Physiology of the peripheral motor system

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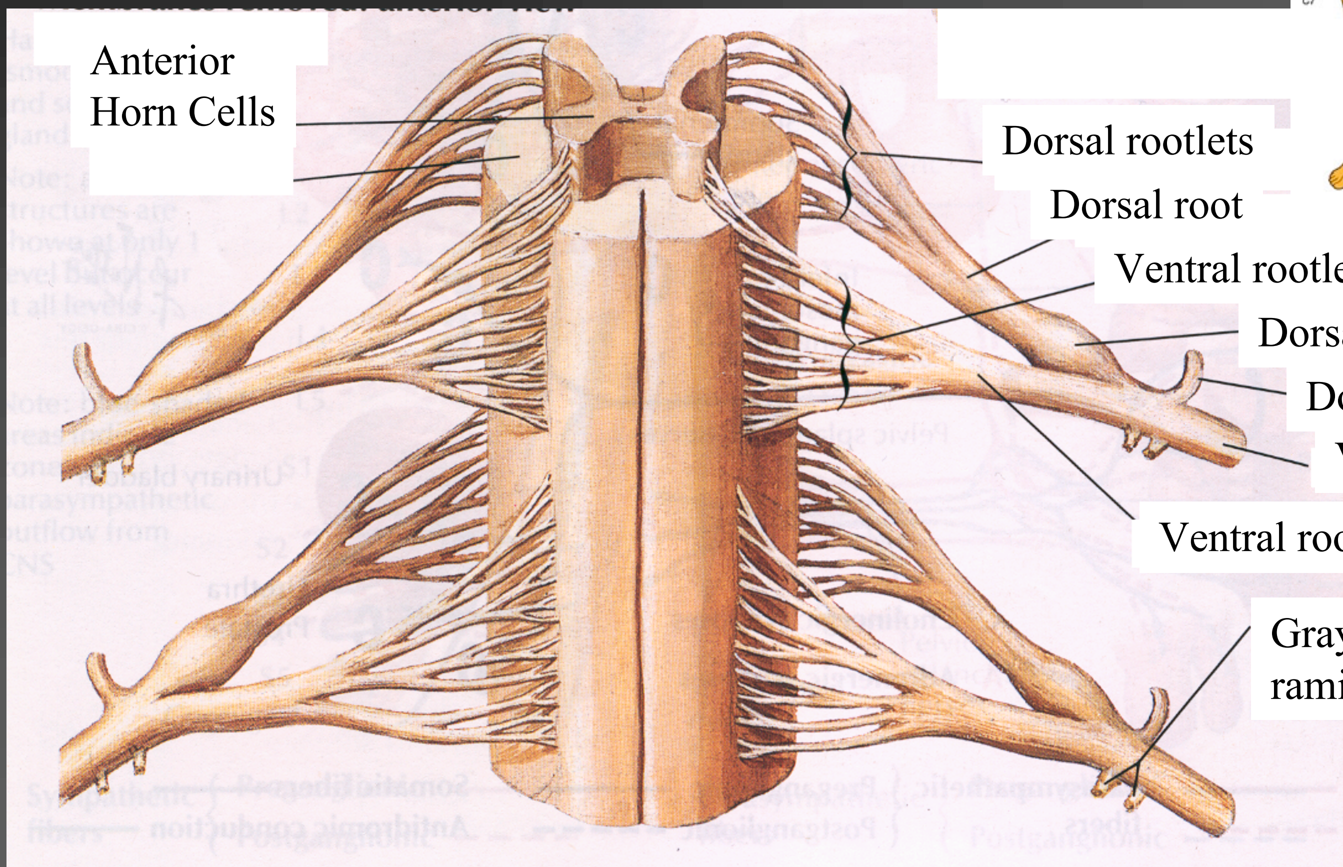
Objectives

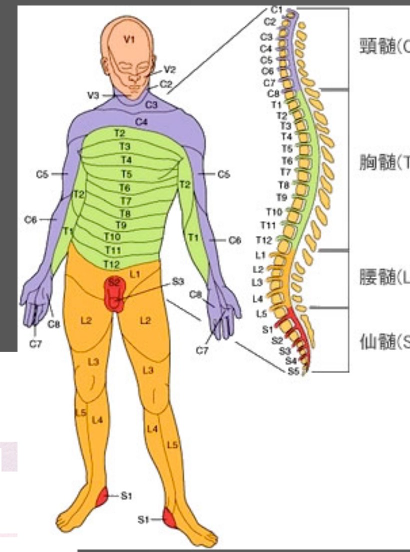
- Review the basic anatomy of the peripheral nervous system
- To understand the concept of the MU and know basic MU properties
- To know Henneman’s size principle of MU recruitment
- To understand how the MU produces force
- To appreciate the impact of disease on the motor system

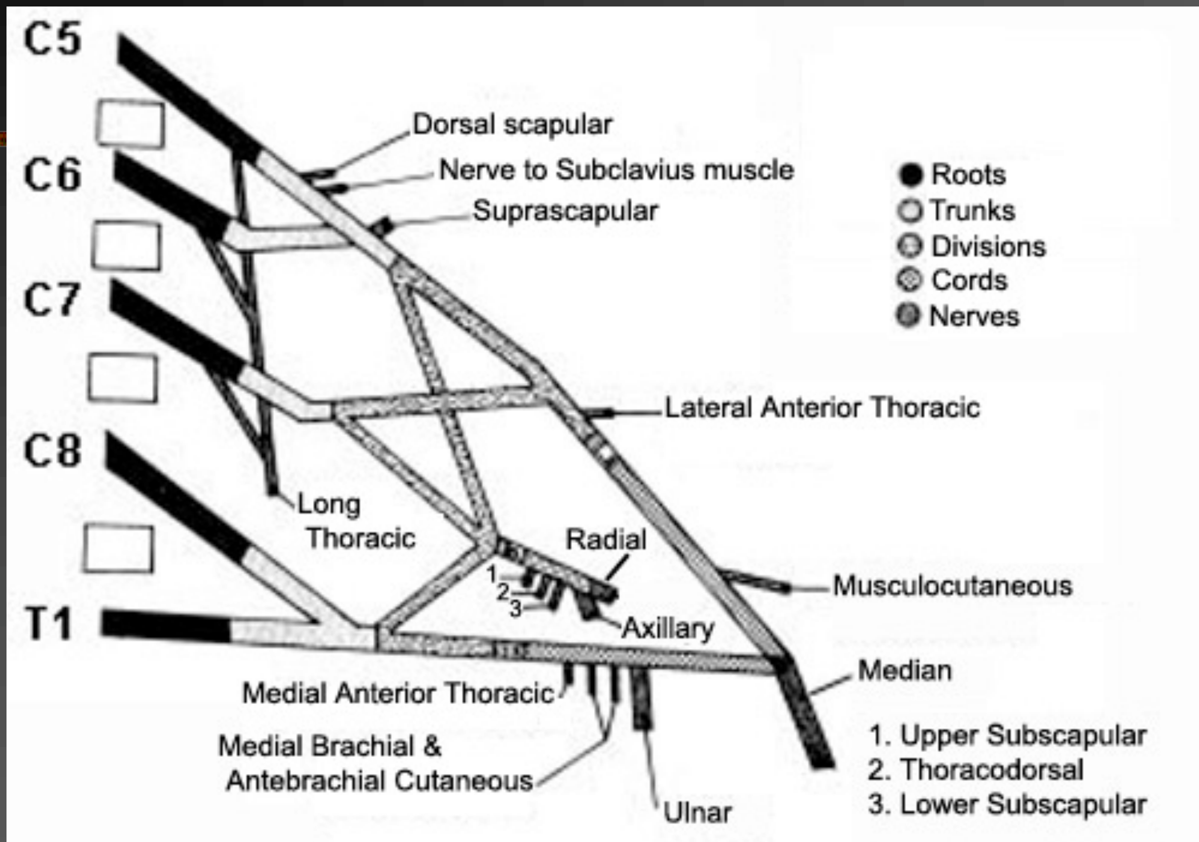
Anatomy of PNS

1. Somatic Nervous System – motor fibers to skeletal muscle, sensory fibers from skin, viscera, muscle and tendon receptors
2. Autonomic Nervous System – generally travel with nerves or vessels and control sweating and blood flow to skin and muscle

Anatomy of PNS



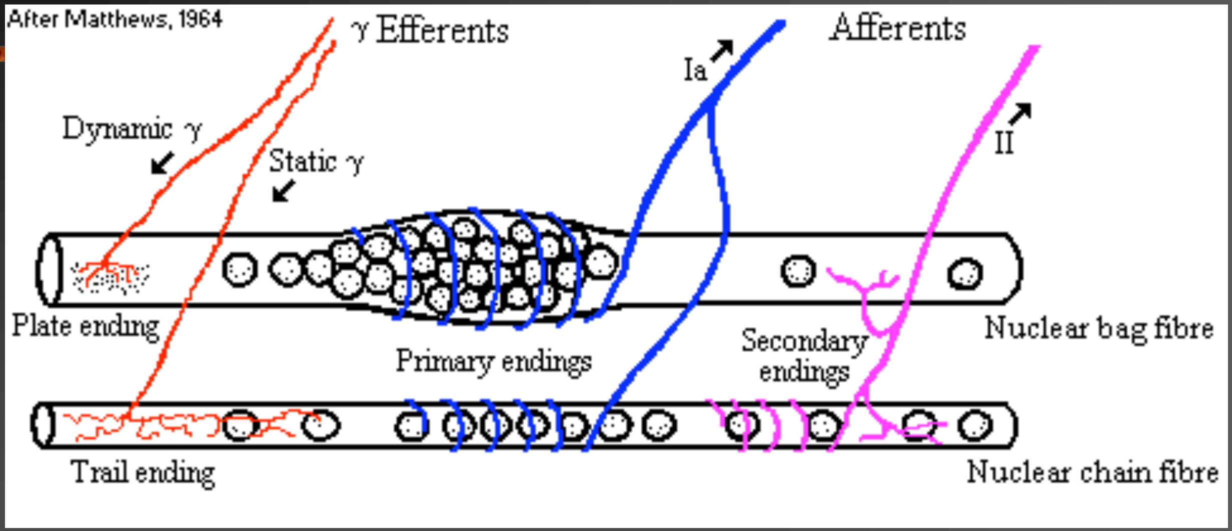



C5
C6
C7
C8
T1
Dorsal scapular
Nerve to Subclavius muscle
Suprascapular
Roots
Trunks
Divisions
Cords
Nerves
Lateral Anterior Thoracic
Long
Thoracic
Radial
Musculocutaneous
Axillary
Median
Medial Anterior Thoracic
Medial Brachial &
Antebrachial Cutaneous
Ulnar
1. Upper Subscapular
2. Thoracodorsal
3. Lower Subscapular

Classes of PNS Efferent Fibers

A – alpha	12 – 20 um	65 – 120 m/s	Extrafusal fibres
A – gamma	2 – 10 um	10 – 50 m/s	Intrafusal fibres
B	1- 5 um	4 – 26 m/s	Presynaptic auton.
C	0.2 – 0.5 um	0.2 – 2.0 m/s	Postsynaptic auton.

Muscle Afferents

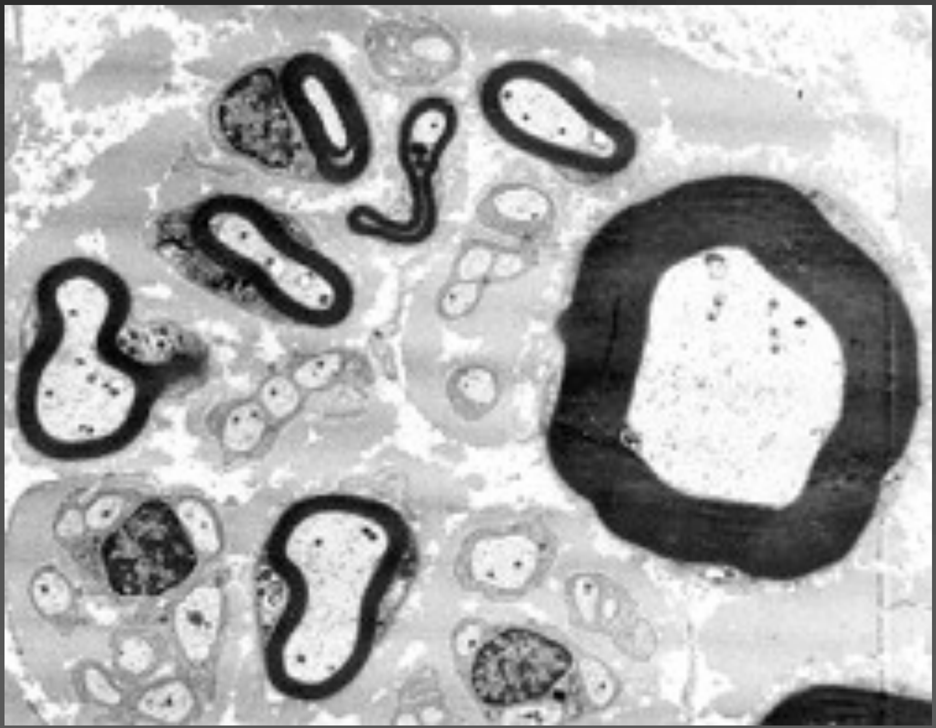


- Ia afferents – nuclear bag and nuclear chain endings
  detect length and rate of change in length
- Ib – golgi tendon organs, detect muscle tension
- II – detect muscle length, little rate sensitivity

Classes of PNS Afferents

Ia	12 – 22 um	65 – 130 m/s	muscle length and rate of change in length
Ib	12 – 22 um	65 – 130 m/s	muscle tension
II	5 – 15 um	20 – 90 m/s	muscle length
III (A-delta)	2 – 10 um	12 – 45 m/s	touch, pain, temperature free nerve endings
IV (C)	0.2 – 1.5 um	0.2 – 2.0 m/s	small pain fibers, muscle pain, visceral receptors

