (Modified from Gordon AM, Huxley AF, Julian FJ: The length-tension diagram of single vertebrate striated muscle fibers. J Physiol 171:28P, 1964.)

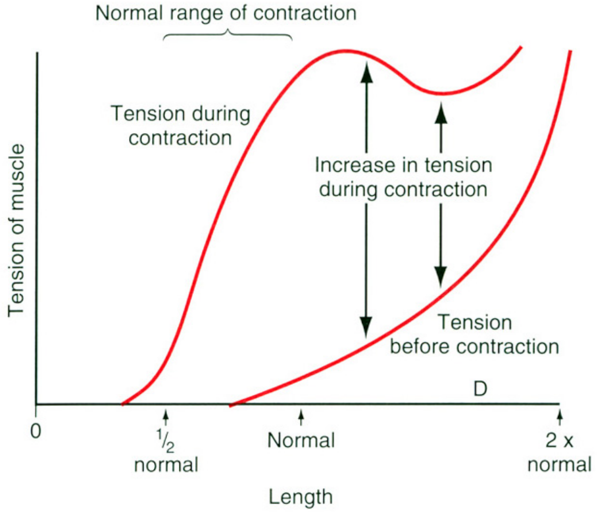


FIGURE 6 – 9

Relation of muscle length to tension in the muscle both before and during muscle contraction.

(from Guyton and Hall, 10th Edition)

Muscle contraction:

A muscle fiber responds to a single neural input with a contractile *twitch*. A fast train of stimuli will twitches that sum together; above the *fusion frequency*, the fiber will be locked in a state referred to as tetanus.

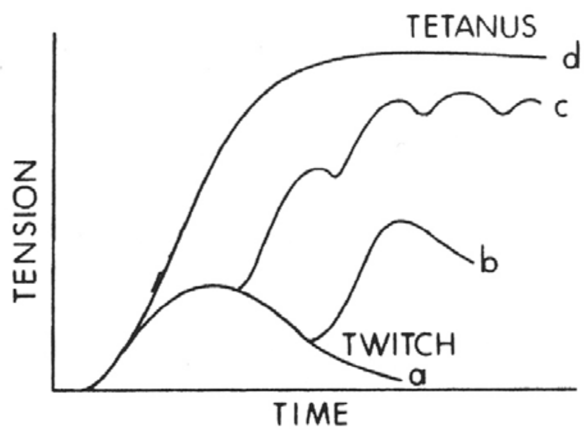


Figure 11.3. Tension versus time for a single stimulus (twitch response) and for a train of stimuli of increasing frequency b, c, d. (From R. D. Keynes and D. J. Aidley, *Nerve and Muscle*, Cambridge University Press, Cambridge, 1981. Reprinted with the permission of Cambridge University Press.)

Force versus activation (cont.):

The total muscle force is modulated by:

– (the frequency of twitches in each of a muscle’s motor units) *rate coding*

  and

– (the number of motor units being activated) *recruitment*