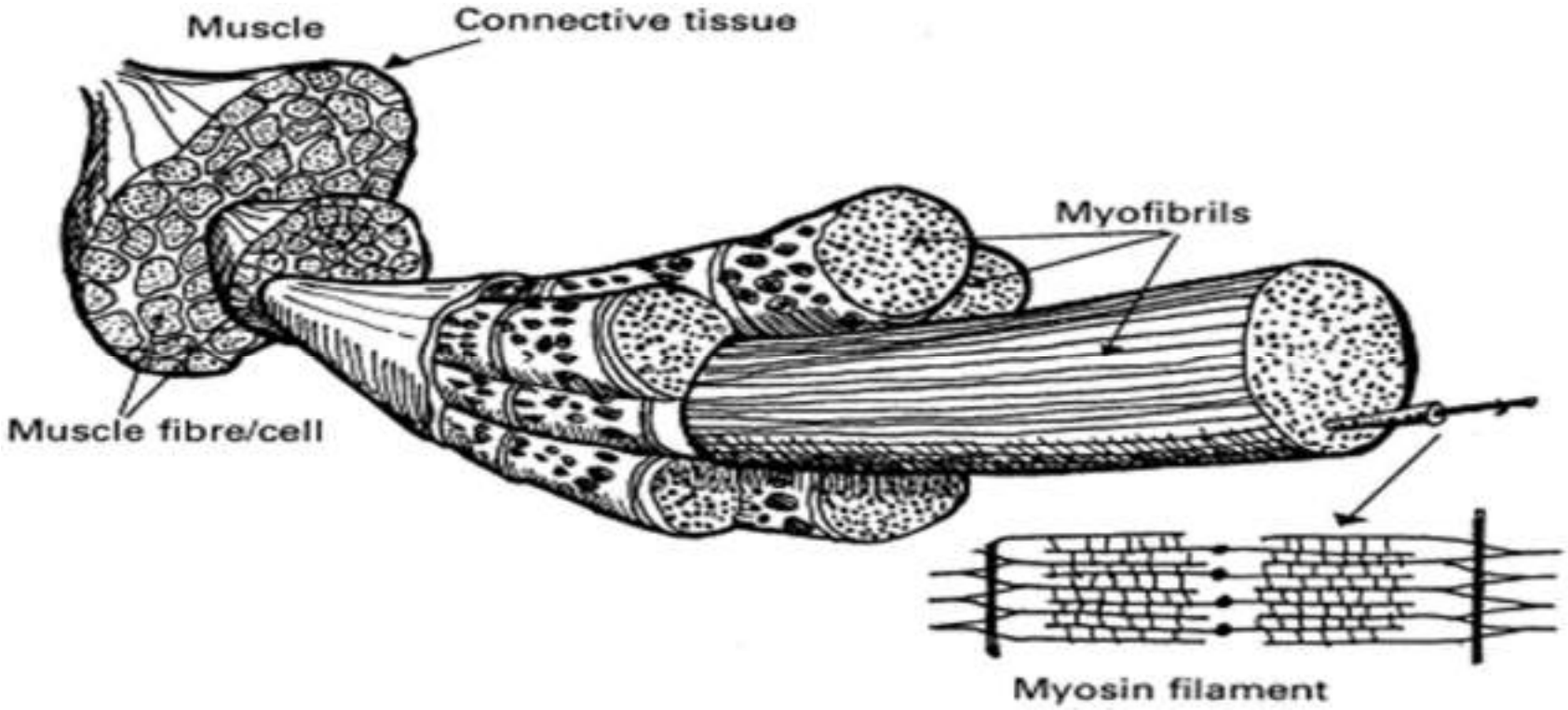
Department of Veterinary Physiology

MJF College of Veterinary & Animal Sciences,
Jaipur, Rajasthan- 303702
B.V.Sc. & A.H.
1st Year (2023-24)

Structure and Function of Muscle

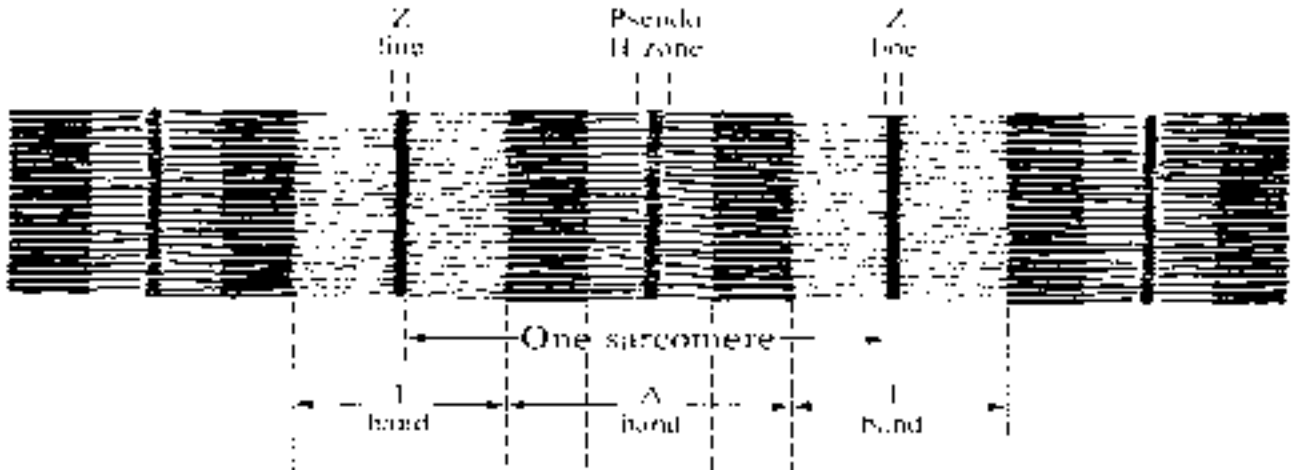


Dr. Brijesh Kumar
Assistant Professor
Dept. of Veterinary Physiology

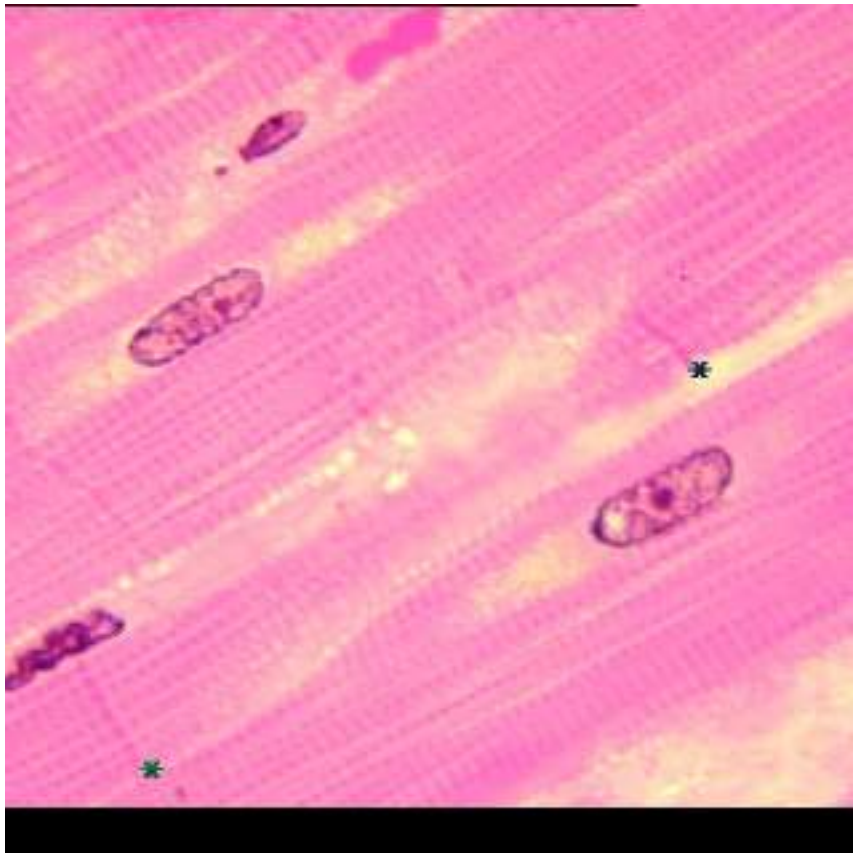
Dr. Sandeep Bissu
Assistant Professor
Dept. of Veterinary Physiology

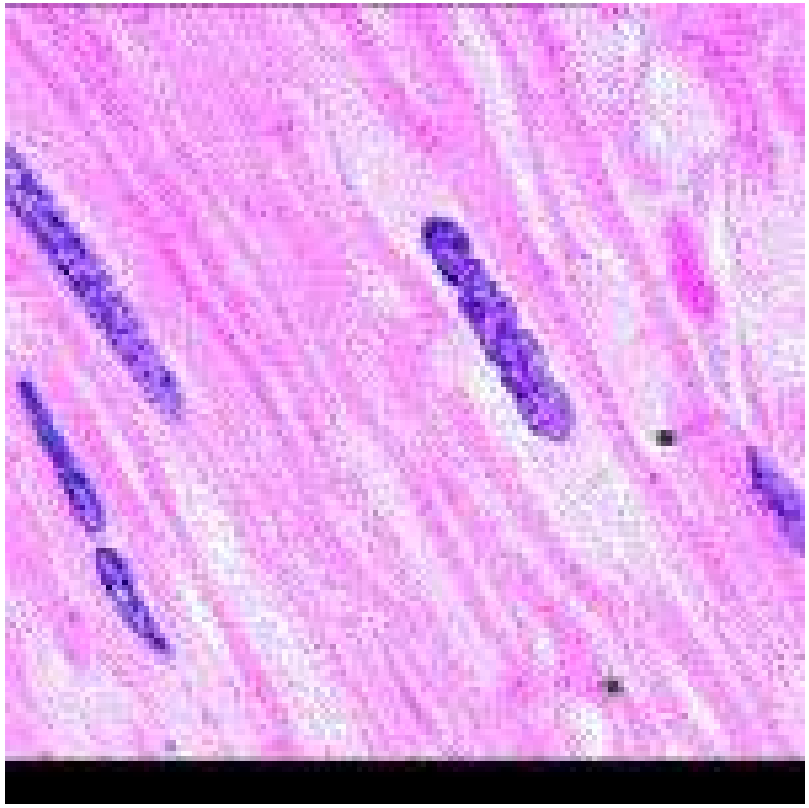
Muscle Types

	SKELETAL	SMOOTH	CARDIAC
METHOD OF CONTROL	VOLUNTARY	INVOLUNTARY	INVOLUNTARY
BANDING PATTERN	STRIATED	NON-STRIATED	STRIATED
NUCLEI/CELL	MULTI	SINGLE	SINGLE