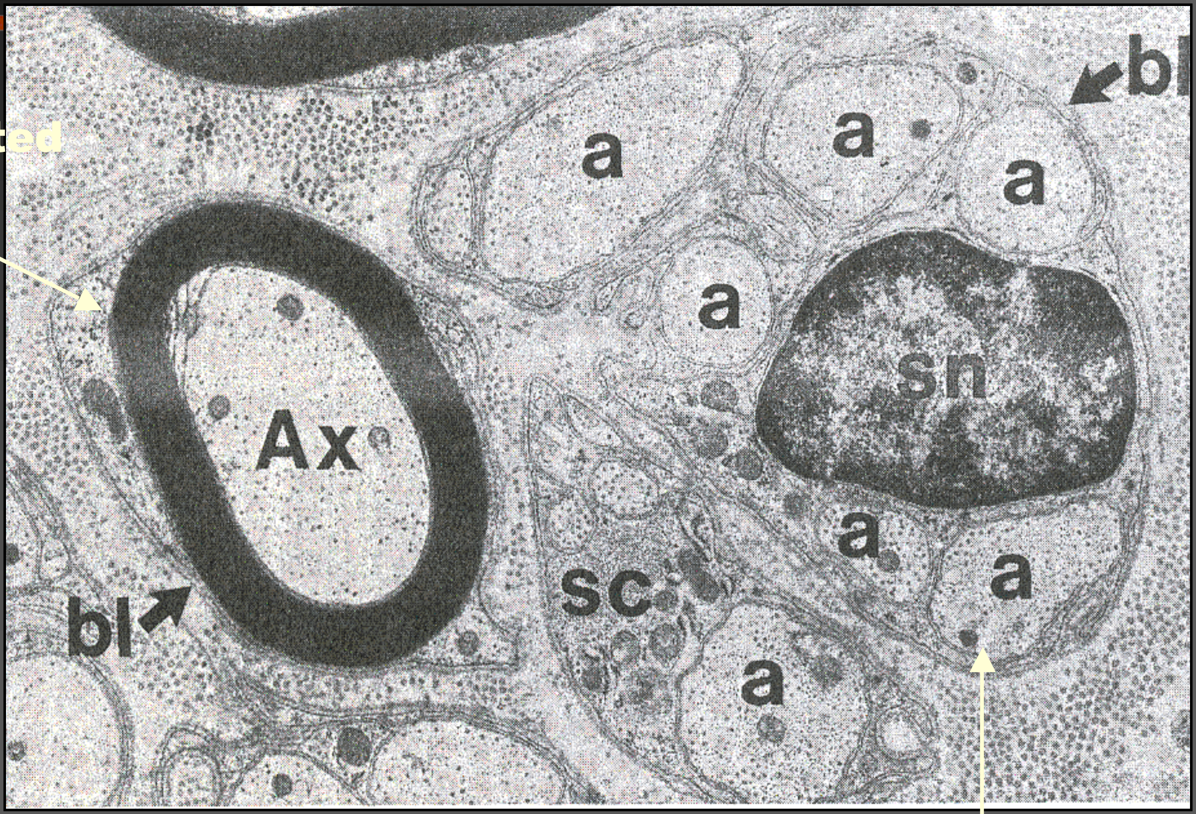
Normal Nerve



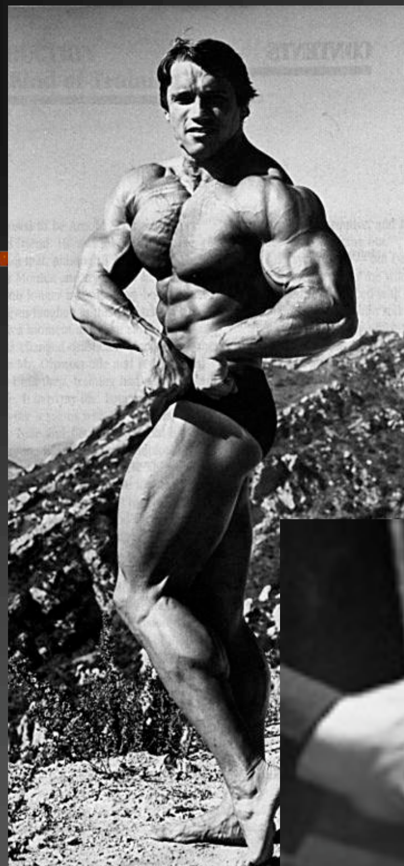
- Large myelinated axons
- Small Myelinated axons
- Unmyelinated axons

Normal nerve

Large myelinated Axon



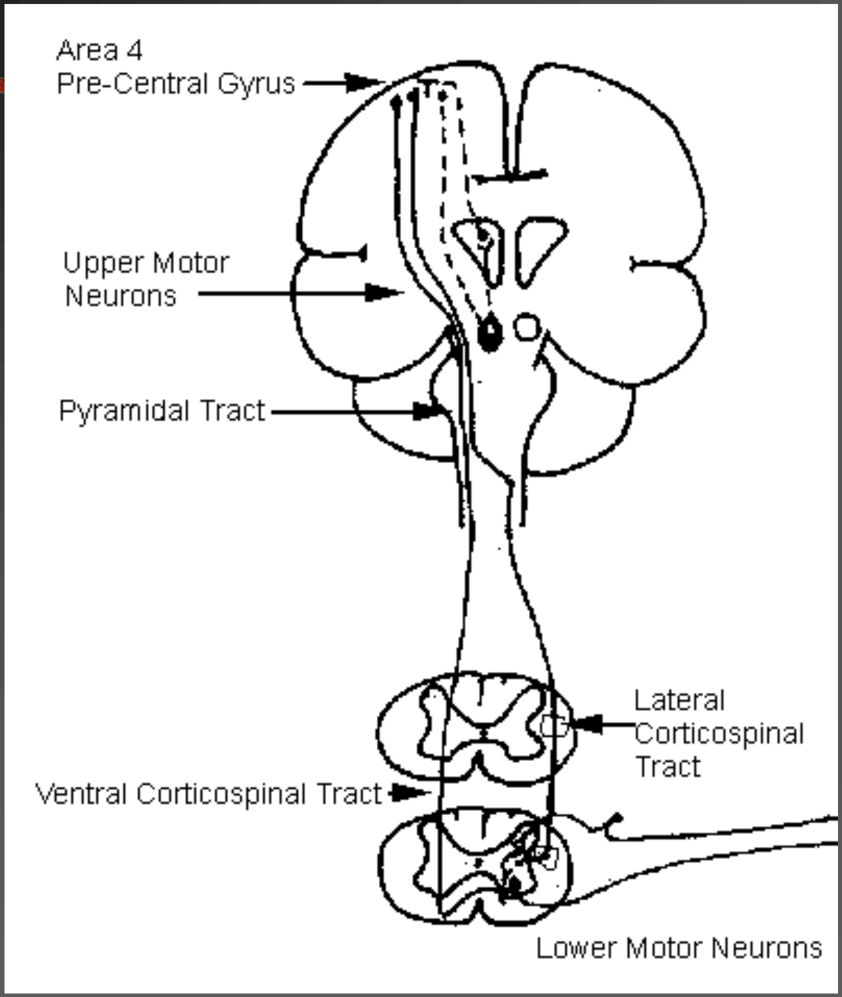
Small unmyelinated Axons




メナード
51
TERNATIONAL WOMEN'S MARATHON メナード
Raita Yamamoto

Motor system schematic

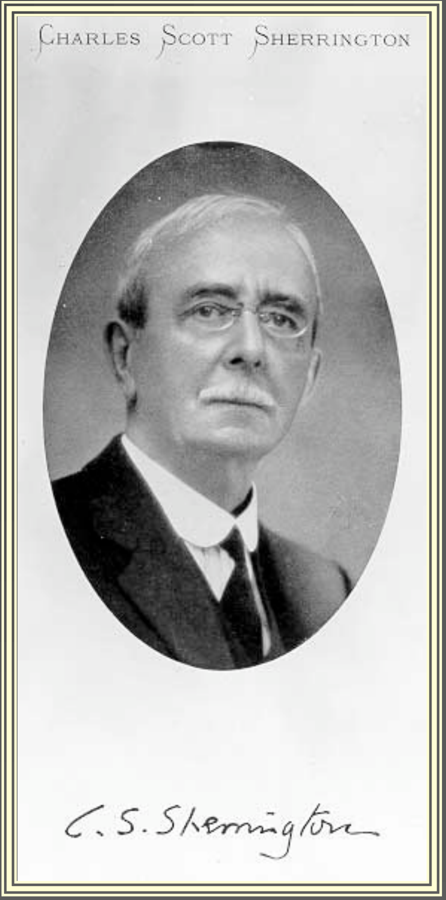
Upper MN
Cortical Neuron & Projections (Pyramidal Tract)



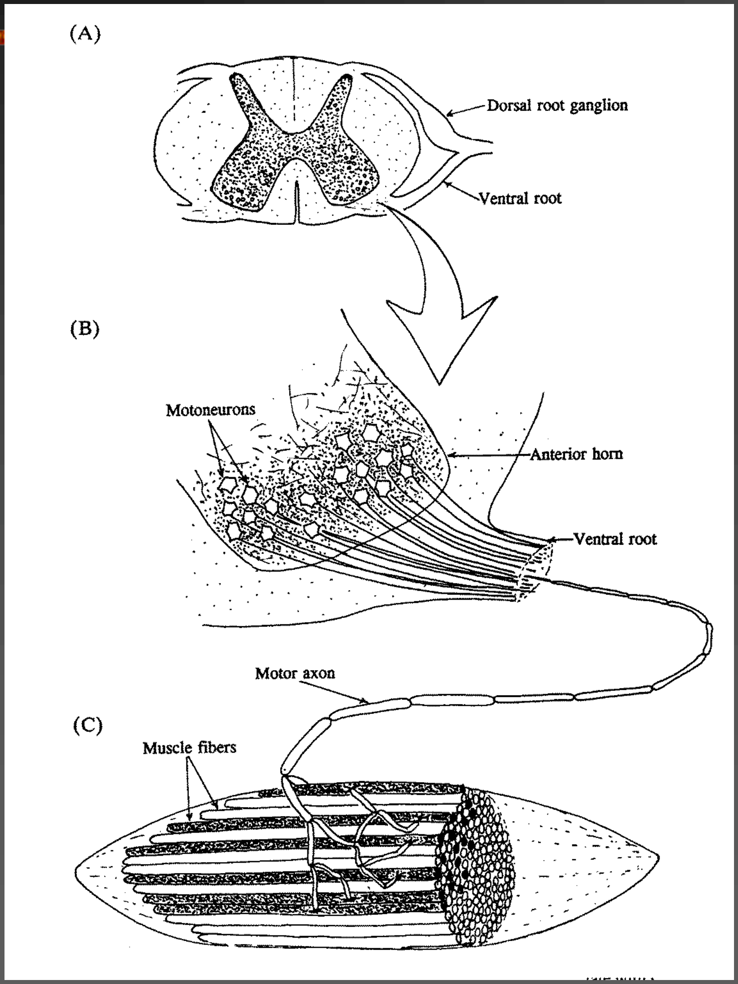
Lower MN

A little history

- Sir Charles Scott Sherrington
- Described concept of MU - reflex work on cats
- “Final common pathway” - 1929



The Motor Unit



Anterior horn cell in ventral horn of cord - lamina IX

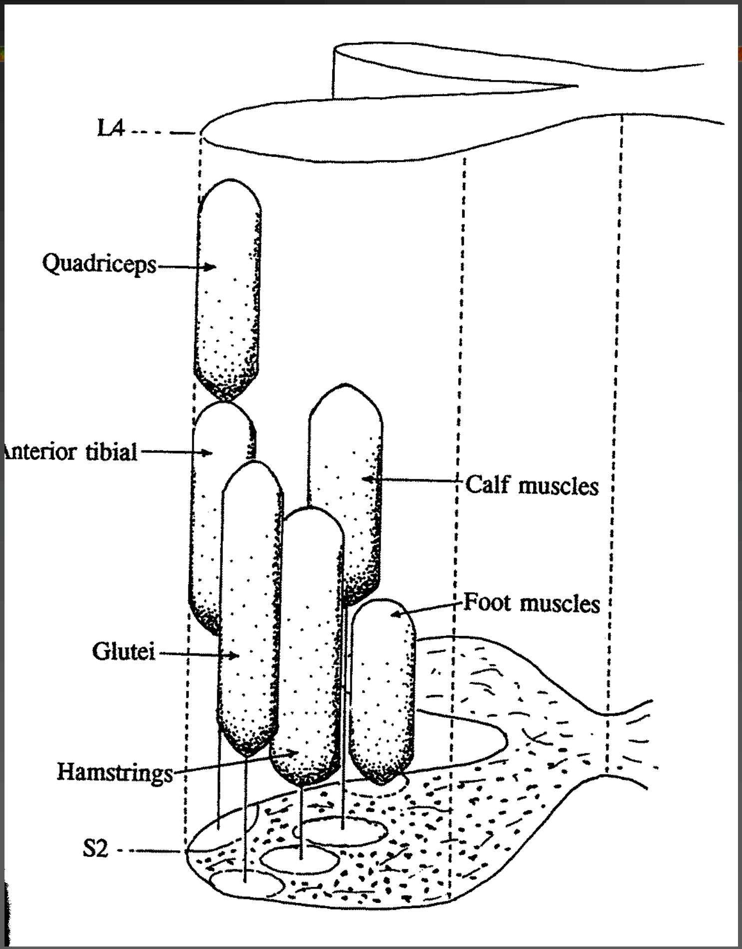
Ventral Root

Myelinated Axon

Neuromuscular Junction

Muscle Fibers

MU Organization

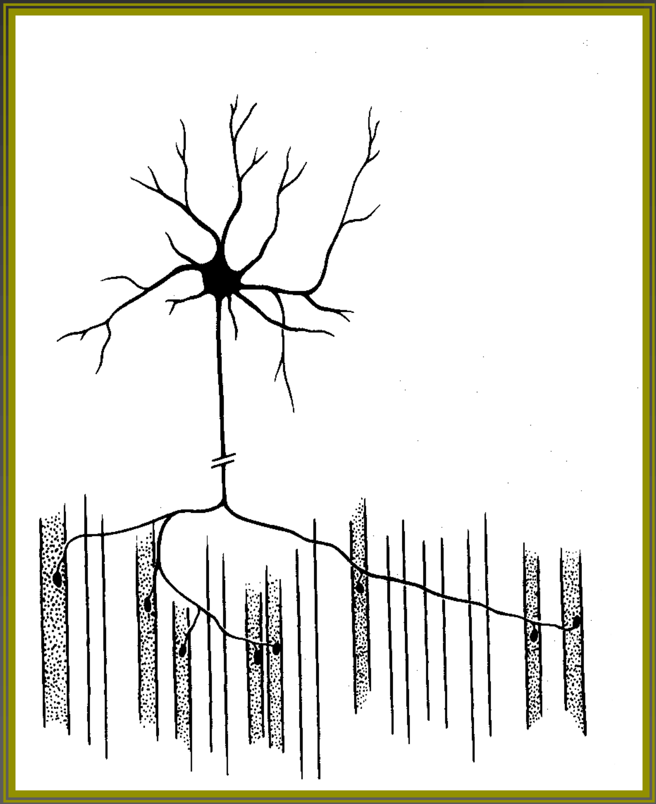


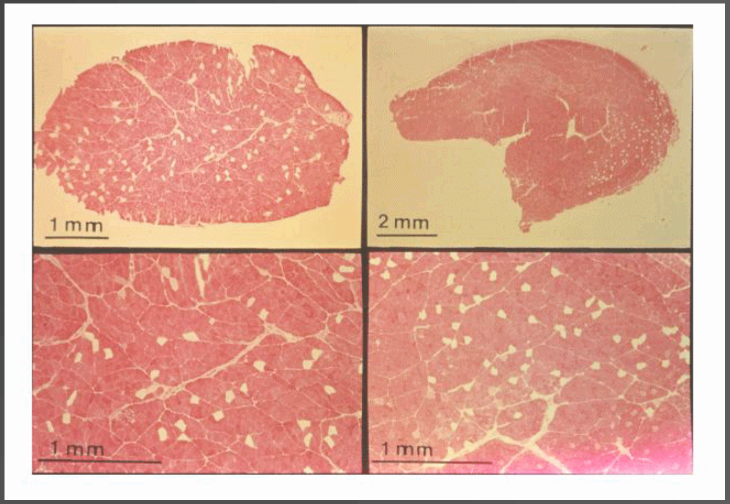
MUs arranged in columns

All muscles receive innervation from multiple columns (levels or "myotomes")