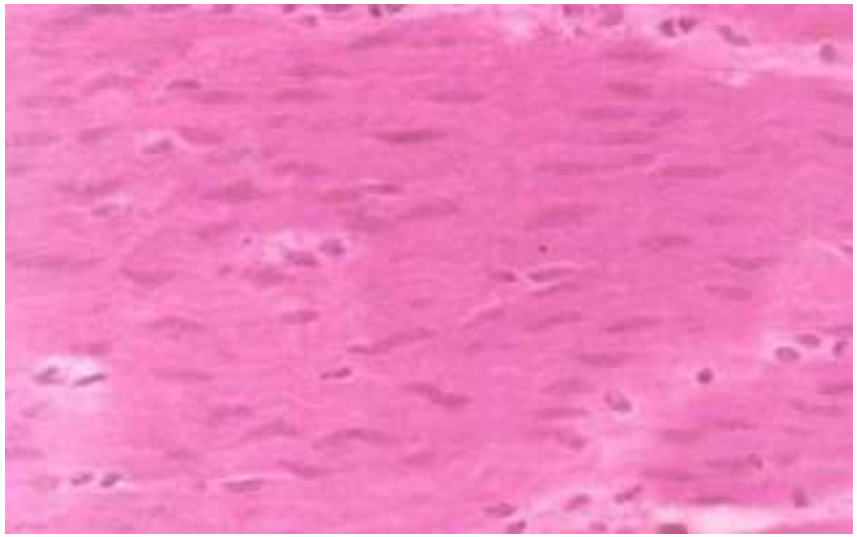


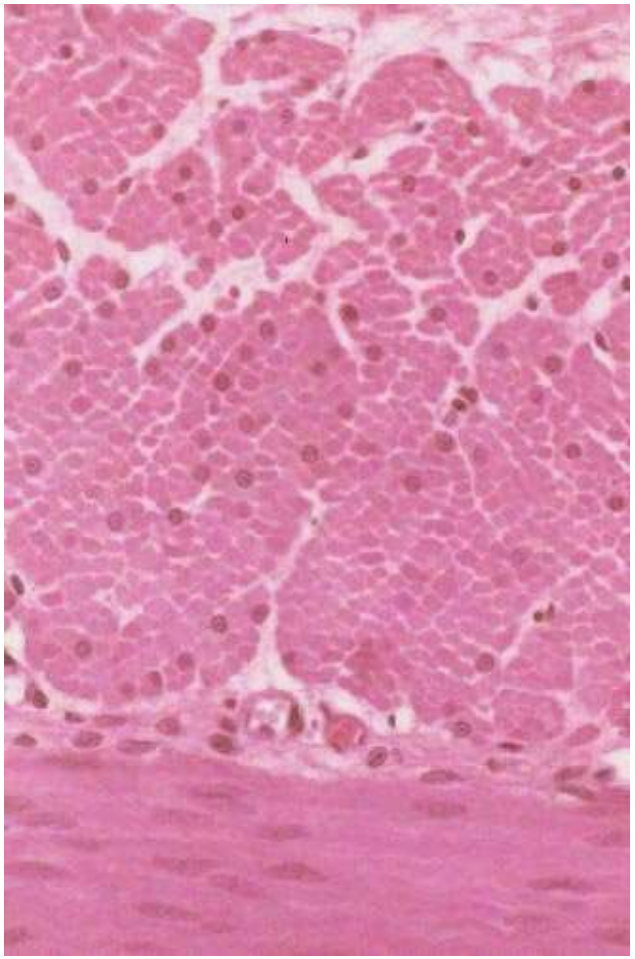
Cardiac Muscle



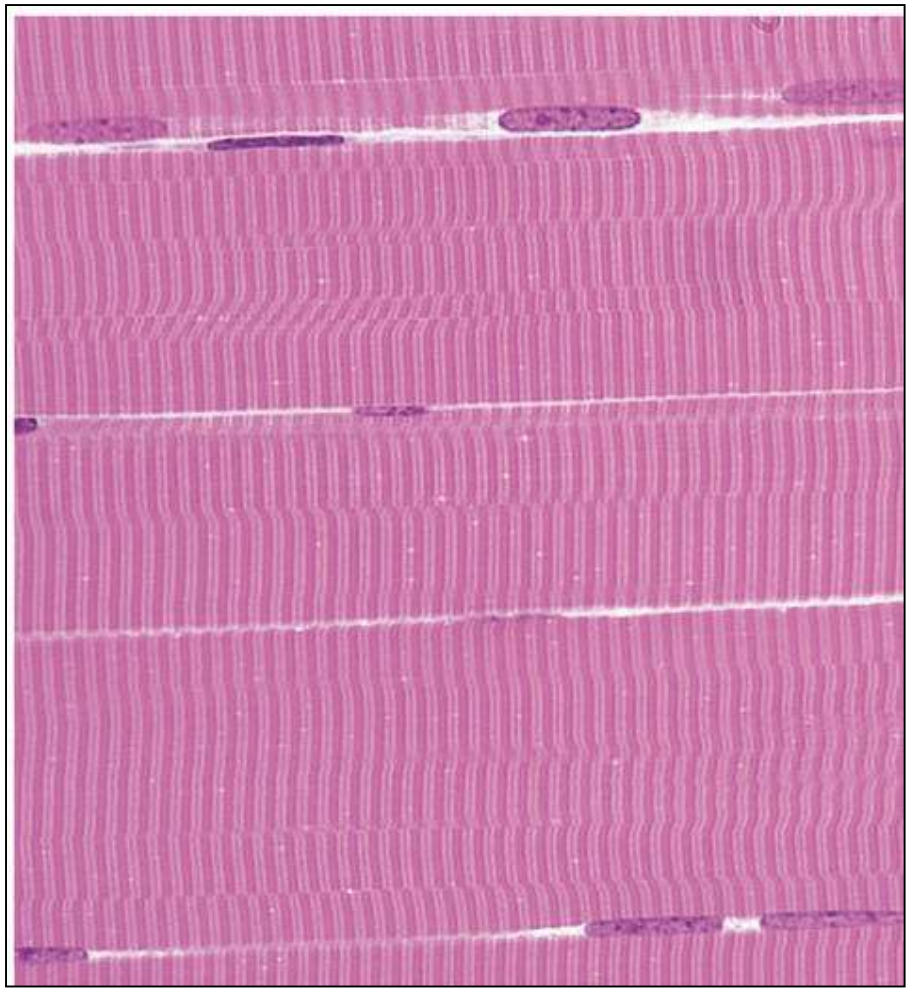


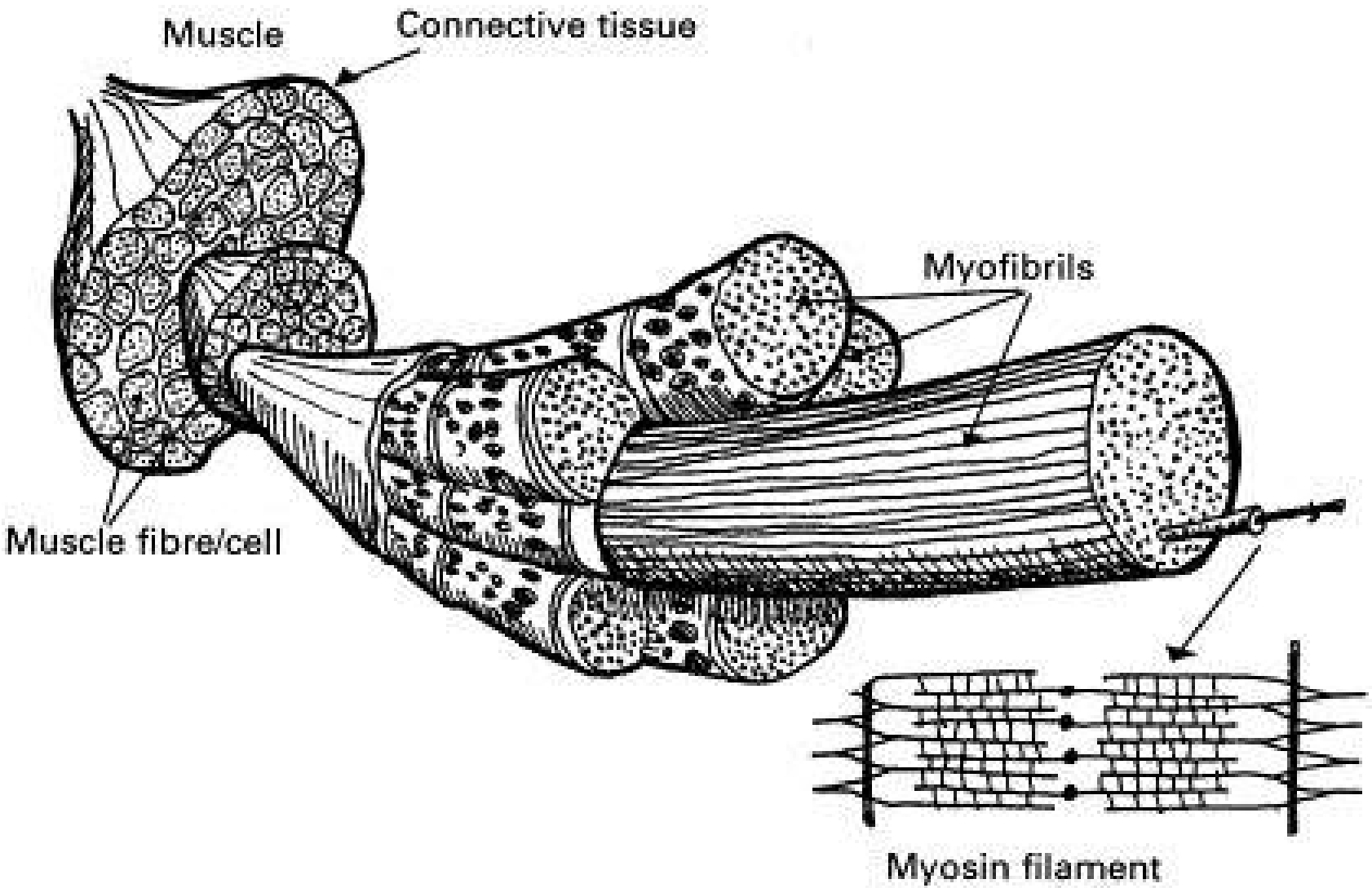
Smooth Muscle



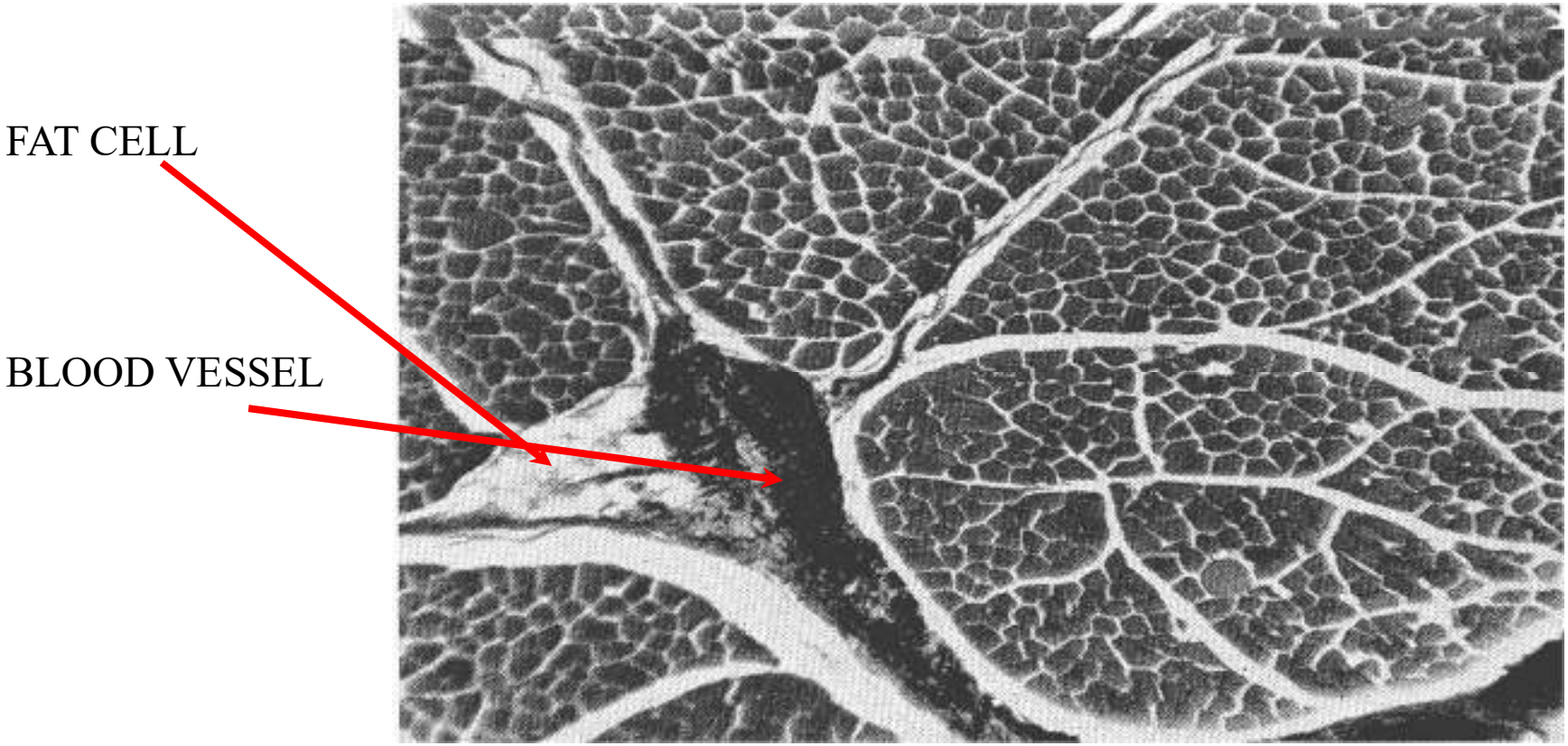


Skeletal Muscle

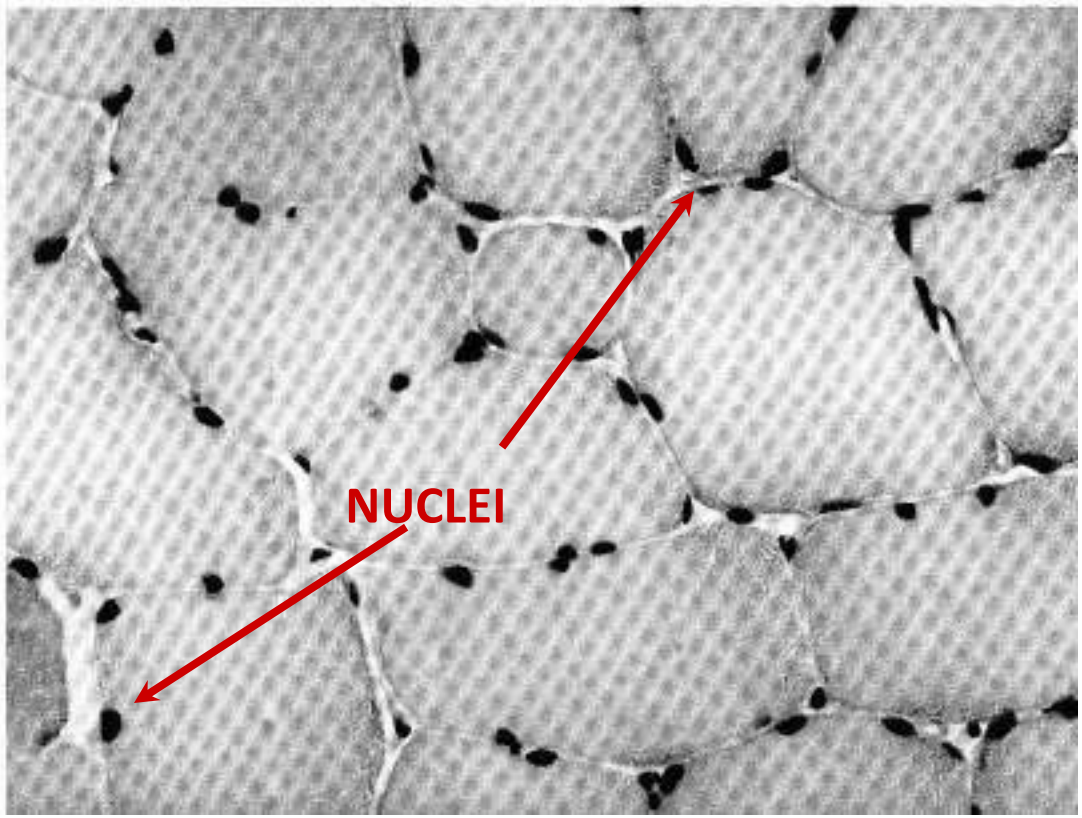


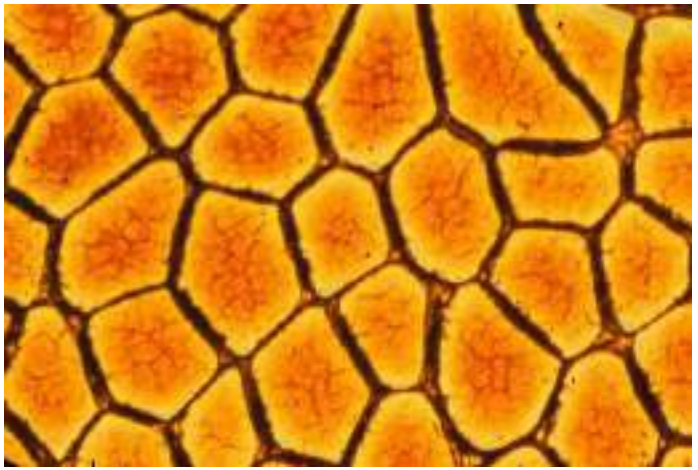

Muscle
Connective tissue
Myofibrils
Muscle fibre/cell
Myosin filament

Muscle Cross Sections Showing Bundles of Myofibers

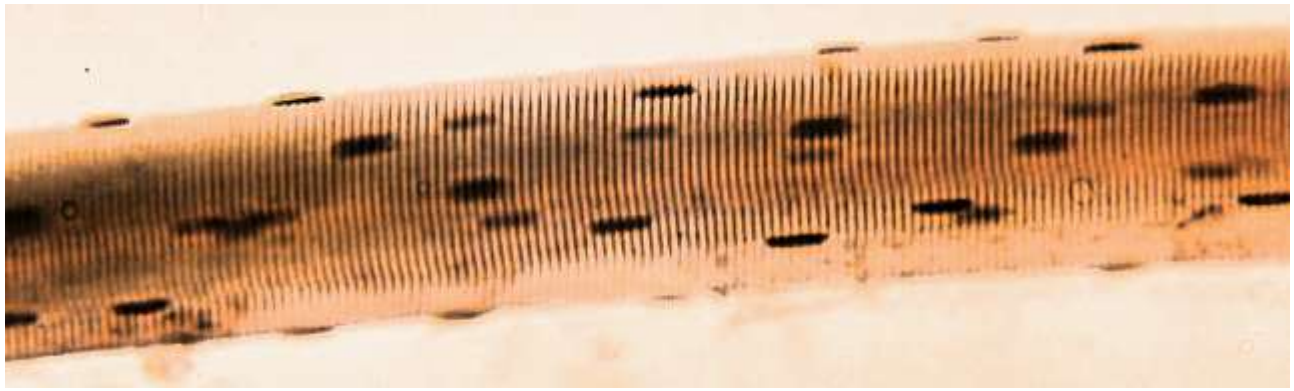


Cross Section of Muscle Fibers





Myofiber



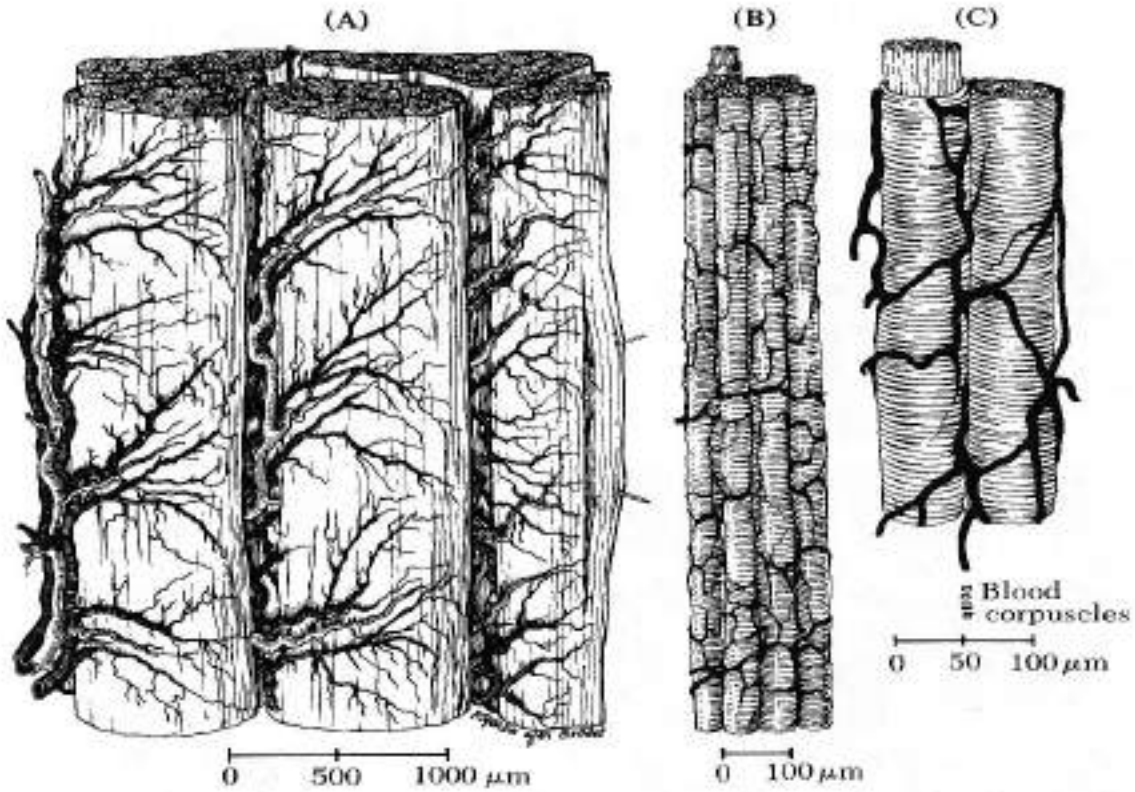
Red and White Fibers in Muscle