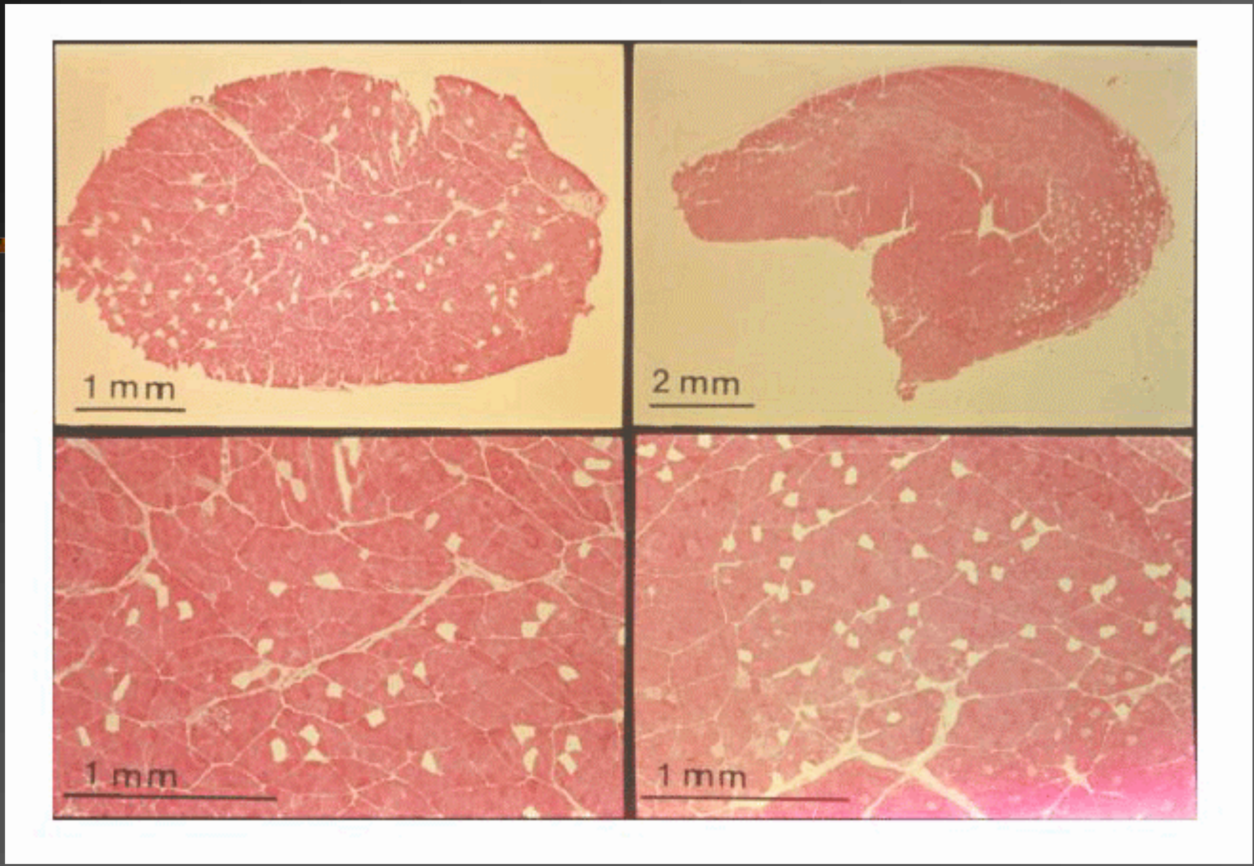
Quads: L2, L3, L4
Biceps: C5, C6
TA: L4, L5

The MU Territory

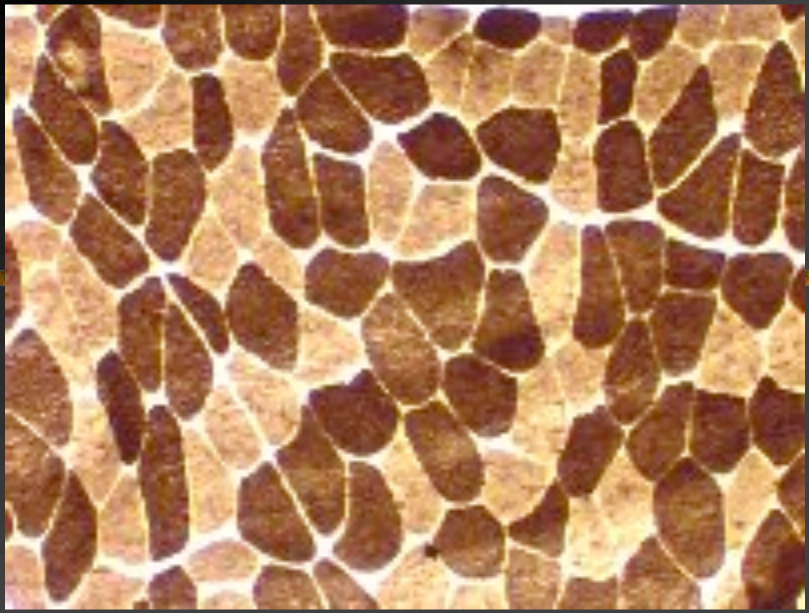




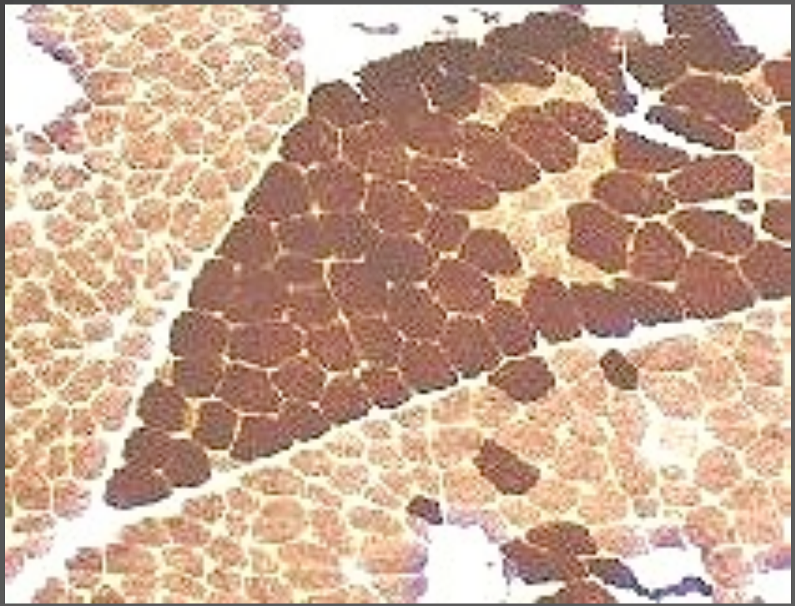
8 – 10 mm in human biceps from EMG studies



Glycogen depletion technique

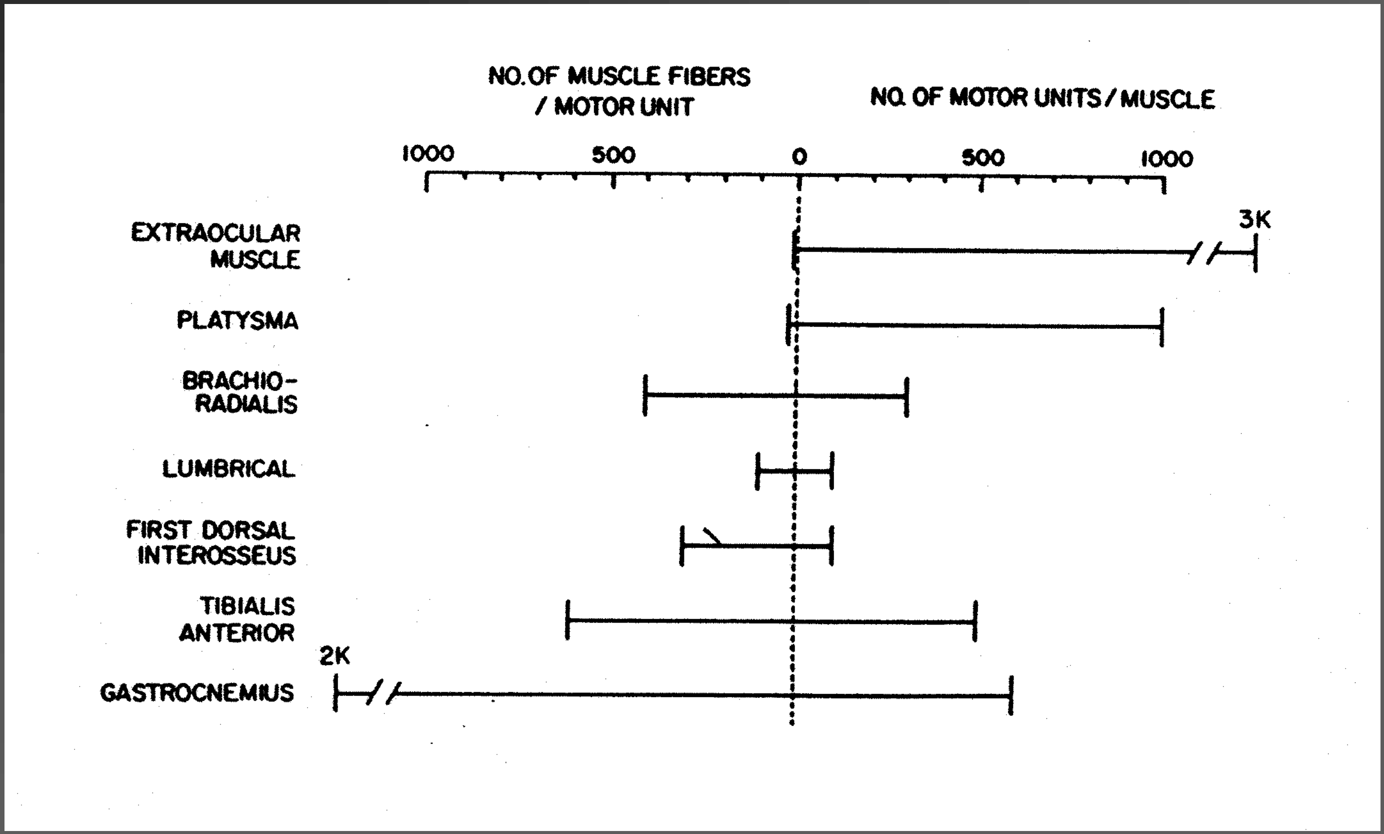


Normal
Myosin ATPase



Fibre Type Grouping

MU Numbers & Innervation Ratios

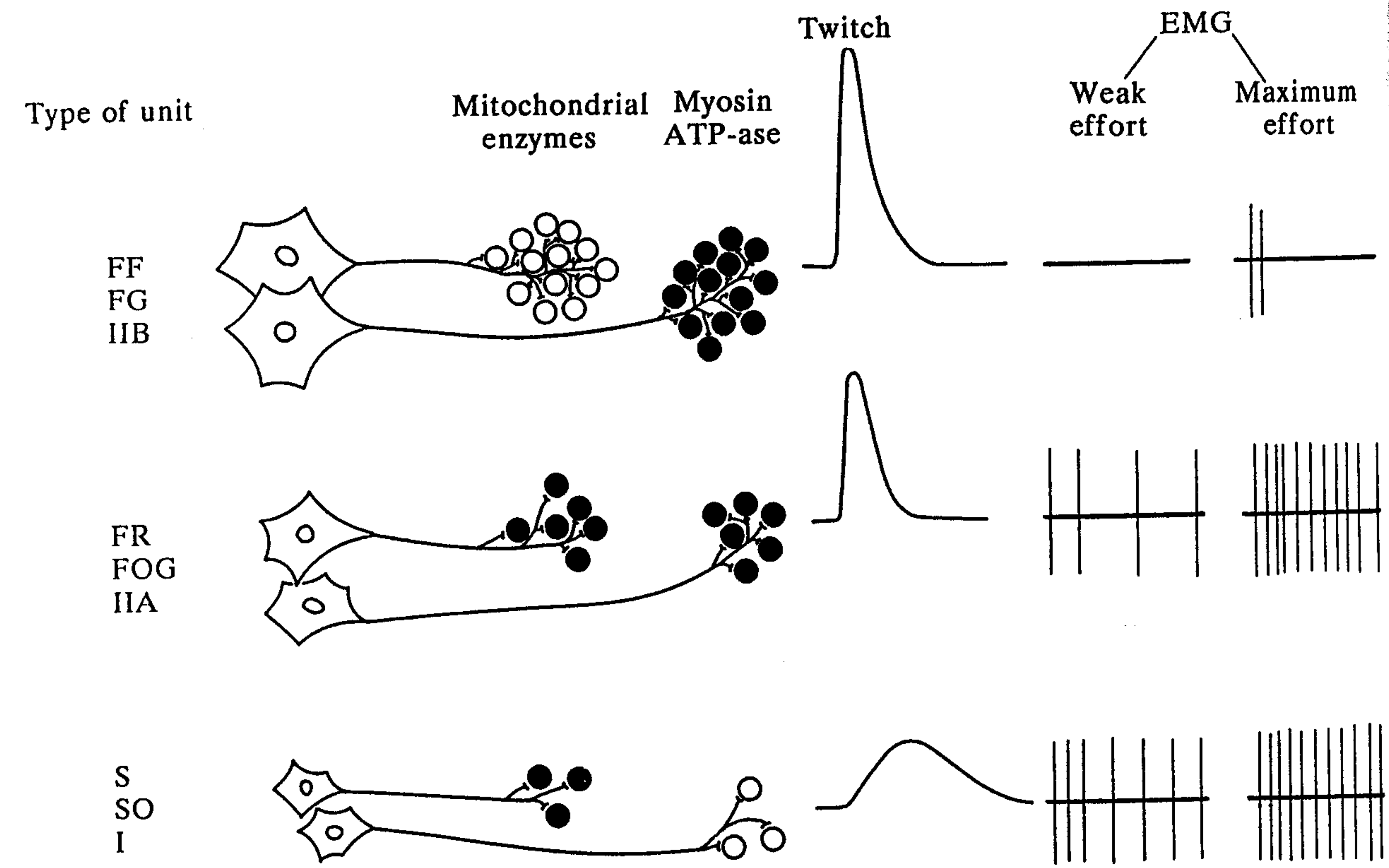


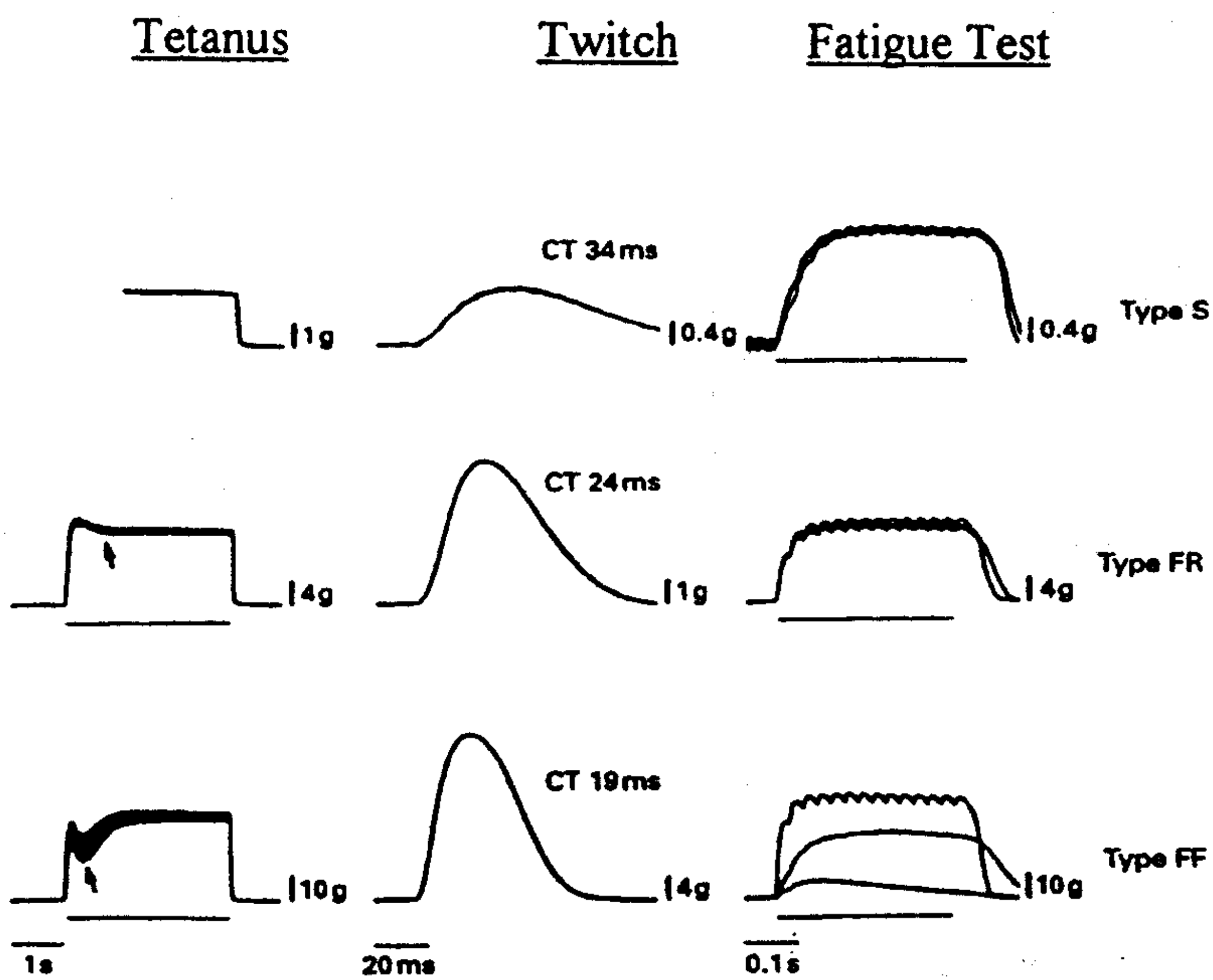
Functional Organization of MUs

- MUs are also organized into functional groups within a given muscle
- E.g. in the biceps supination MUs are grouped, and flexor MUs are grouped
- This allows for more efficient force generation and smoother motor control

MU Types

- MUs are often classified into different types
- Classification system is dependant on whether physiologic, histochemical, or biochemical features are measured
- In general MUs are either slow and fatigue resistant or vice versa

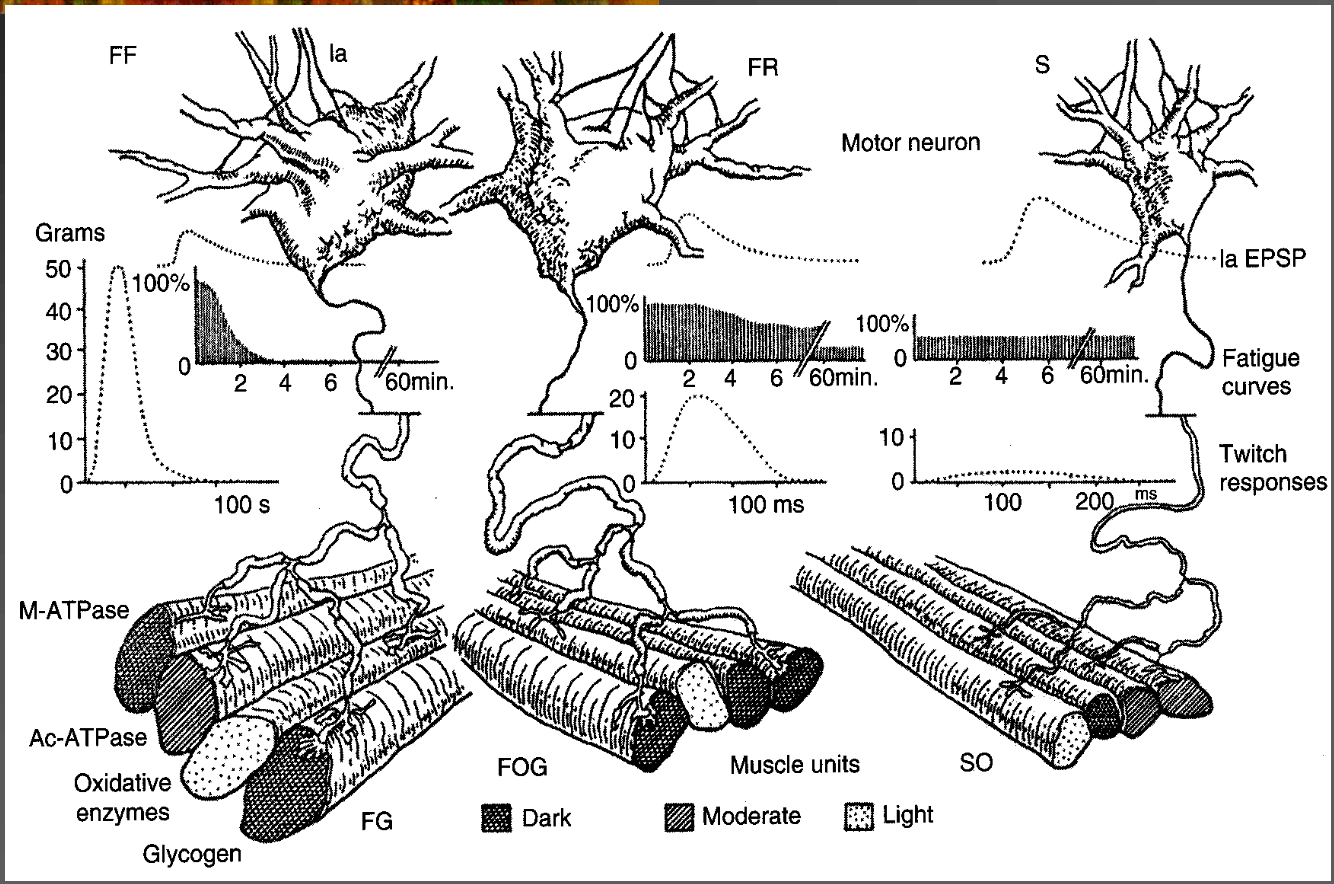

Type of unit
Mitochondrial enzymes
Myosin ATP-ase
Twitch
EMG
Weak effort
Maximum effort
FF
FG
IIB
FR
FOG
IIA
S
SO
I


Tetanus
Twitch
Fatigue Test
CT 34 ms
1 g
0.4 g
0.4 g
Type S
CT 24 ms
4 g
1 g
4 g
Type FR
CT 19 ms
10 g
4 g
10 g
Type FF
1 s
20 ms
0.1 s

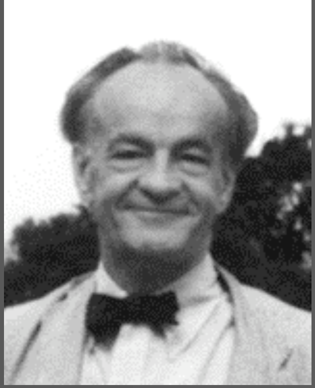
Motor Unit Types

	I	IIA	IIB
	S	FR	FF
	SO	FOG	FG
Twitch CT	Slow	Fast	Fast
Twitch Force	Small	Intermediate	High
Fatigue	Low	Low	High
Myoglobin	High	High	Low
Capillary Supply	High	High	Low
Mitochondria	Many	Many	Few
Glycogen	Low	High	High
Oxidative Enzymes	High	High	Low
Glycolytic Enzymes	Low	High	High
MN cell body	Small	Moderate	Large
AHP	Long	Moderate	Short
	Marathon	1500m	Max Jump 100 m

MU Types


FF
Ia
FR
S
Motor neuron
Grams
50
40
30
20
10
0
100 s
100%
0
2
4
6
60min.
Ia EPSP
100%
0
2
4
6
60min.
100%
0
2
4
6
60min.
Fatigue curves
20
10
0
100 ms
10
0
100
200
ms
Twitch responses
M-ATPase
Ac-ATPase
Oxidative enzymes
Glycogen
FG
FOG
Muscle units
SO
Dark
Moderate
Light

MU Recruitment - Size Principle Henneman 1957



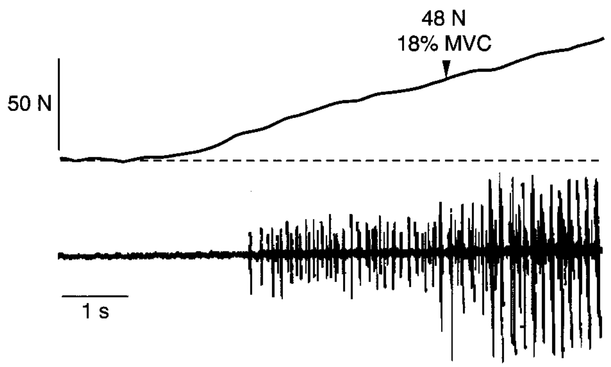


FIGURE 3.7 Recording of motor unit potentials in a human subject during a ramp force generated by the plantarflexors. Larger action potentials appear at selected levels of torque, representing the force threshold for that motor unit. Each action potential generated by a given motor unit will have a similar amplitude and shape. Only the amplitudes can be differentiated in this graph because of the slow time scale in plotting the graph. *(Unpublished observation, V.R. Edgerton)*

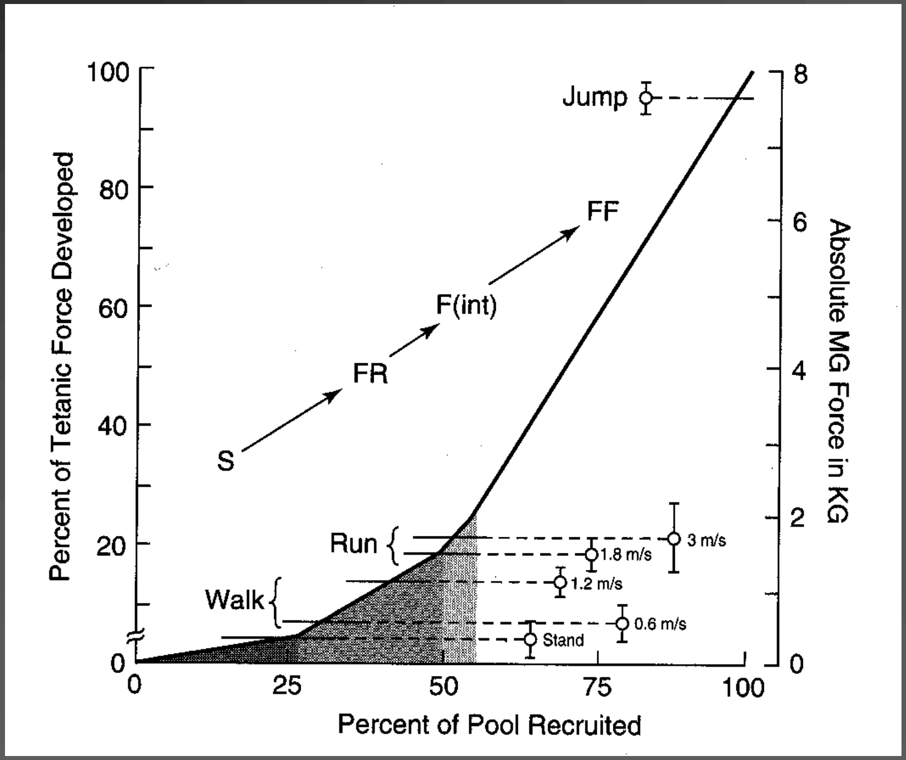
Henneman

- Excitatory Input (IA afferents)
- Size of intracellular spike recording from motor neuron
- Axonal CVs

Mainly in unanaesthetized decerebrate cats

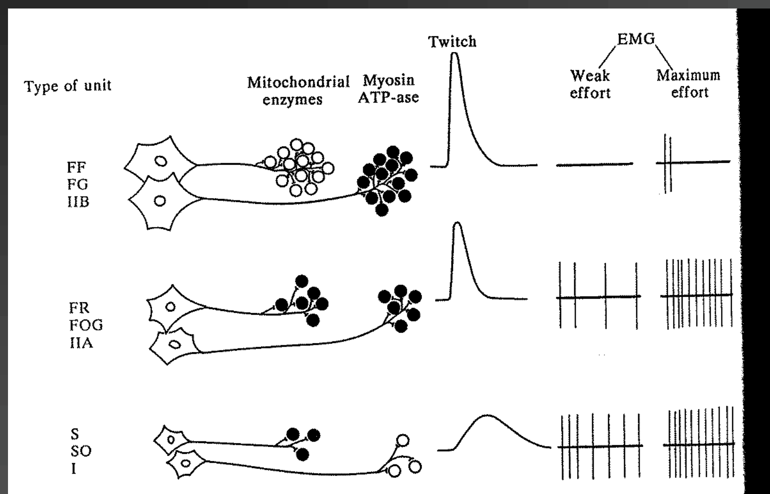
Denny-Brown 1930's

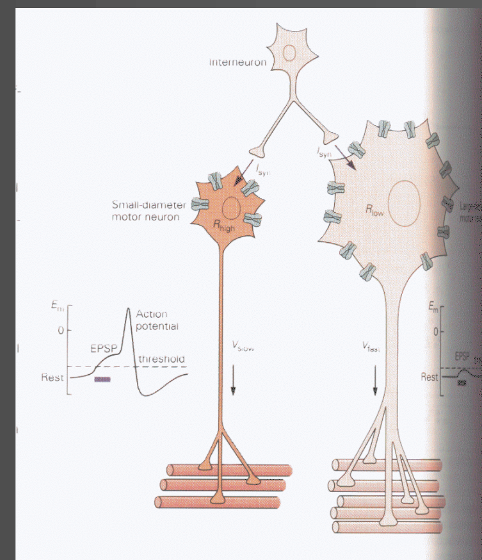
Size Principle



Size Principle

Excitation



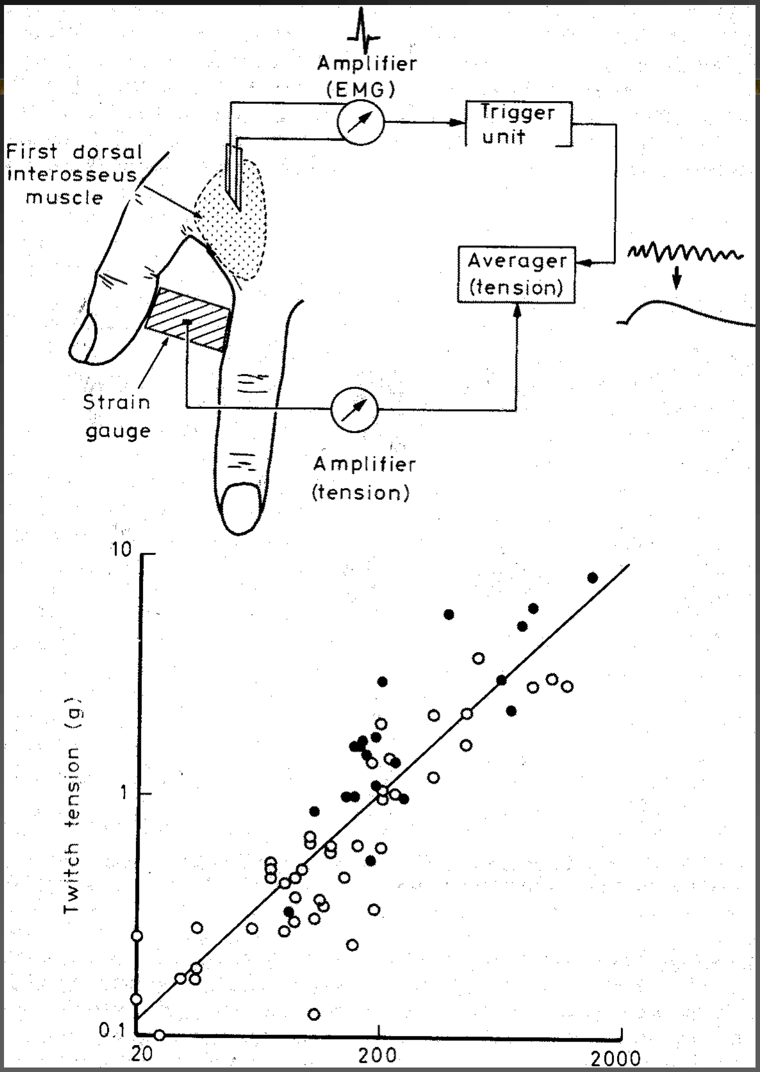


V = I x R (Ohm's law)