Fiber types

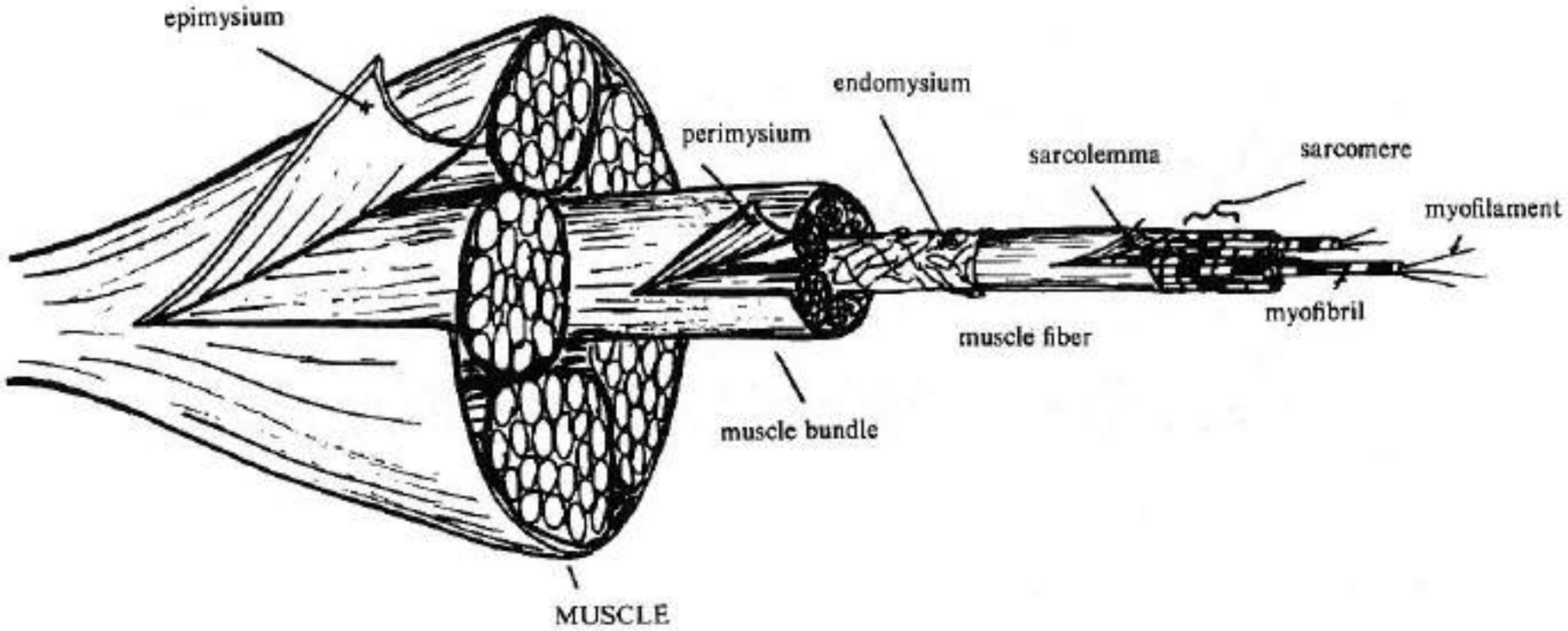
Characteristics	Type 1	Type 2A	Type 2X(D)	Type 2B
Reddness	++++	+++	+	+
Myoglobin content	++++	+++	+	+
Fiber diameter	+	+	+++	++++
Contraction speed	+	+++	+++	++++
Fatigue resistance	++++	+++	+	+
Contractile action	tonic	tonic	phasic	phasic
Number of mitochondria	++++	+++	+	+
Mitochondria size	++++	+++	+	+
Capillary density	++++	+++	+	+
Oxidative metabolism	++++	++++	+	+
Glycolytic metabolism	+	+	+++	++++
Lipid content	++++	+++	+	+
Glycogen content	+	+	++++	++++
Z disk width	++++	+++	+	+

* The characteristics are relative to the other fiber types.