Voltage of EPSP = current x resistance

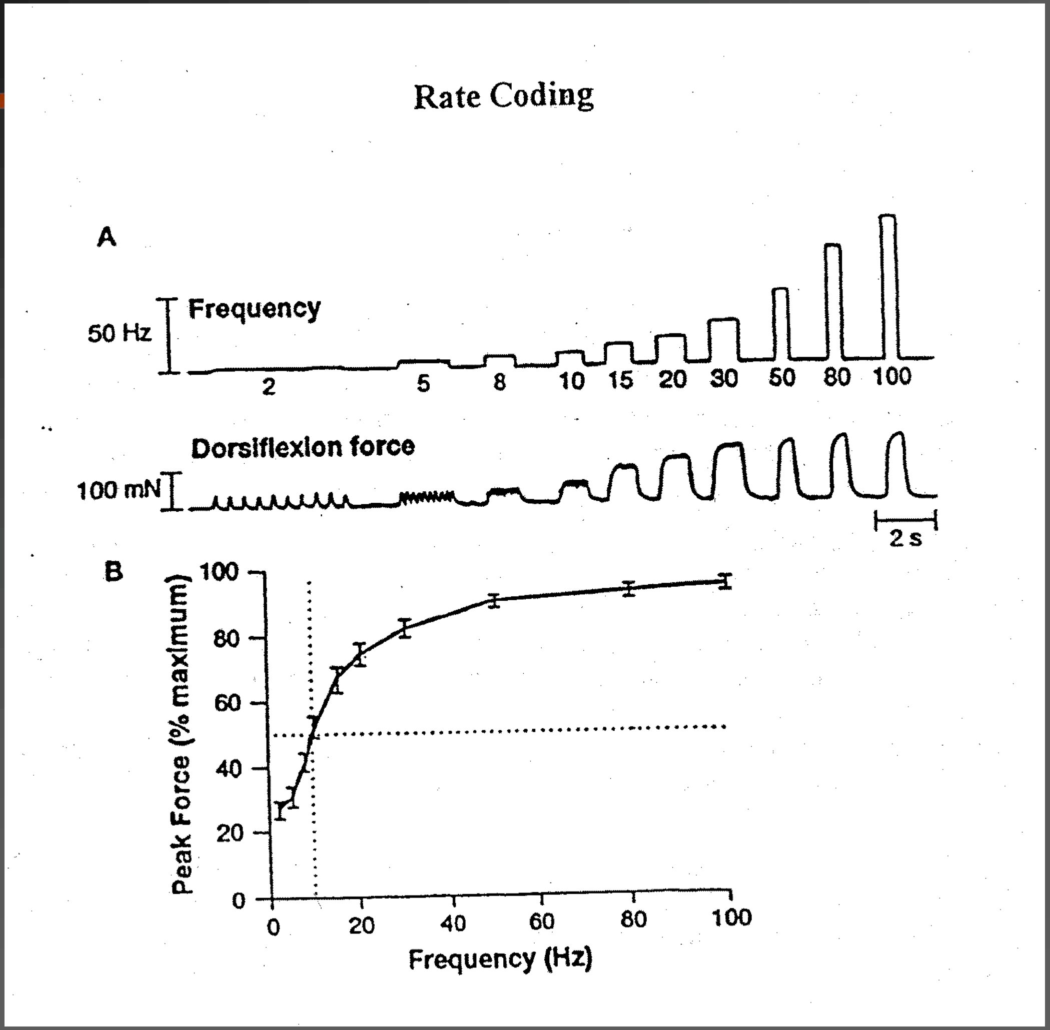
The smaller the neuron, the larger the resistance due to the increased channel density

Size Principle - Human



MUs with smaller twitch tensions and slower contraction times are recruited before larger, faster MUs

Rate Coding



Rate Coding
A
50 Hz
Frequency
2
5
8
10
15
20
30
50
80
100
Dorsiflexion force
100 mN
2 s
B
Peak Force (% maximum)
100
80
60
40
20
0
0
20
40
60
80
100
Frequency (Hz)

MU Firing Frequencies

- Onset 5-7 Hz
- Min. sustained 8 – 10 Hz
- Maximum 20 – 40 Hz

Recruitmet patterns of MUs

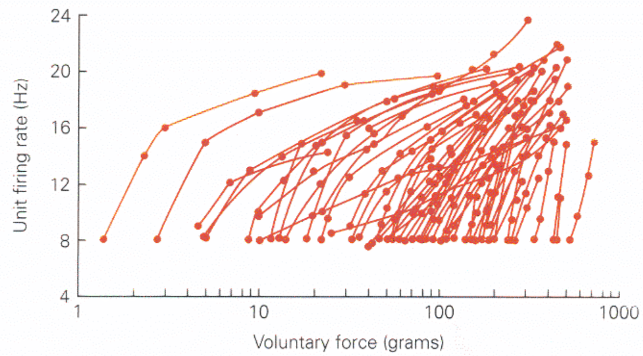


Figure 34-12 **For motor tasks that require a slow increase in force, motor units are gradually recruited one at a time and their firing frequency is increased progressively.** Units fire at about 8 Hz when first recruited and their firing rate increases as the load on the muscle increases. The record here is from the extensor digitorum communis of a human subject. (Adapted from Monster and Chan 1977.)

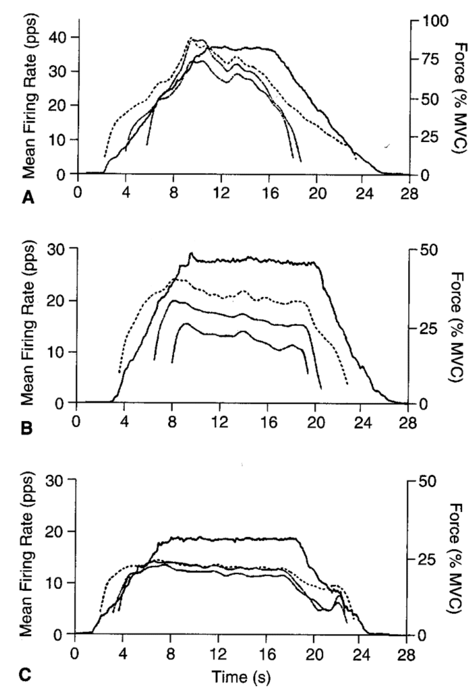


FIGURE 3.9 Examples of firing rates of motor units in tibialis anterior during isometric dorsiflexion of the ankle at (A) 80%, (B) 50%, and (C) 30% of maximum voluntary contraction (MVC). The force record (showing plateau) is the thick line. The other three lines show mean firing rates of detected motor units. Firing rates decrease throughout the constant-force interval at all force levels. *(Reprinted with permission from de Luca CJ, Foley PJ, Erim Z. Motor unit control properties in constant-force isometric contractions. J Neurophysiol 1996;76:1503–1516.)*

Recruitment - decruitment

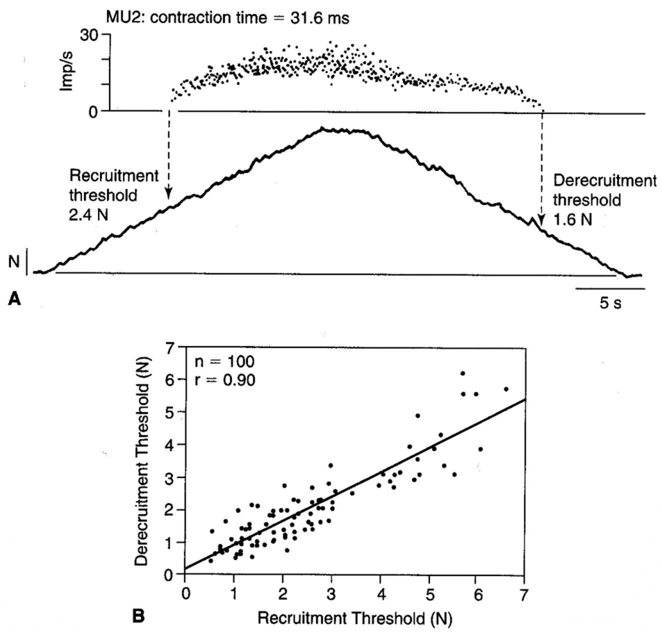
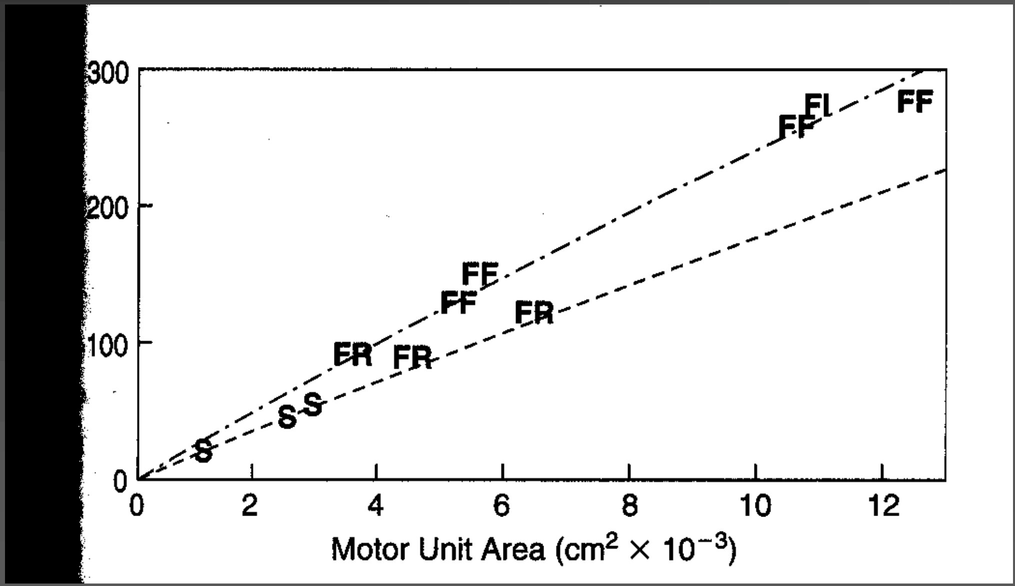


FIGURE 3.8 **A.** Recruitment and derecruitment of a motor unit in the extensor carpi radialis of human subjects during isometric imposed-ramp contraction and relaxation. Derecruitment threshold is lower than recruitment threshold. **B.** Relationship between recruitment and derecruitment thresholds for 20 extensor carpi radialis motor units. Again, the derecruitment threshold is systematically lower than the recruitment threshold. *(Modified from Romaiguere P, Vedel JP, Pagni S. Comparison of fluctuations of motor unit recruitment and de-recruitment thresholds in man. Exp Brain Res 1993;95:517–522.)*

Overall force production

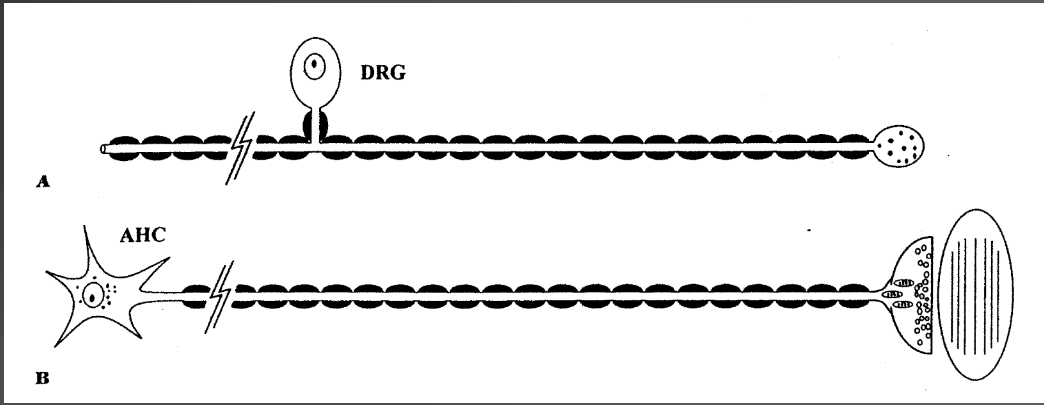


Is the recruitment order fixed?