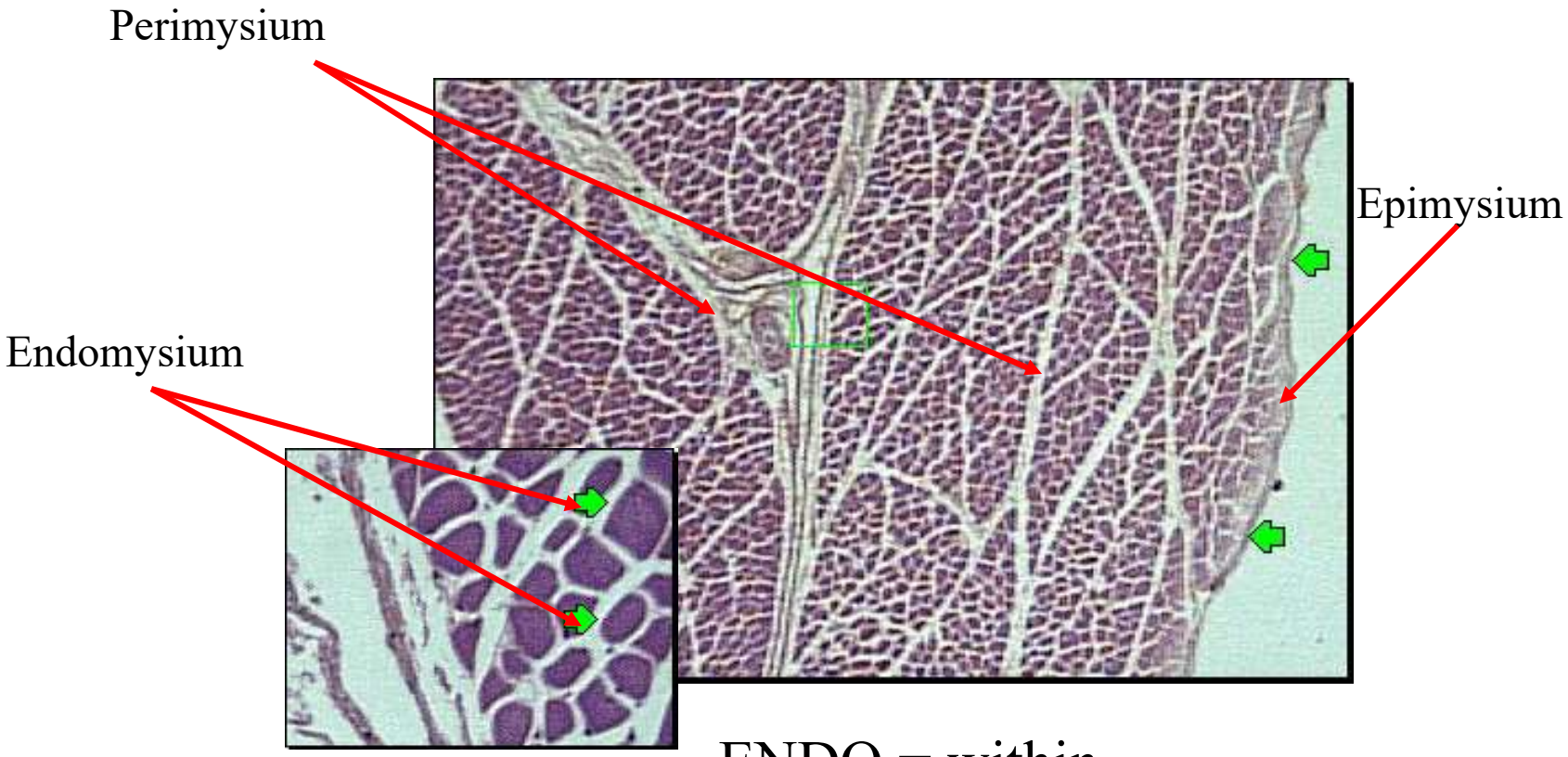
The Blood Supply for Myofibers



Connective Tissues

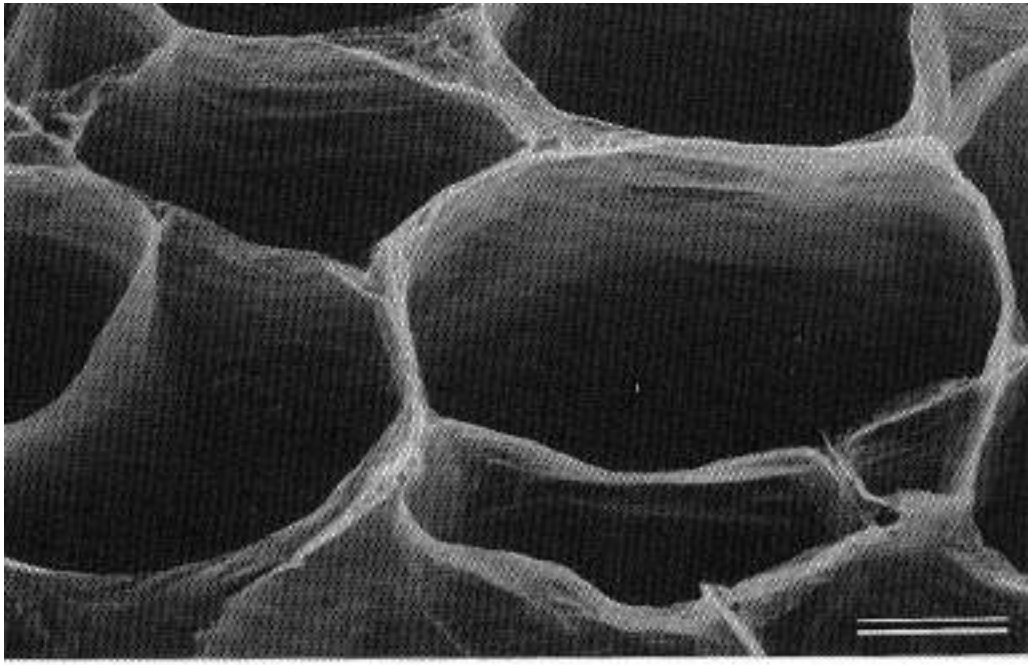


Position of Mysiums in Muscle



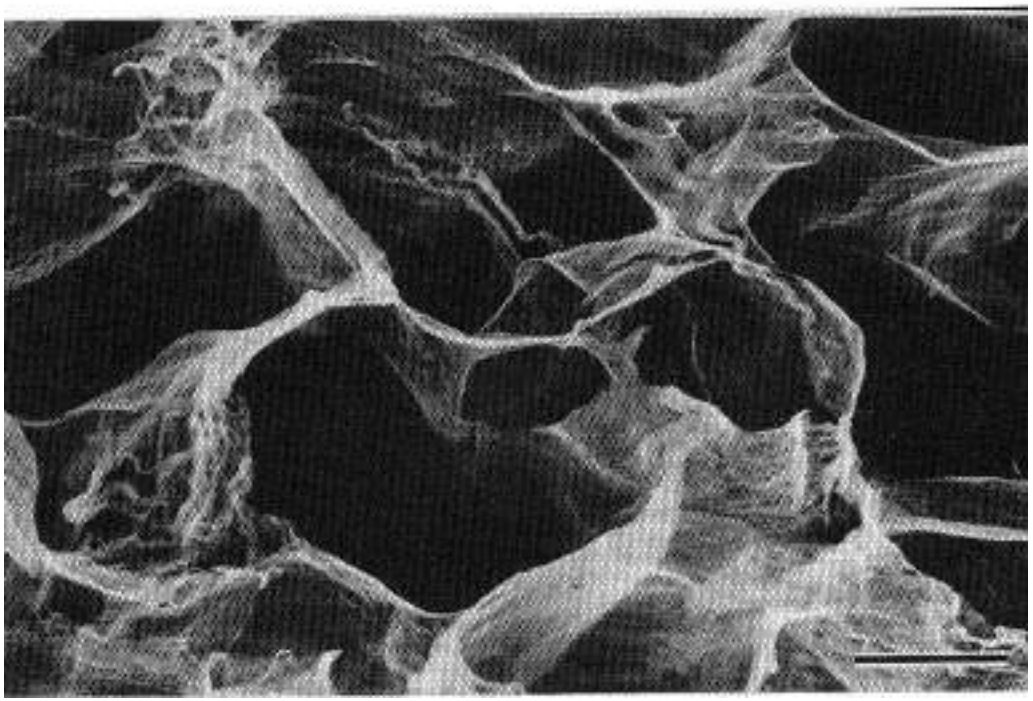
ENDO = within
PERI = around
EPI = upon

• Endomysium from muscle not aged



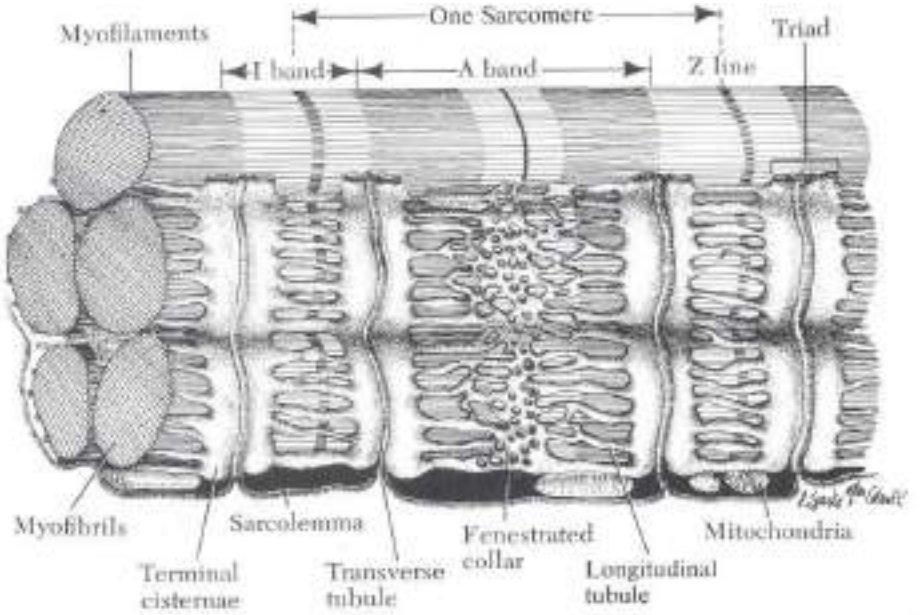
(a)

• Endomysium after cooler aging (28 D At 4°C)