- Are ST units always recruited before FT?
- Cutaneous vibratory stimuli can lower the threshold of FT MUs and raise the threshold of ST MUs (Garnett and Stephens, 1980)
- Varying the task changes the relative recruitment threshold of MUs in a given muscle - eg. biceps supination vx flexion
- Selective activation of FT MUs has been shown in the cat, not consistently in humans

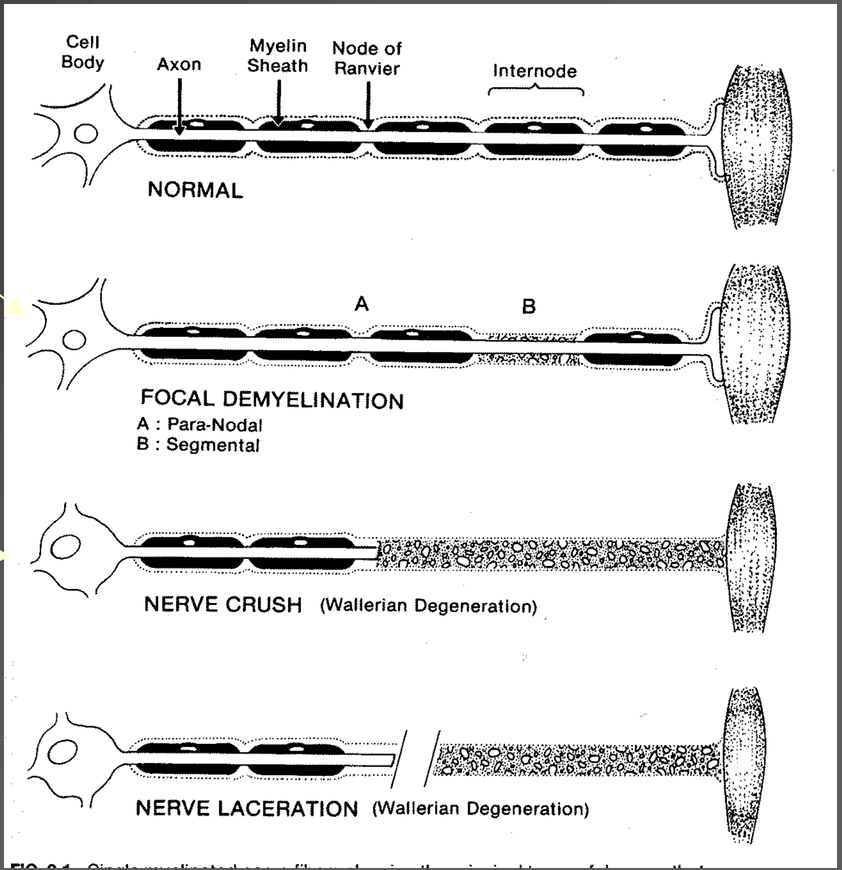
Motor Unit Injury

- Motor neuron
  - ALS
- Axon
  - Trauma
- Myelin
  - Compression injury
- Neuromuscular junction
  - Myasthenia
- Muscle
  - Muscular dystrophy

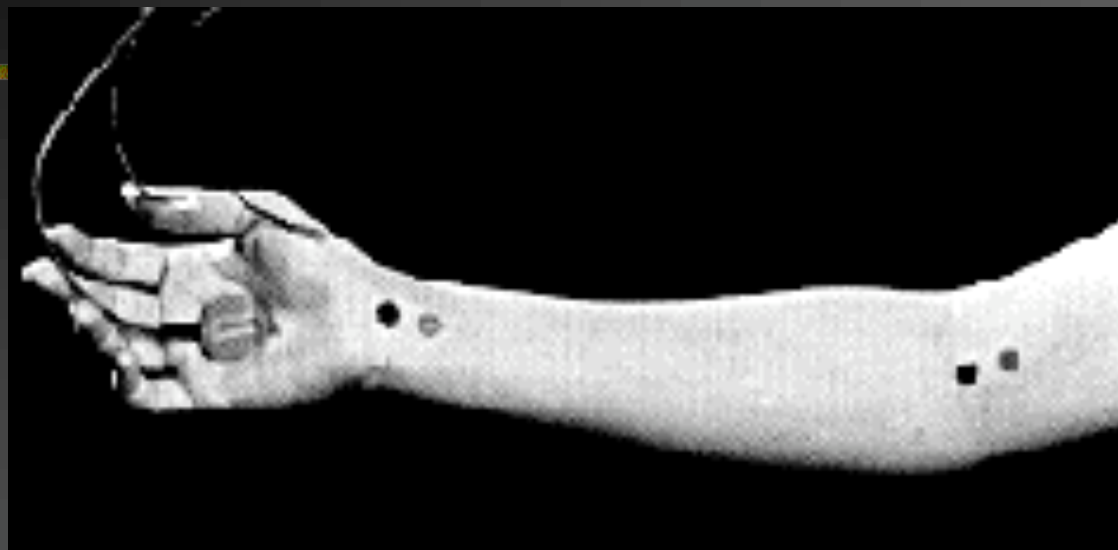


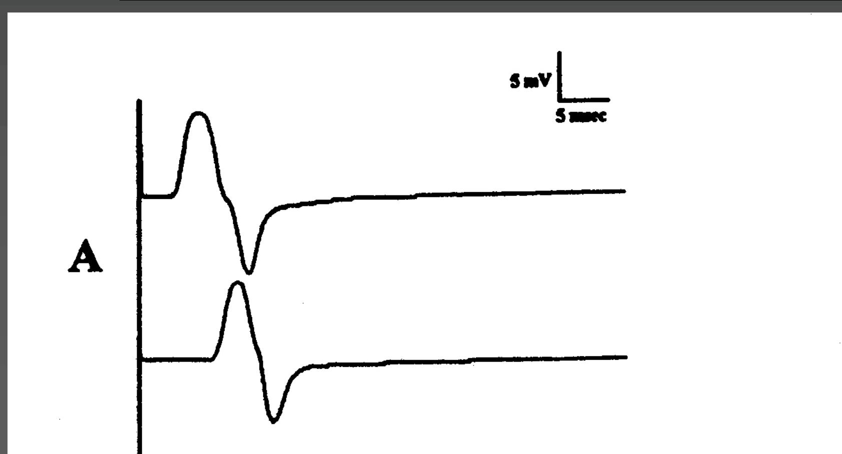
Motor Nerve Injury

- Neurapraxia
  - focal myelin injury
  - conduction block
- Axonotmesis
  - axonal injury
  - conduction block
  - denervation
- Neurotmesis
  - injury to axon and supporting connective tissue



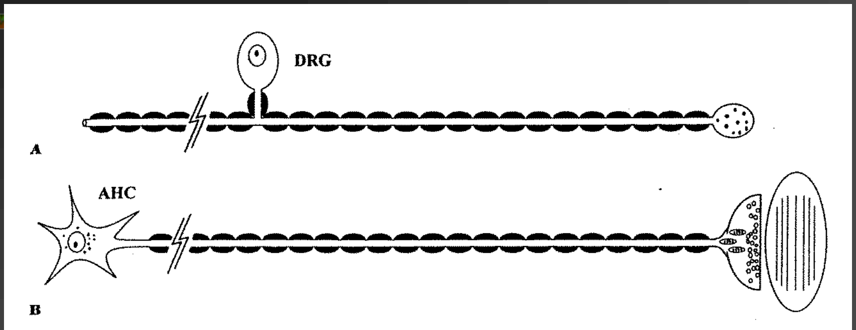
Electrodiagnosis - Nerve Conduction Studies

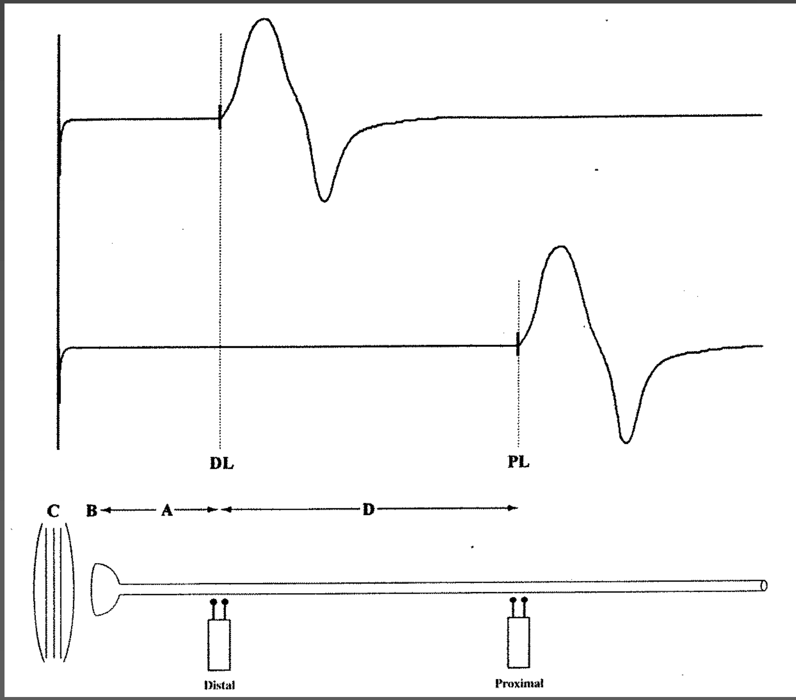


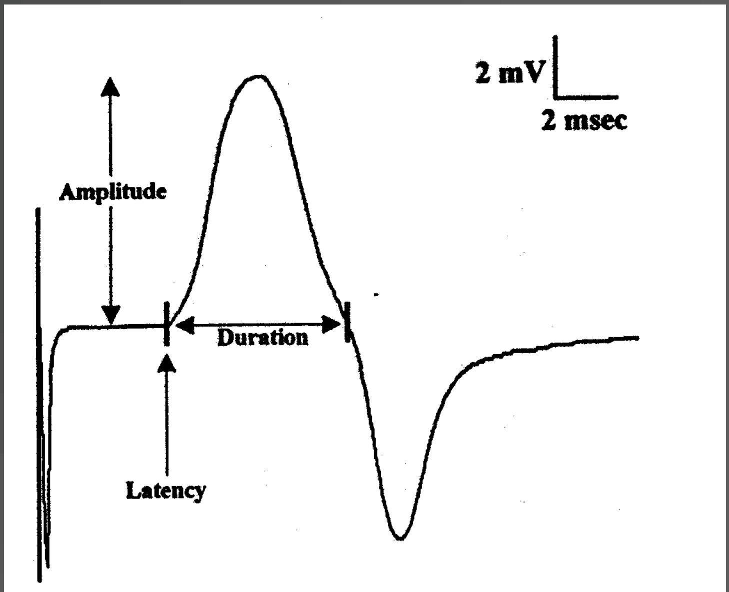


M-potential size
Motor nerve CV

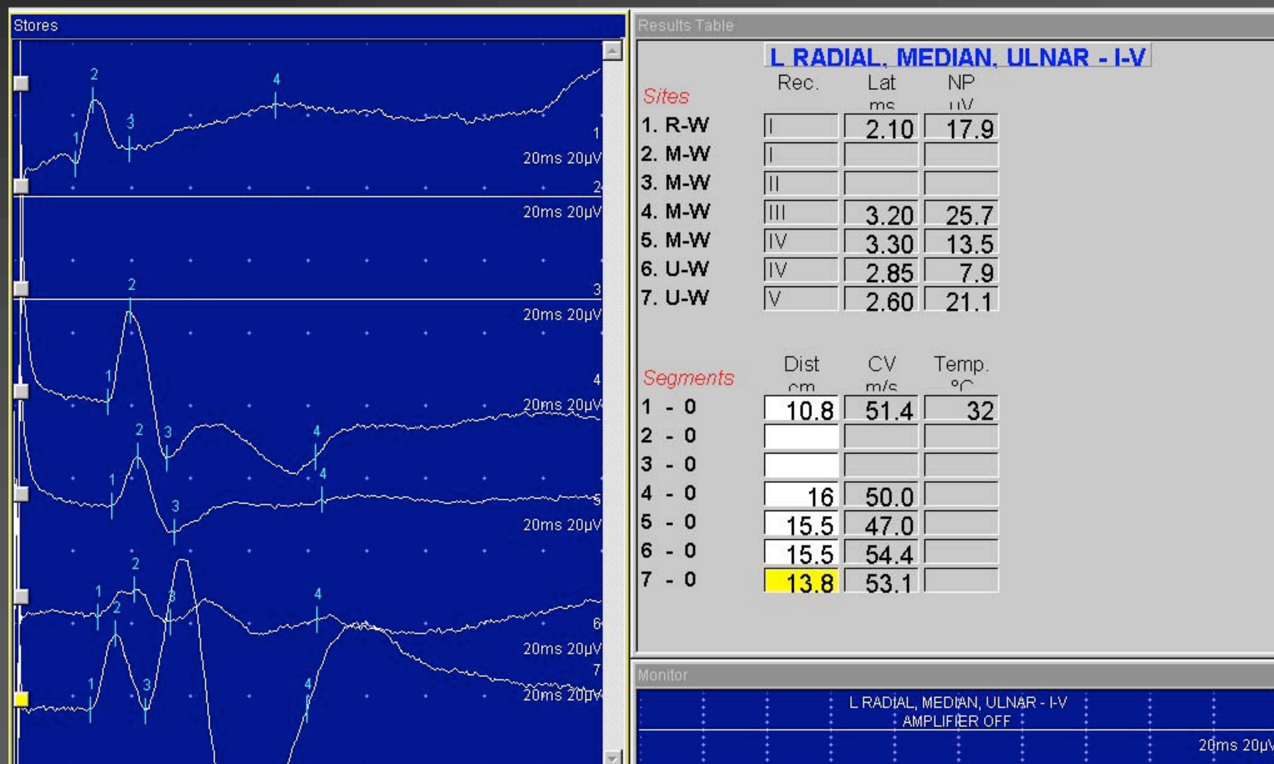
Motor nerve conduction studies



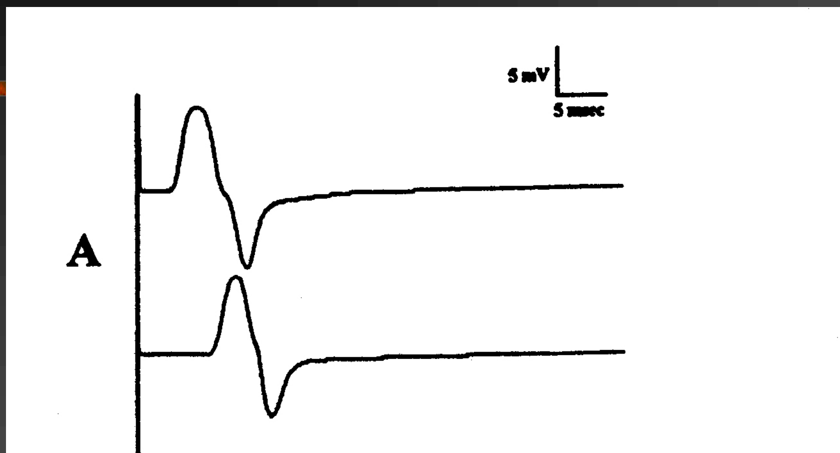




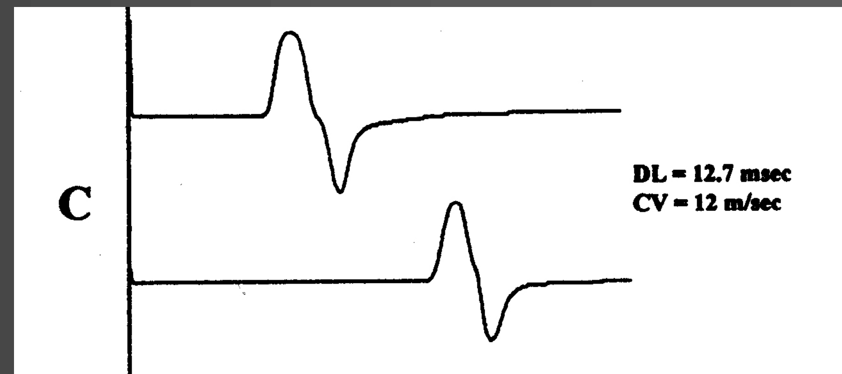
Sensory Nerve CS



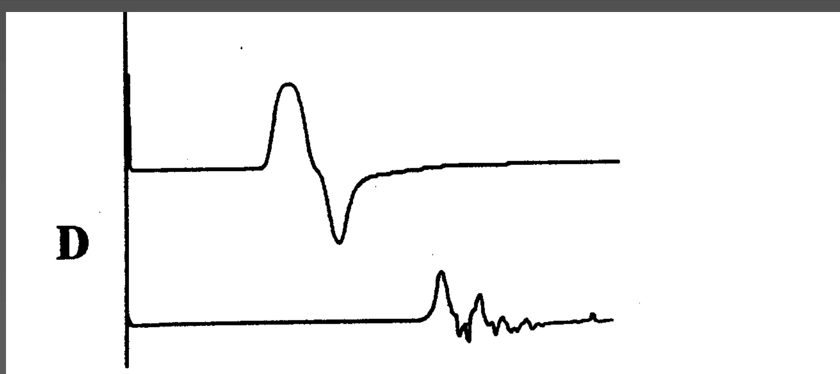
Electrodiagnosis in nerve injury



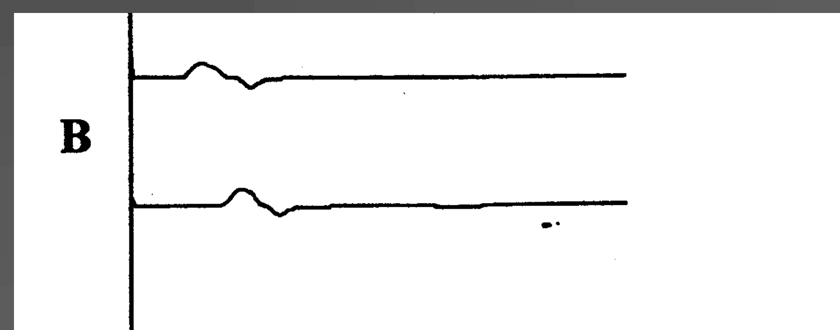
Normal



Generalized myelin injury

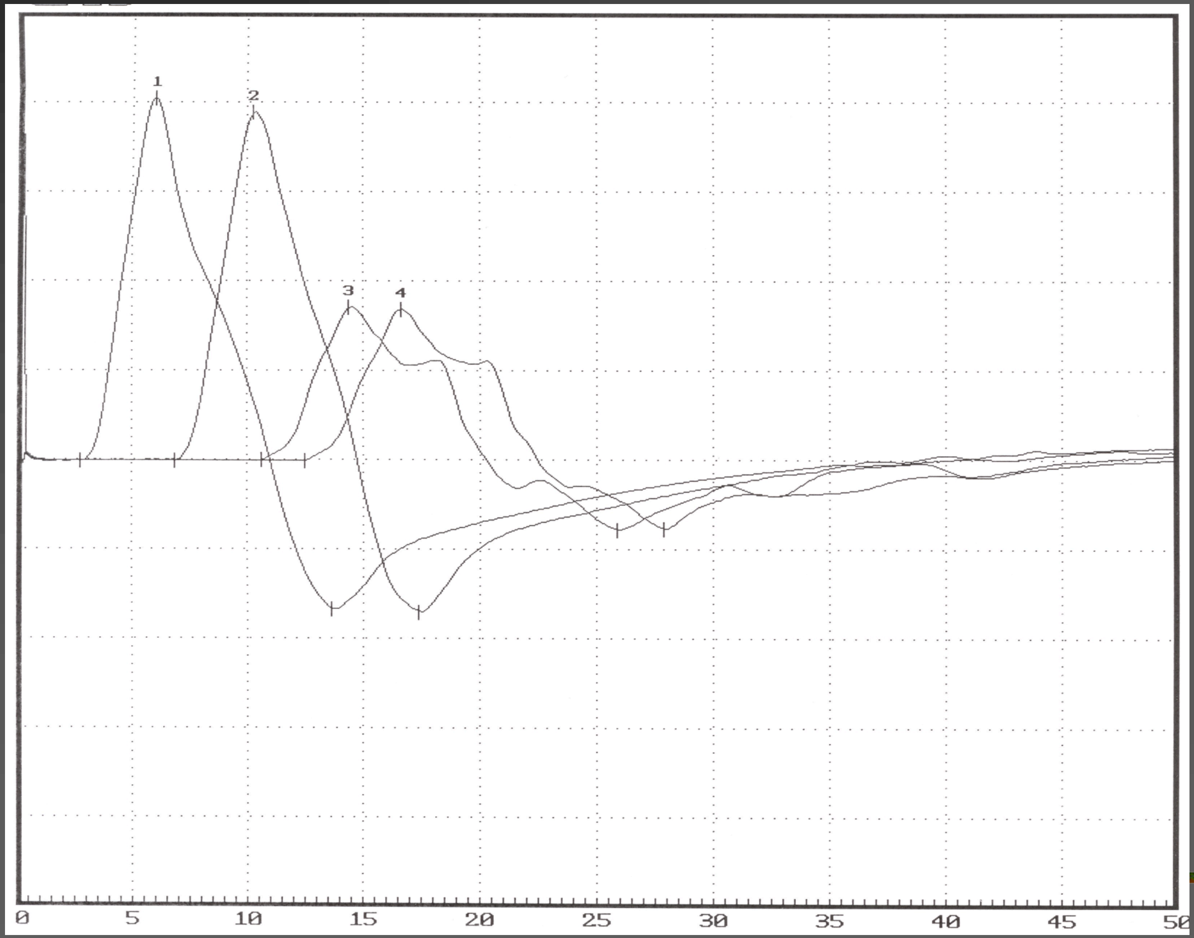


Focal Demyelination



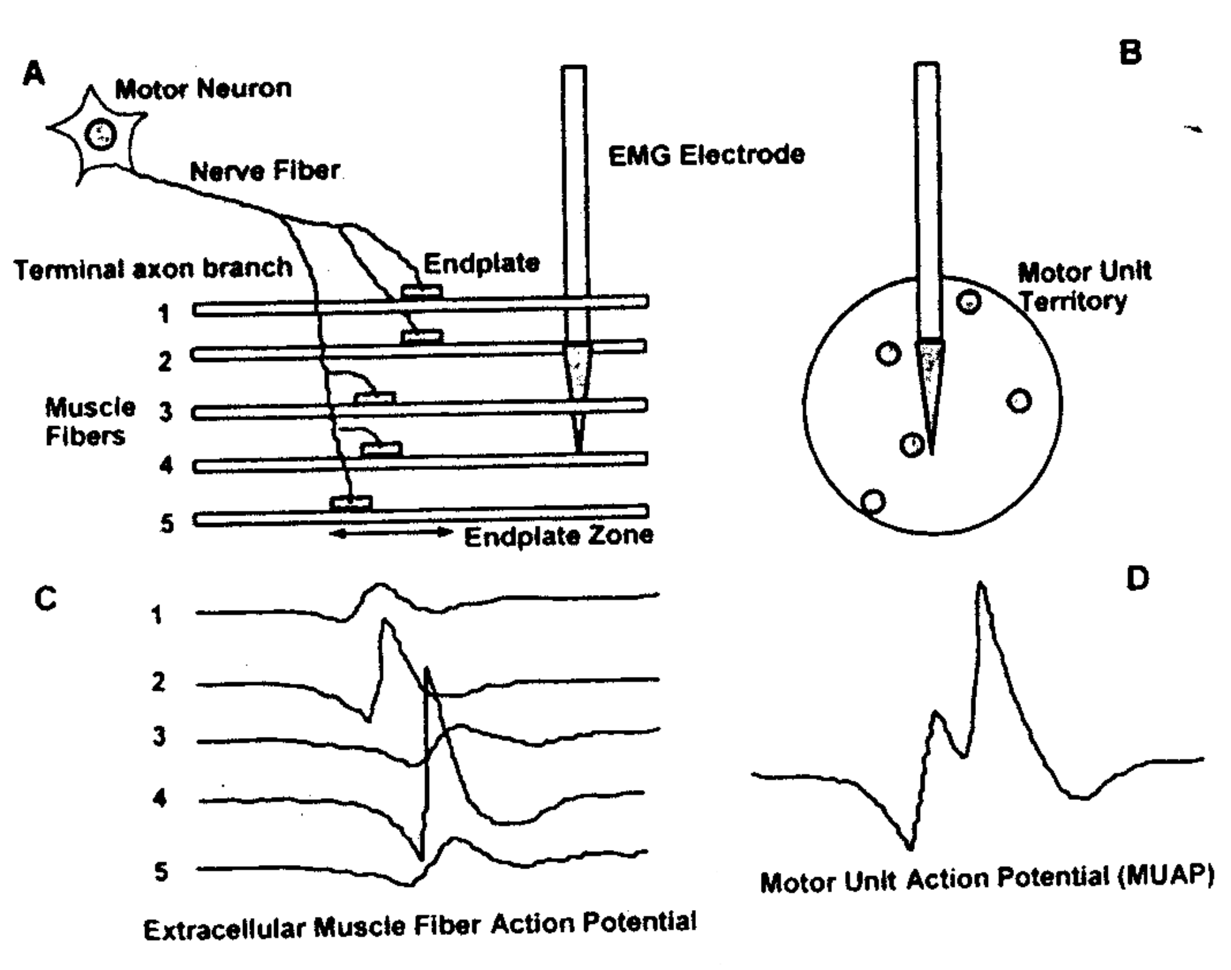
Axonal loss

Conduction block

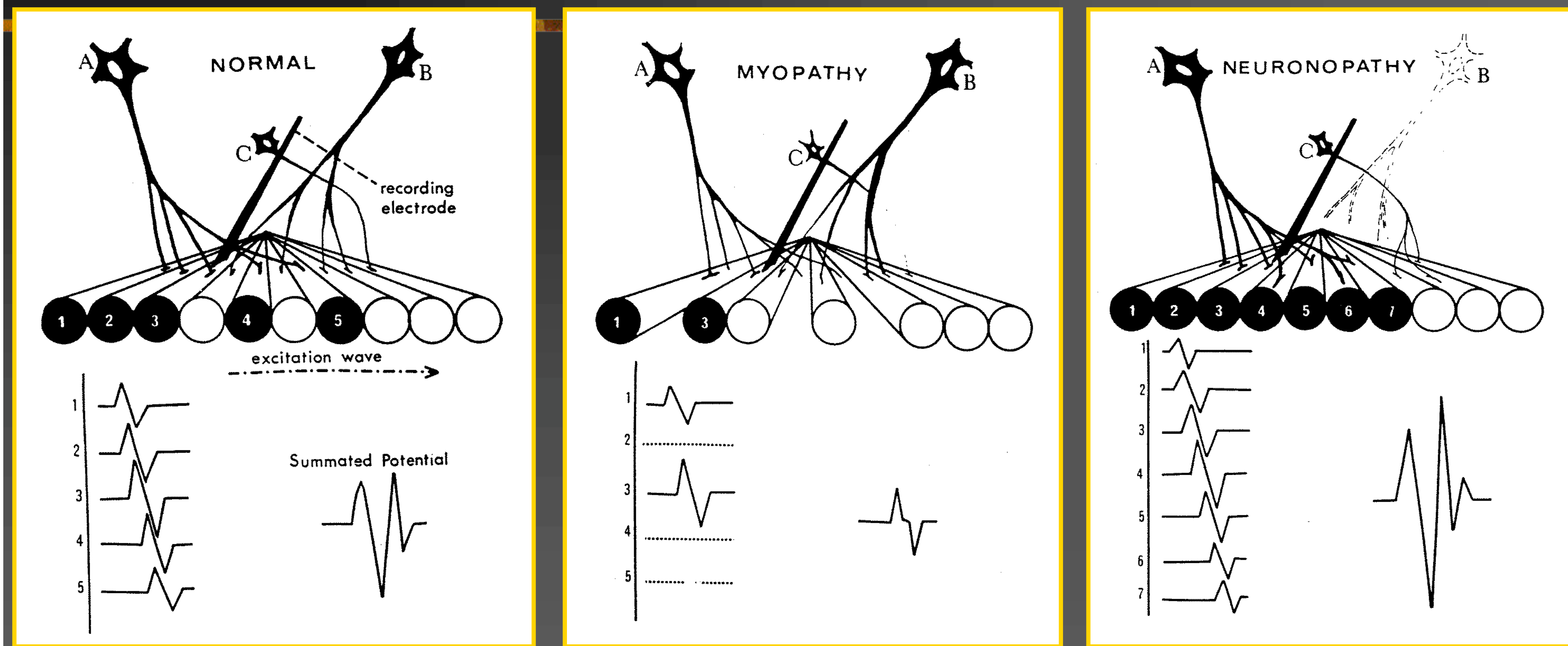


Needle EMG

Needle EMG



A
Motor Neuron
Nerve Fiber
EMG Electrode
Terminal axon branch
Endplate
1
2
Muscle Fibers
3
4
5
Endplate Zone
B
Motor Unit Territory
C
1
2
3
4
5
Extracellular Muscle Fiber Action Potential
D
Motor Unit Action Potential (MUAP)

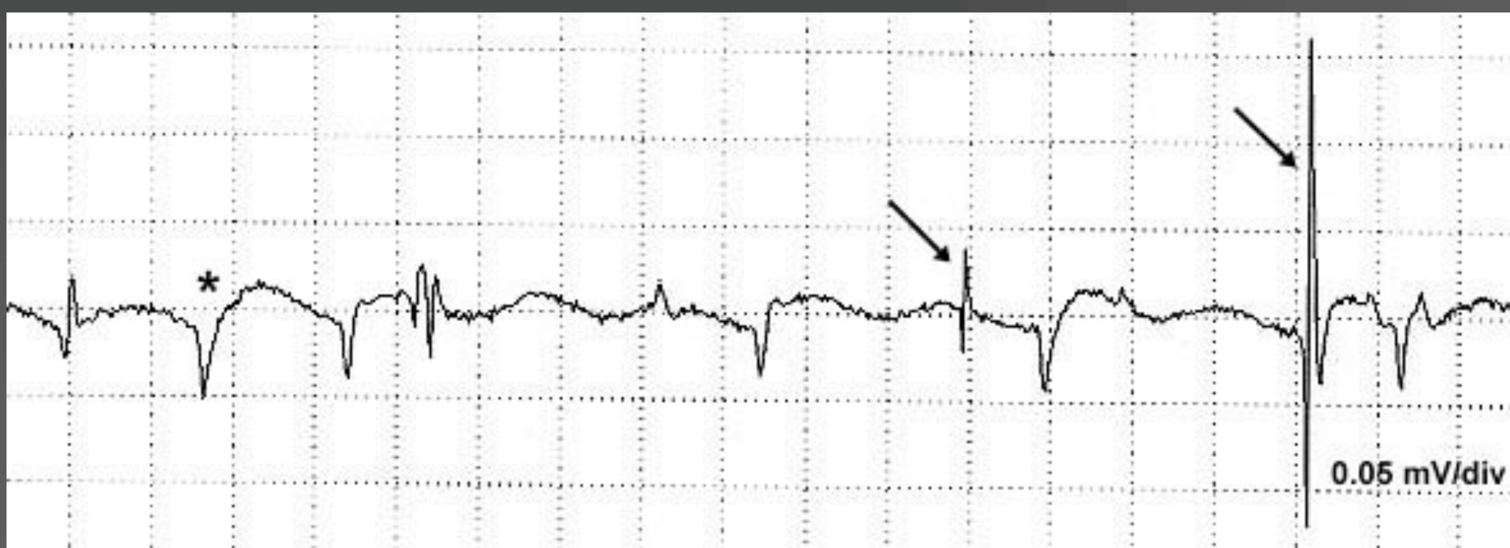


NORMAL
A
B
C
recording electrode
1 2 3 4 5
excitation wave
1
2
3
4
5
Summated Potential
MYOPATHY
A
B
C
1 3
1
2
3
4
5
NEURONOPATHY
A
B
C
1 2 3 4 5 6 7
1
2
3
4
5
6
7