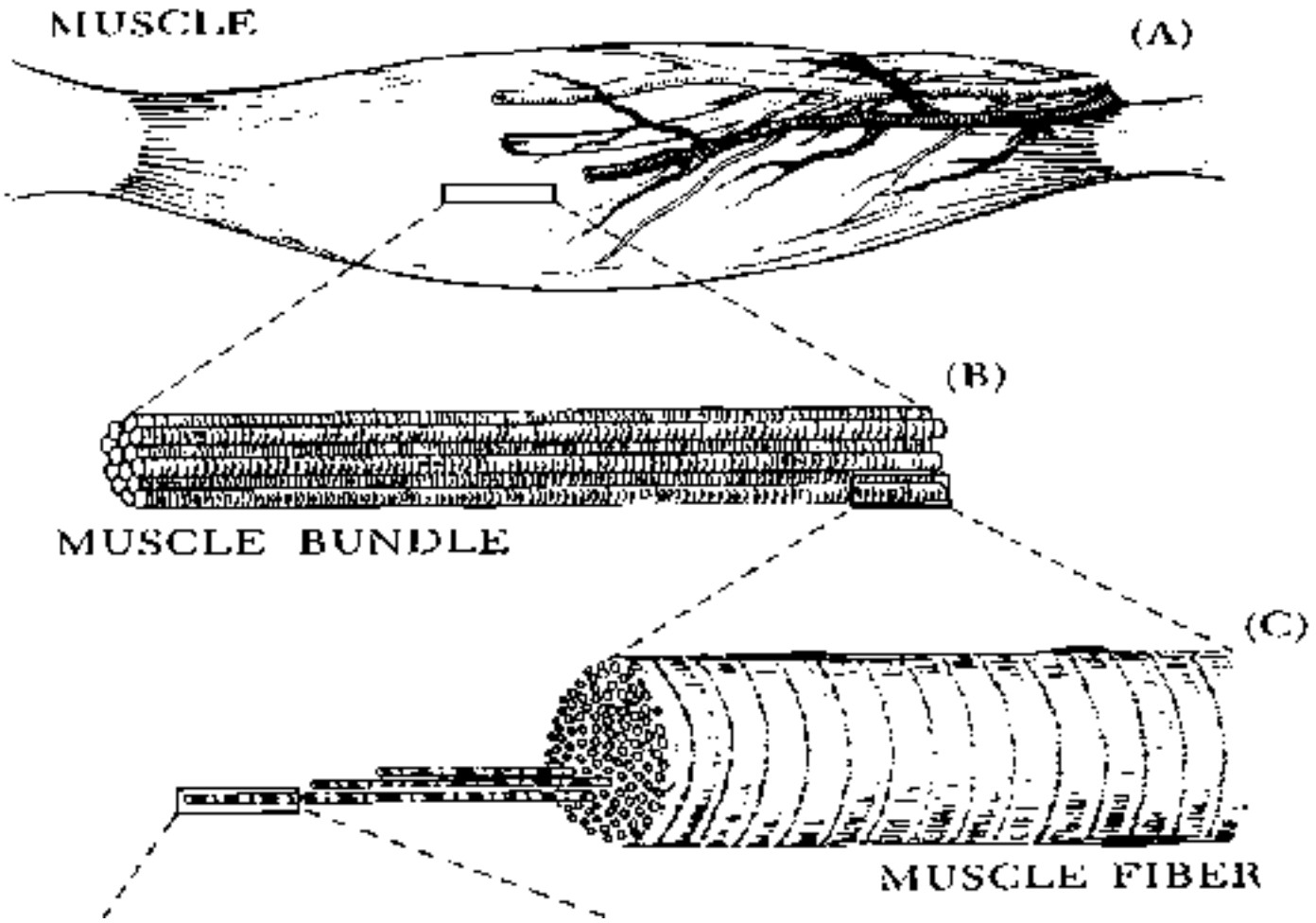


The Sarcoplasmic Reticulum

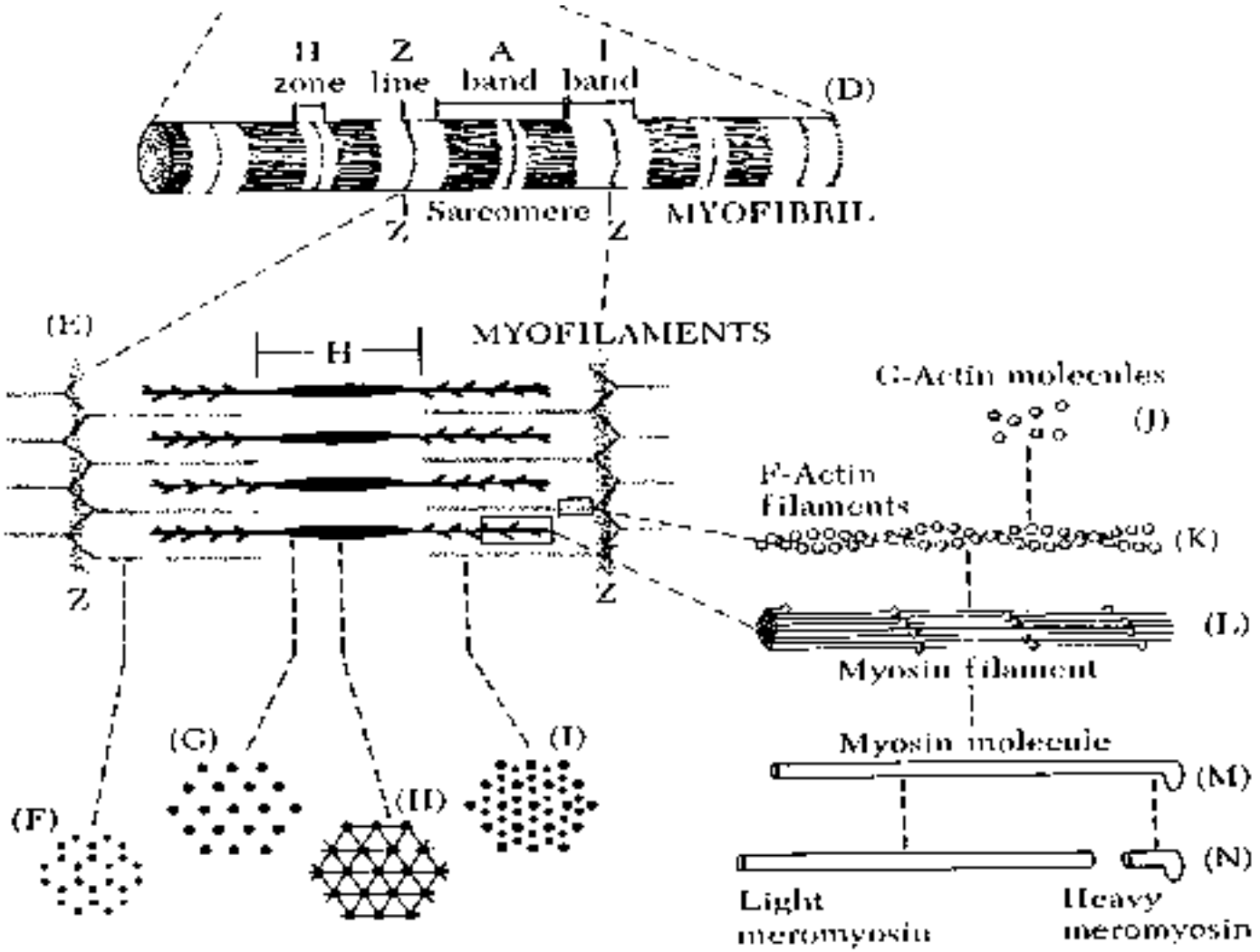
- Sarcoplasmic reticulum
  - T-tubule
- Calcium Storage
- Required for contraction



Structure of Muscle



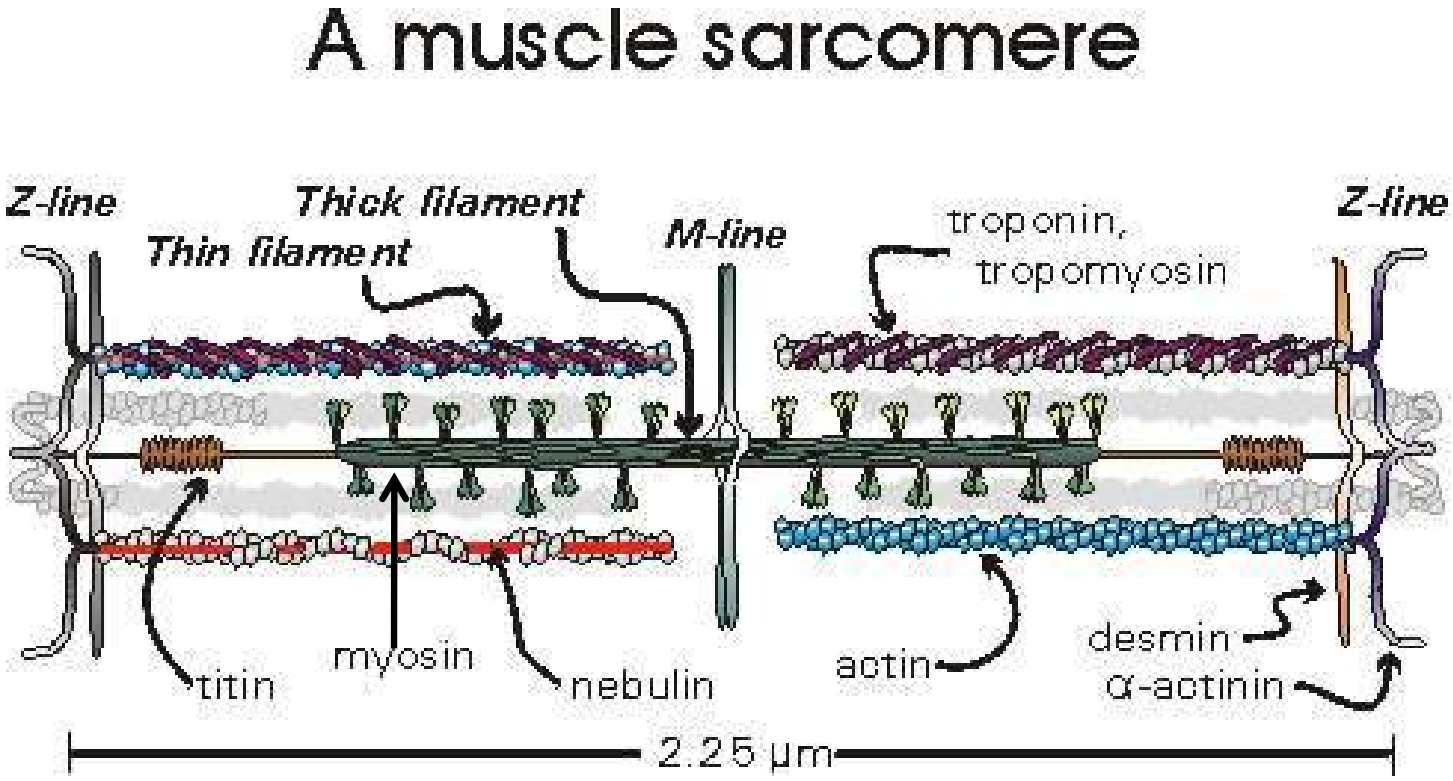
Structure of Muscle (Cont)