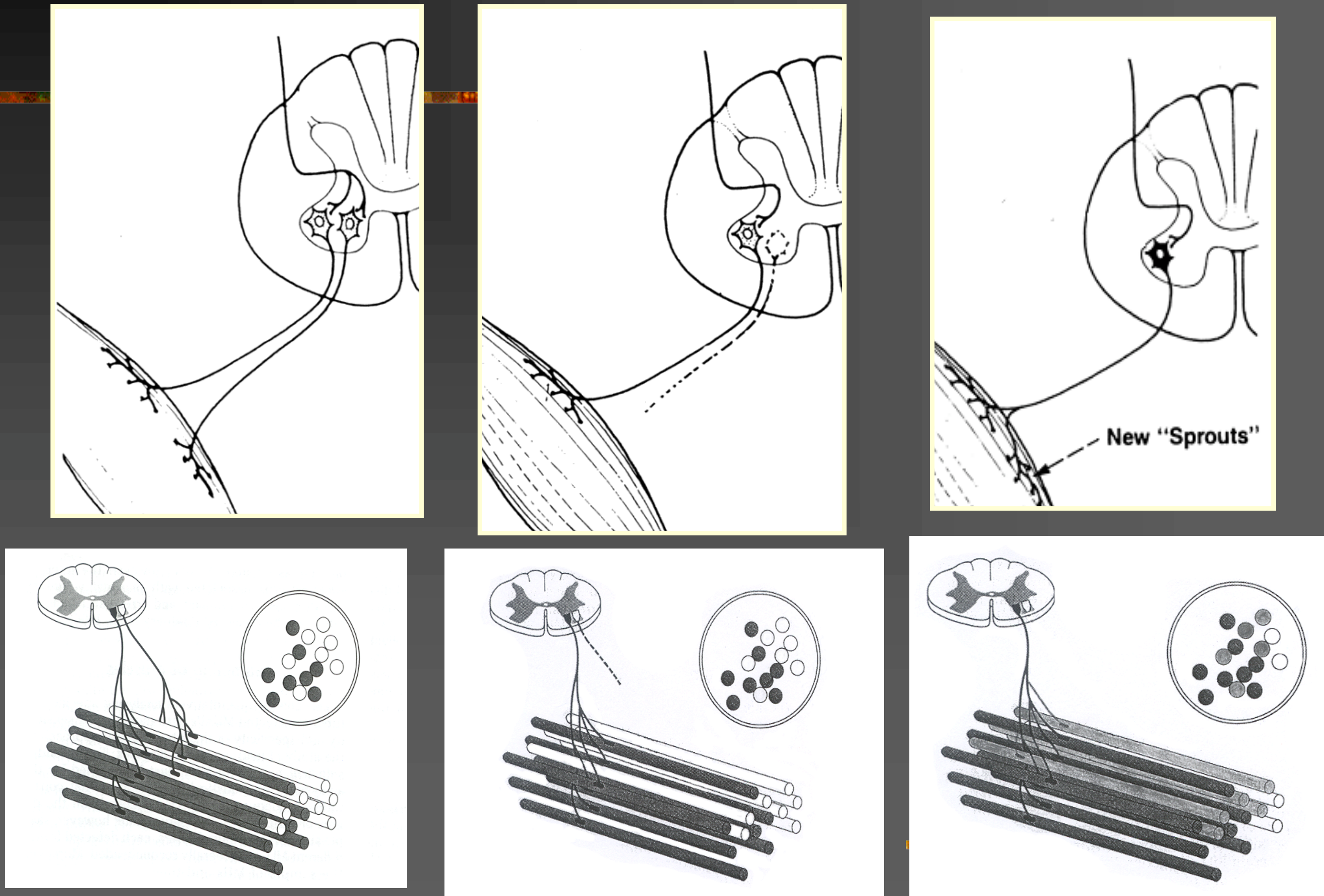
Anterior Horn Cell or Axonal Injury

With complete nerve resection electrically inexcitable in 3 - 5 days

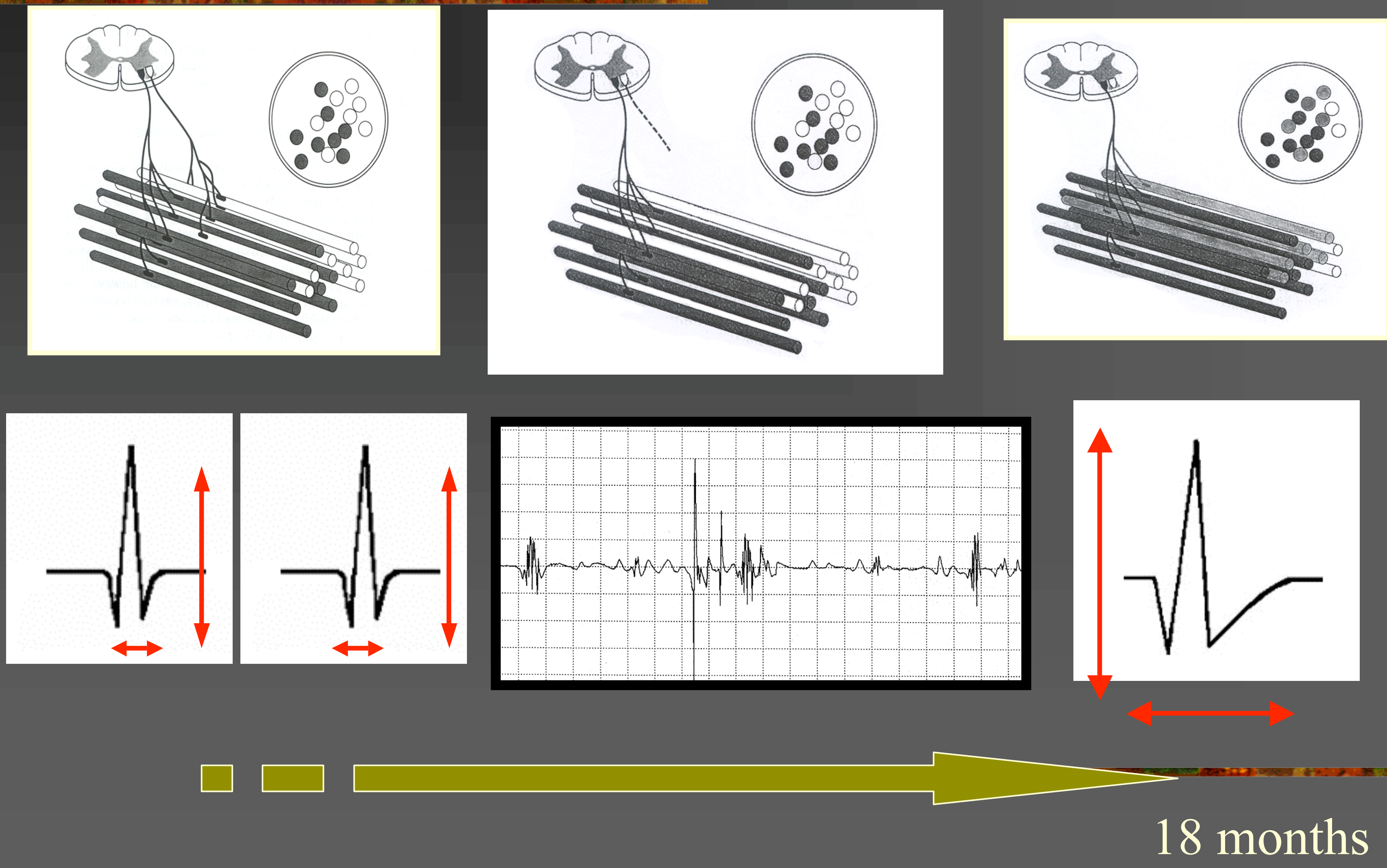
Needle EMG will show spontaneous “Fibrillations” and “Positive Sharp Waves” - Indicates denervation



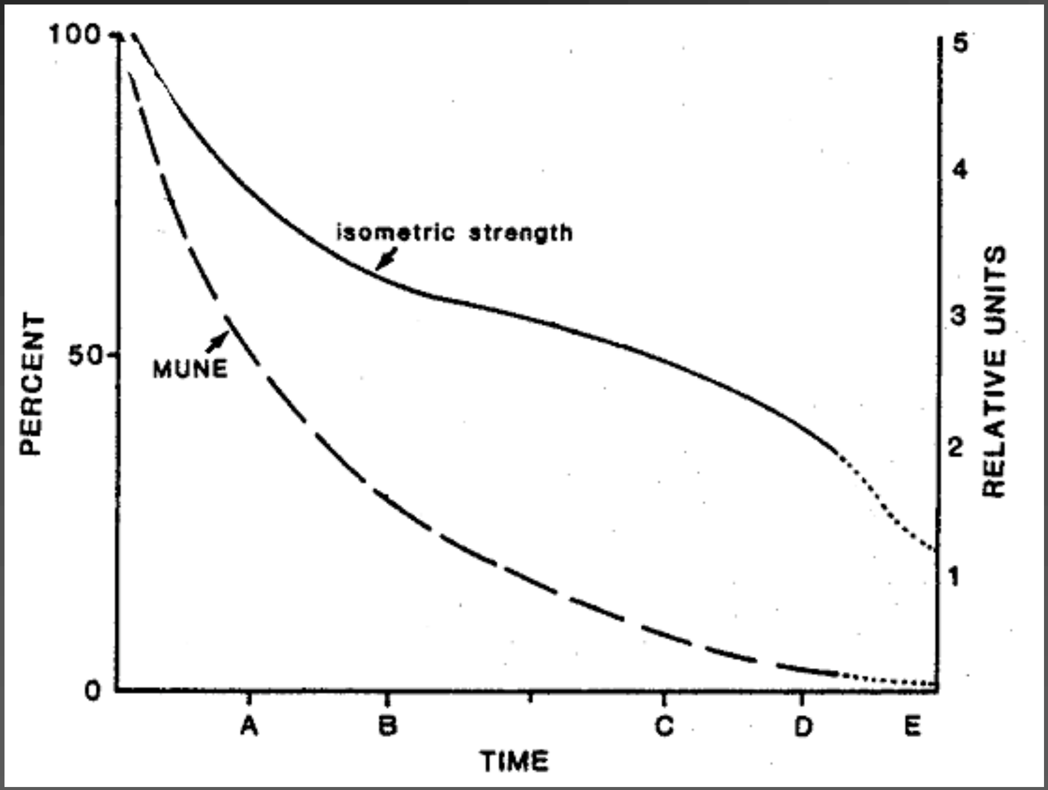
MU Remodeling

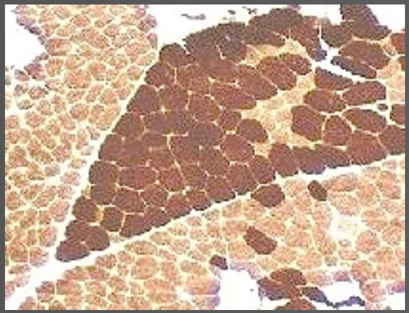


MU Remodeling and the MUP



MU Remodeling

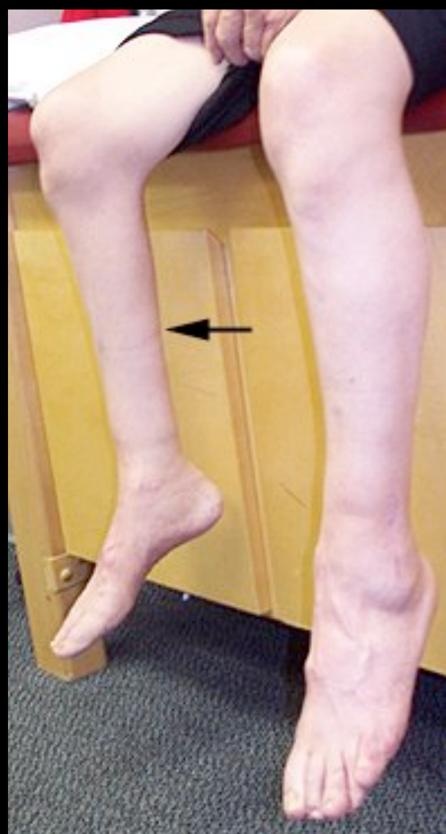




Strength preserved despite a decrease in MU number

MU Remodeling

Post-polio syndrome



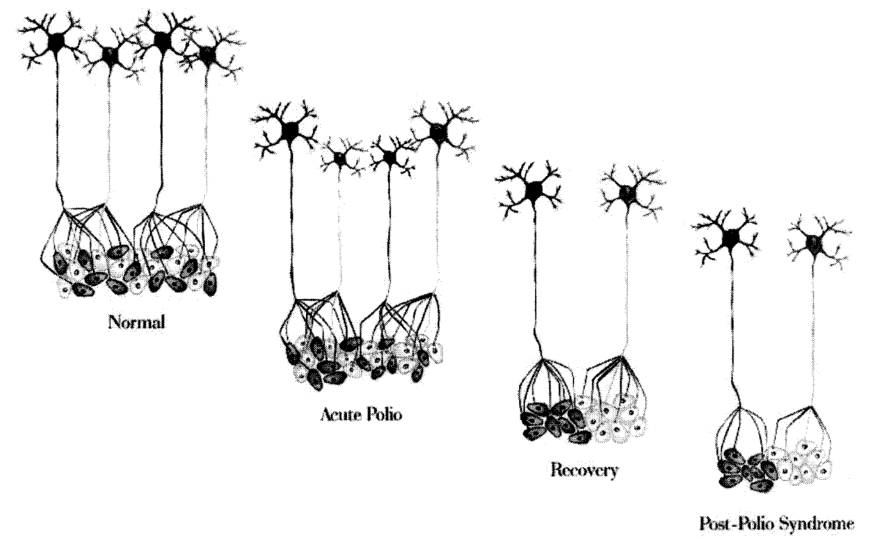


FIGURE 1. Pathophysiology of post-poliomyelitis syndrome. **Normal:** Four normal motor units are presented. Normal motor units show muscle fibers with a fiber type that is determined by the motor neuron that innervates them. **Acute polio:** Invasion of two motor neurons by poliovirus produces degeneration of the affected motor neuron and eventual denervation of associated muscle fibers. **Recovery:** Recovery after paralytic polio occurs through sprouting from axonal termini from surviving motor neurons with reinnervation of muscle fibers. This process also produces grouping of muscle fibers of a single fiber type (fiber-type grouping). Further recovery can occur through muscle fiber hypertrophy. **Post-poliomyelitis syndrome:** Distal degeneration of enlarged post-polio motor units with denervation of muscle fibers is believed to be the most likely cause of post-poliomyelitis syndrome.