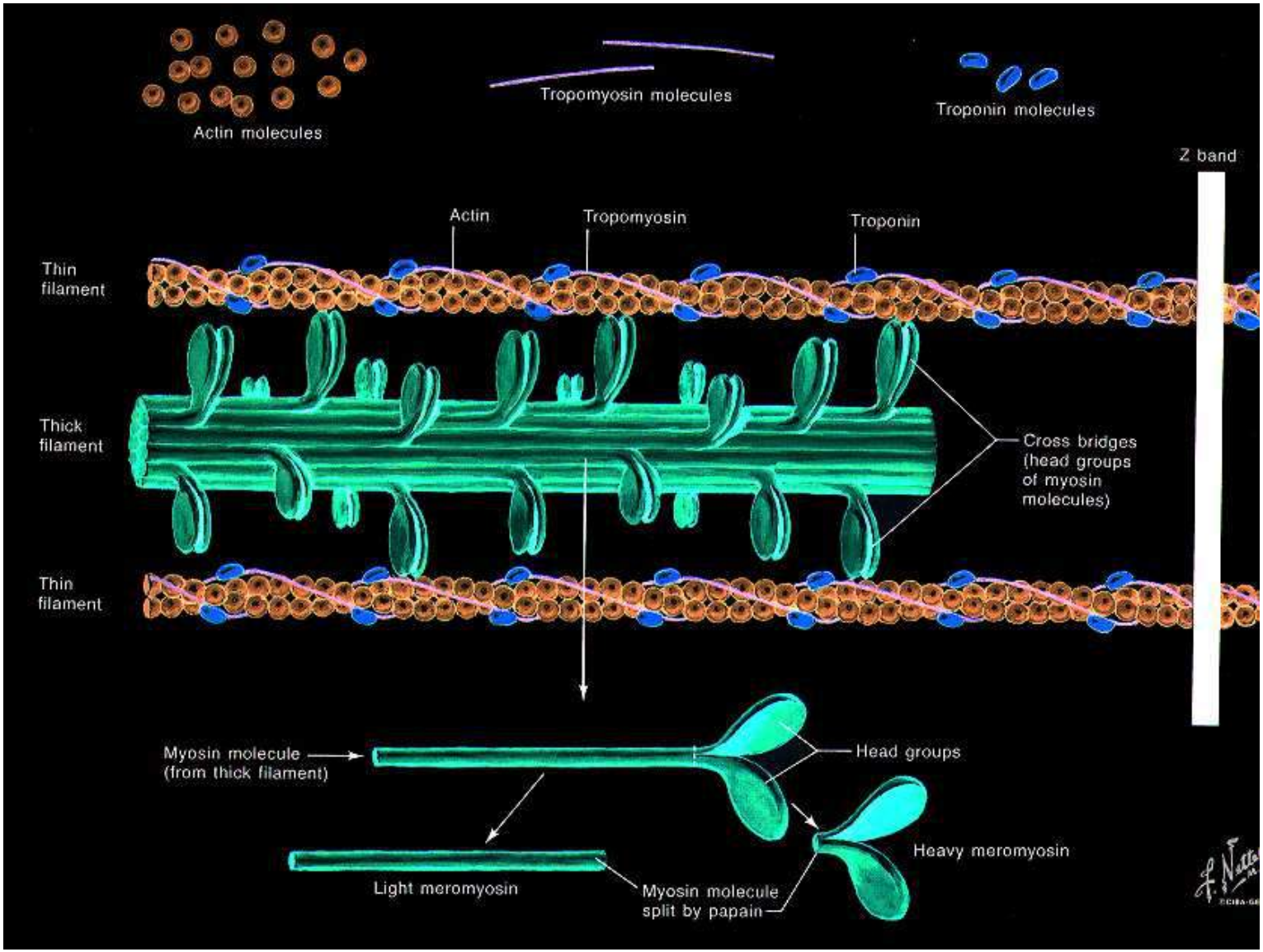
Sarcomere

- Functional unit of a muscle

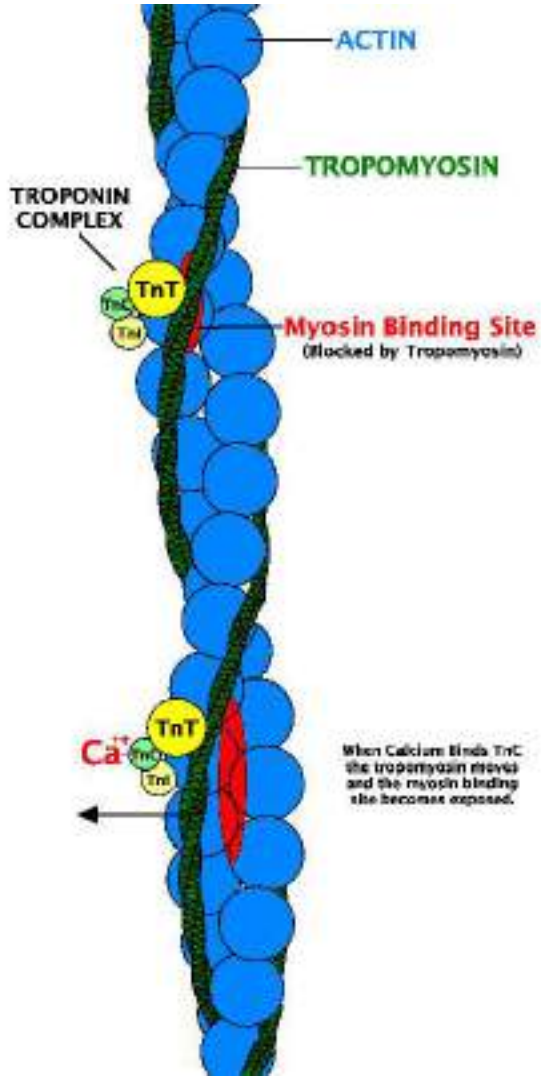
- Runs from z-line to z-line
  - Actin
  - Myosin



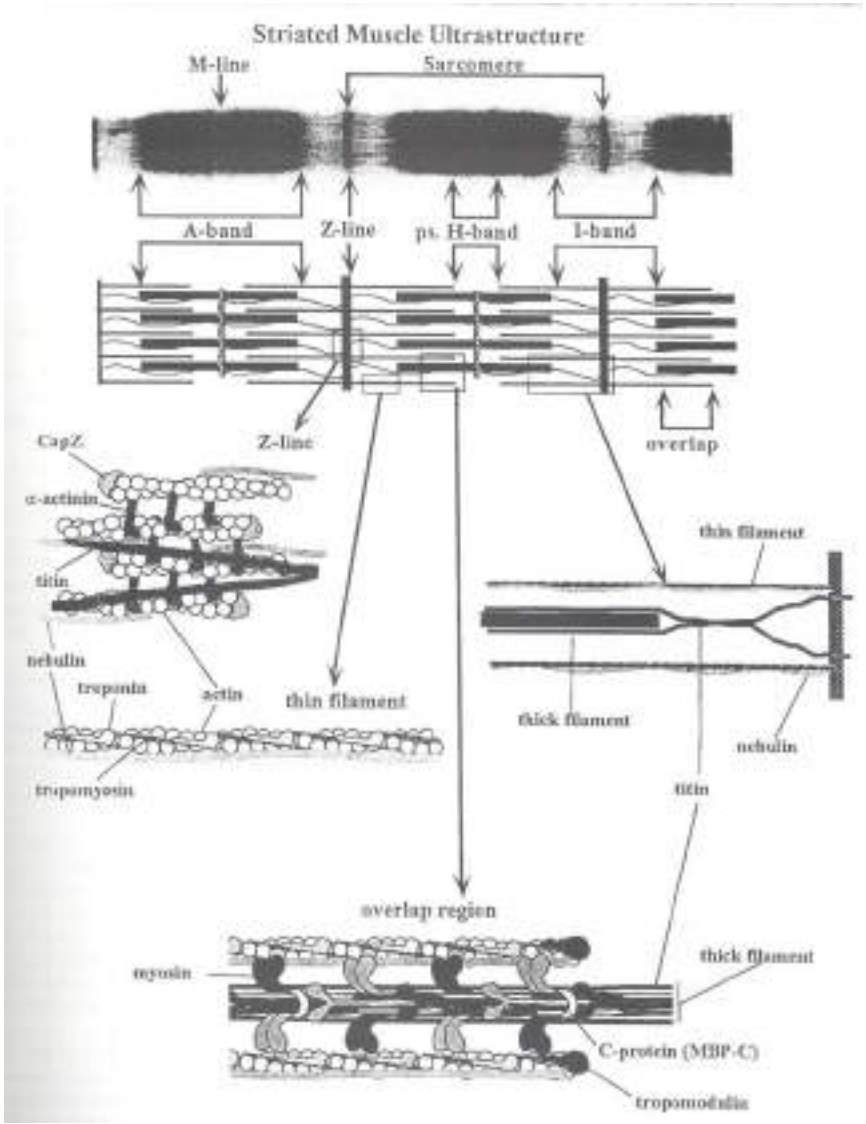
Myosin Filament



Actin Filament



Muscle Structure



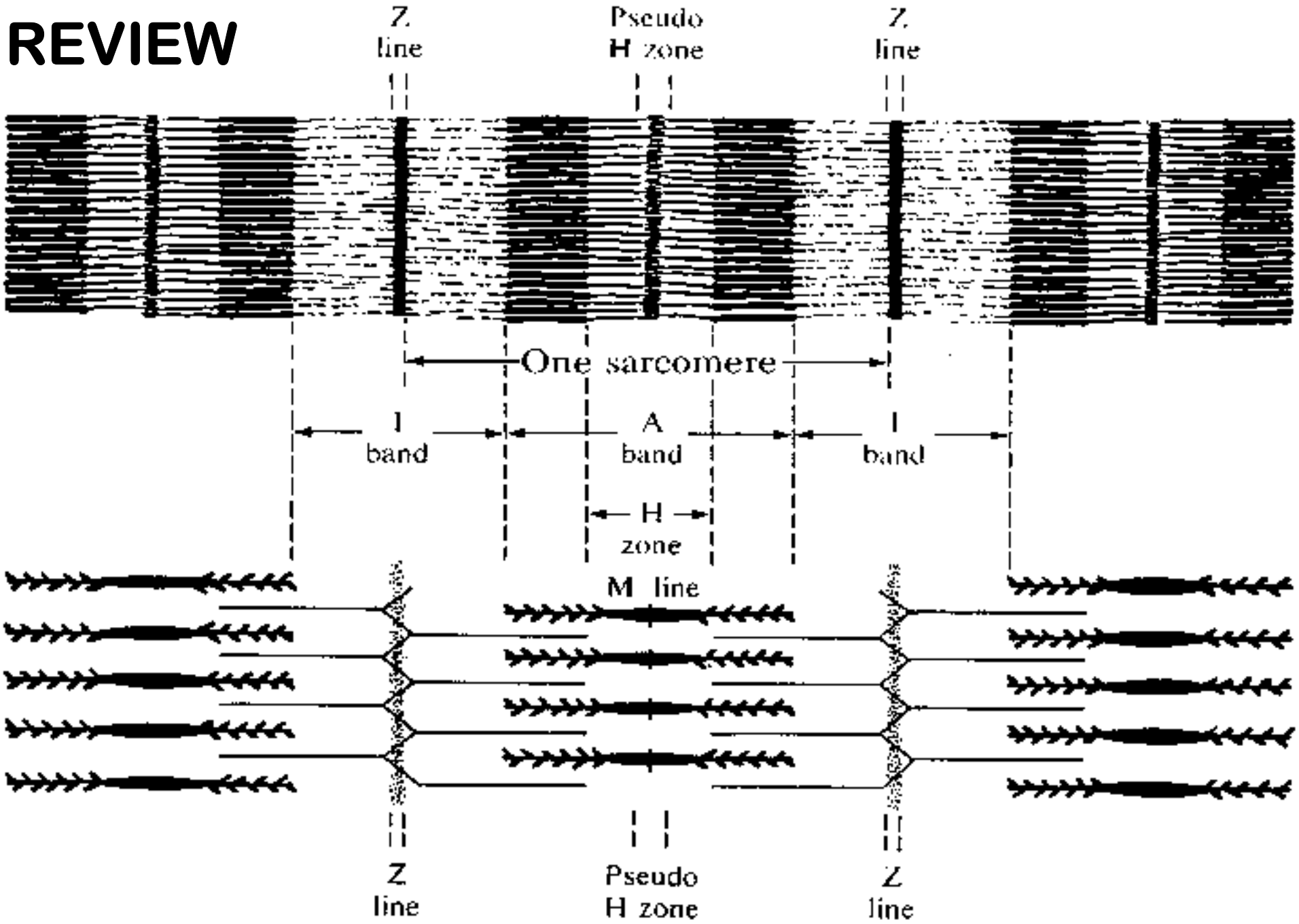
Critical Contractile Proteins

Table 22–2. Proteins of the Myofibril

Protein	Molecular Weight	Subunits	Location	% Myofibrillar Protein
Contractile				
Myosin	520,000	2 of 220Kd[1], 4 of 20Kd	Thick filaments	43
Actin	42,000		Thin filaments	22
Tropomyosin	68,000	2 of 34Kd	Thin filaments	5
Troponin	69,000	30Kd, 21Kd, 18Kd	Thin filaments	5
Structural				
Titin	2,800,000		Full sarcomere	8
Nebulin	600,000		Thin filaments	3
C protein	140,000		Thick filaments	2
α-actinin	200,000	2 of 100Kd	Z lines	2
M protein	160,000		M lines	2
Desmin	55,000		Z lines	<1

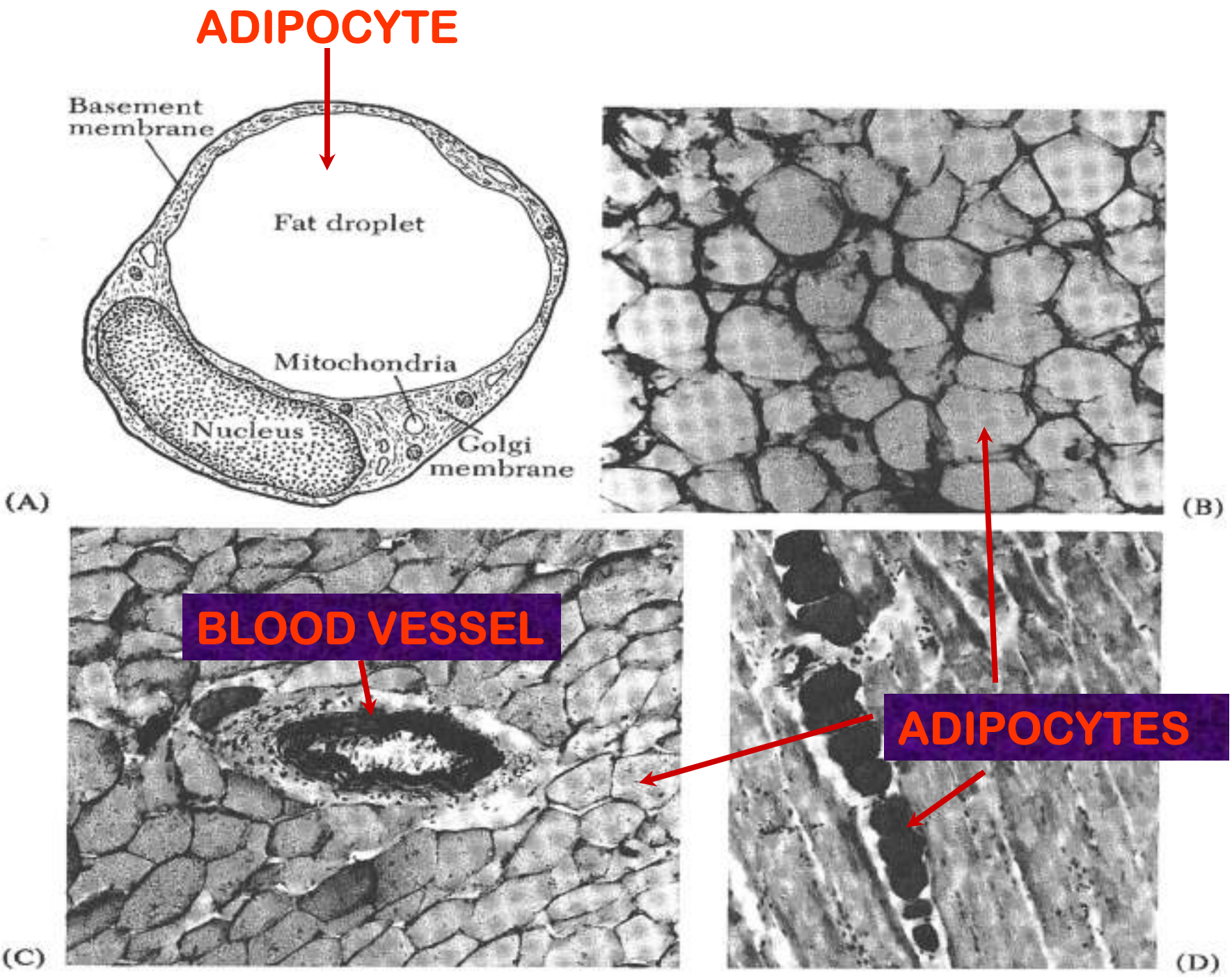
[1]Kilodalton = 1,000 daltons. One dalton is a unit of mass very nearly equal to that of a hydrogen atom.

REVIEW


Z line
Pseudo H zone
Z line
One sarcomere
I band
A band
I band
H zone
M line
Z line
Pseudo H zone
Z line

Fat Structures

ADIPOSE TISSUE

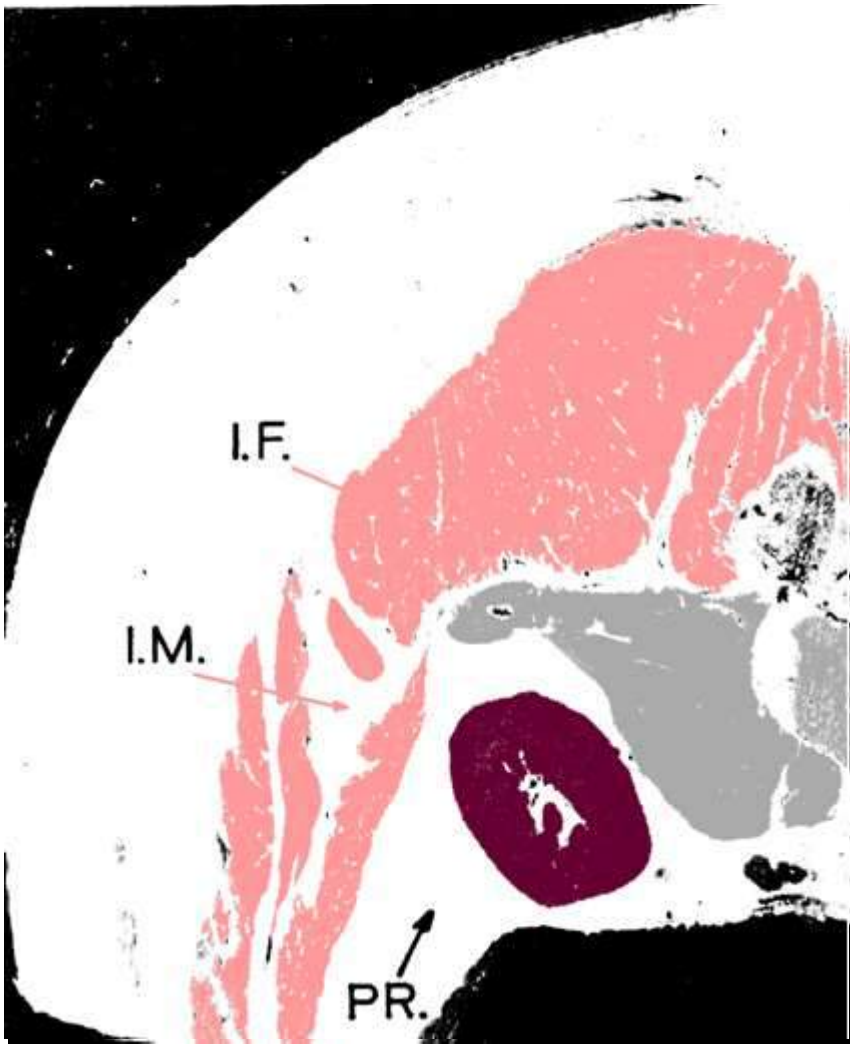


Fat Layers and Depots

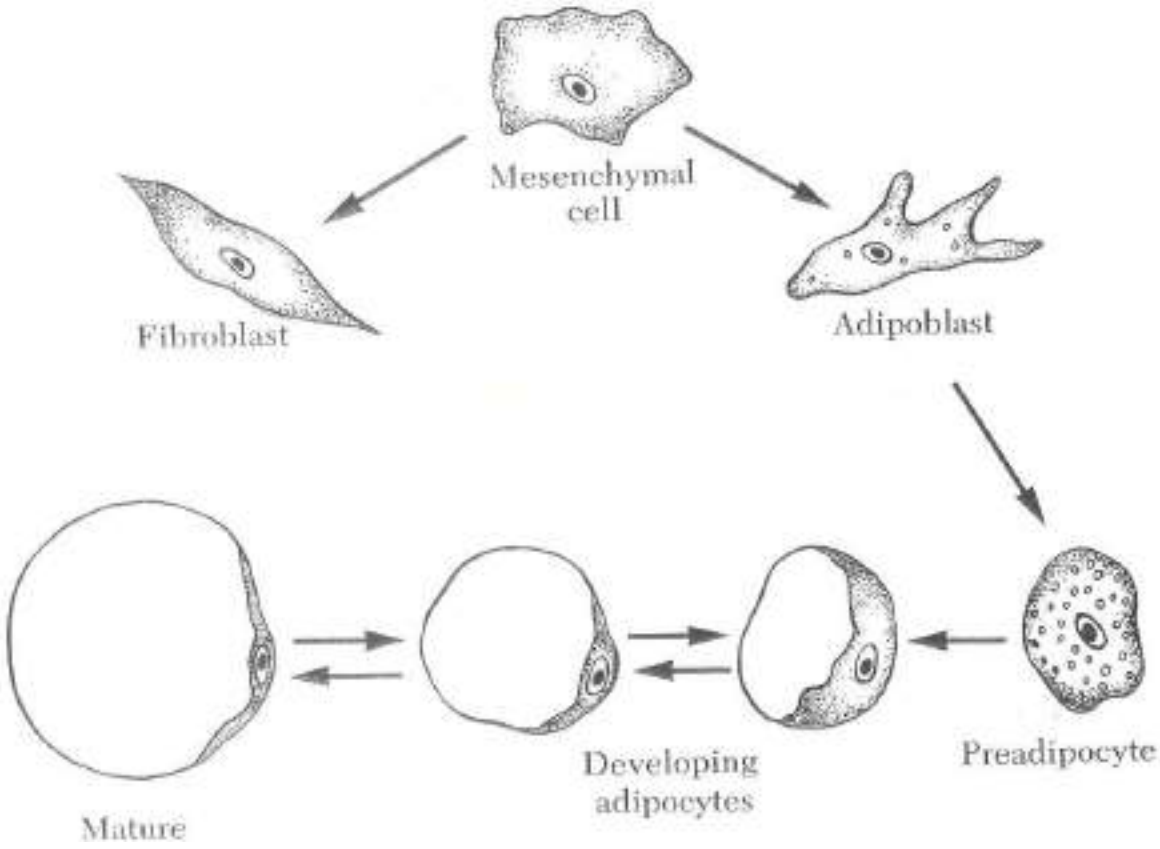
I.F. = Inter-fasicular or intramucular (marbling)

I.M. = Intermuscular (seam fat)

PR. = Perinephric or Peri-renal (fat around the kidneys)

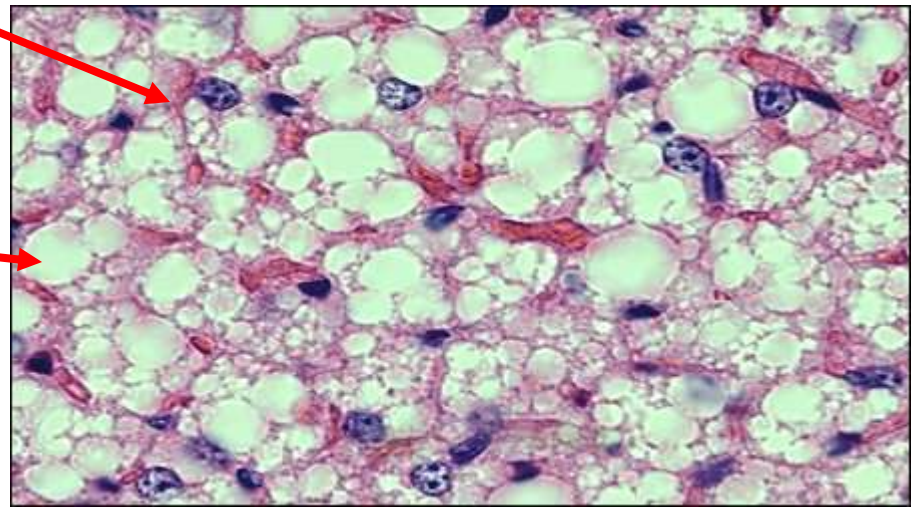


FAT CELLS


Mesenchymal cell
Fibroblast
Adipoblast
Preadipocyte
Developing adipocytes
Mature

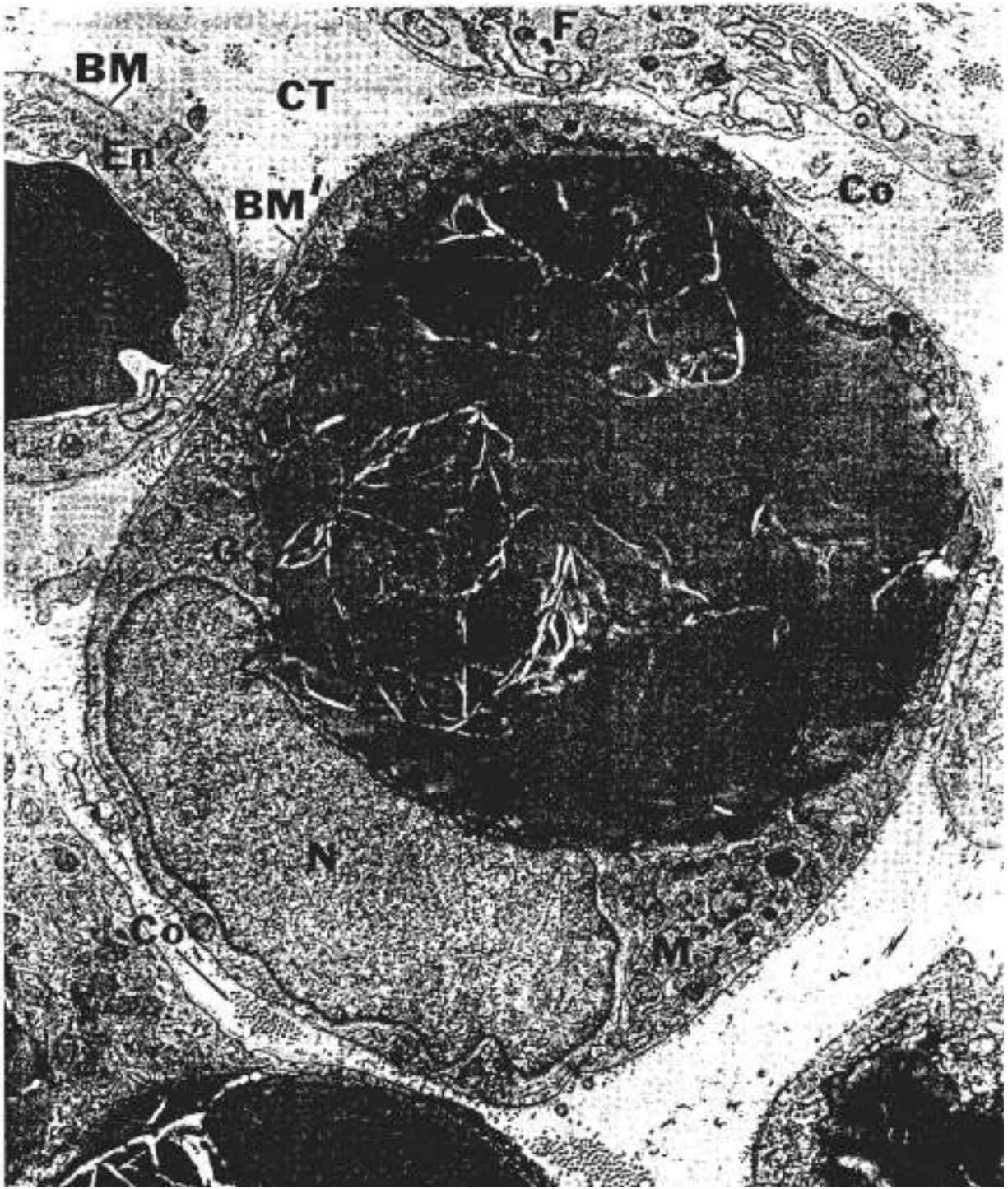
Adipogenesis

- Adipoblasts
  - 20 microns in diameter
- Adipocytes
  - 120 micron in diameter
  - 300 micron in obese

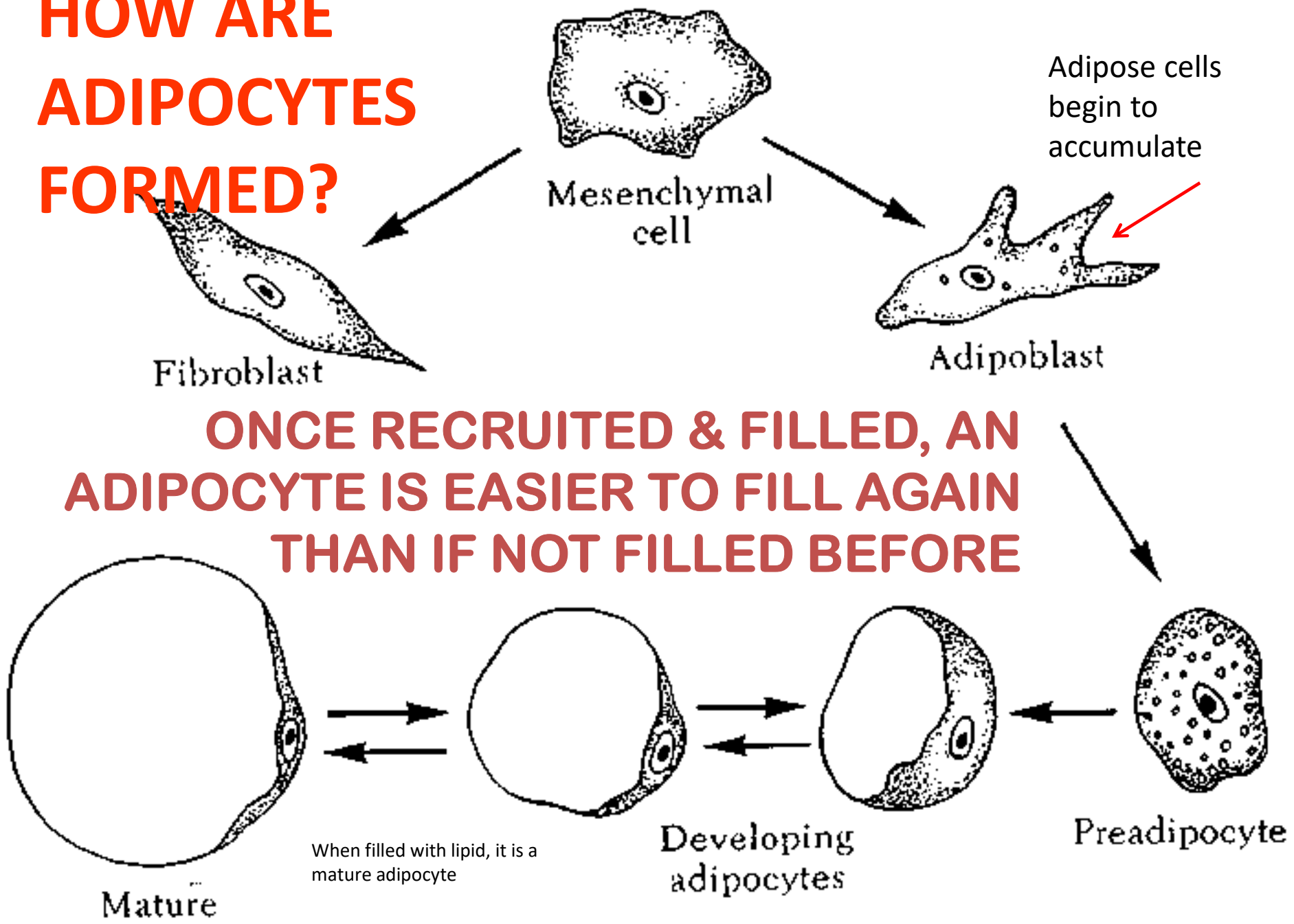


- Cellular make-up
  - 95% of cytoplasm is lipid
  - Remainder primarily nucleus

ADIPOCYTE



HOW ARE ADIPOCYTES FORMED?



ONCE RECRUITED & FILLED, AN ADIPOCYTE IS EASIER TO FILL AGAIN THAN IF NOT FILLED BEFORE

Muscle Contraction

Introduction

- Overall structure of muscle is designed for contraction and relaxation, which leads to movement and locomotion.
- The ability to contract and relax is lost during the transformation of muscle to meat.
- Events surrounding this conversion greatly impact meat palatability

Introduction

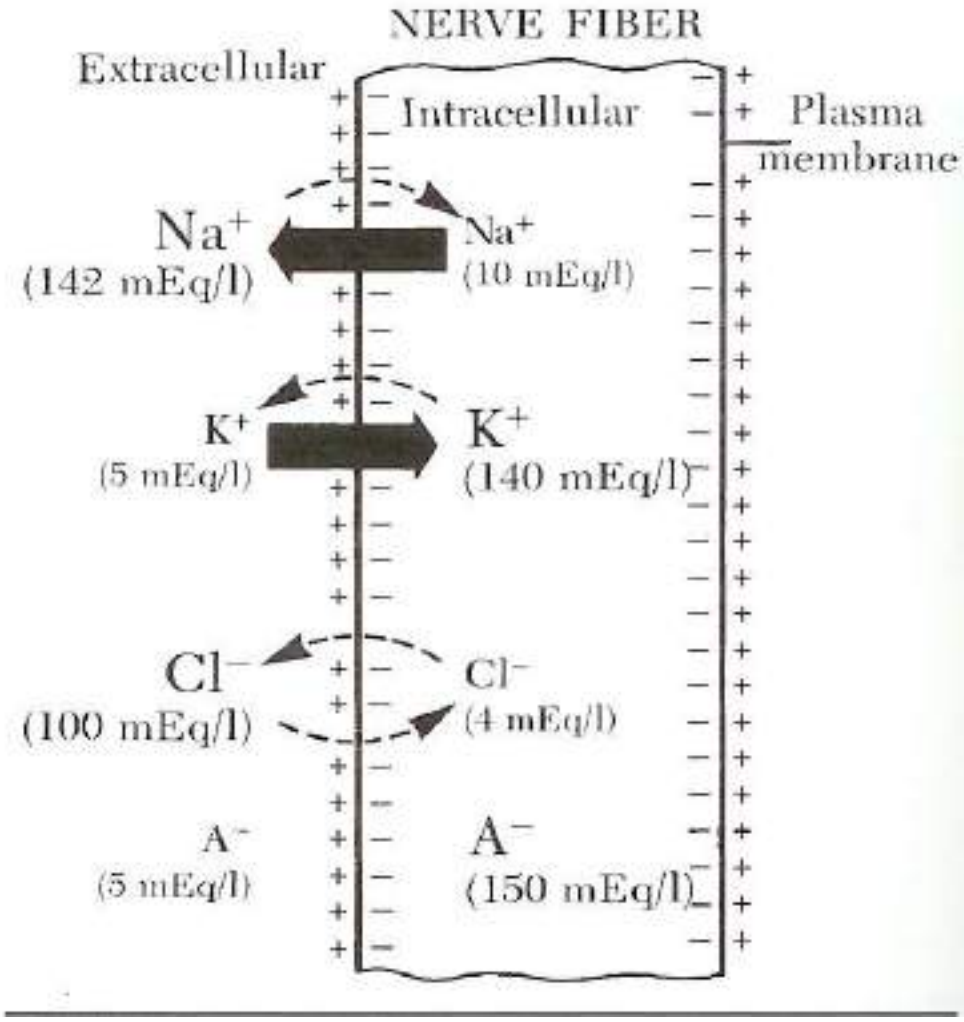
- The biochemical processes that provide energy to the living muscle cause the accumulation of metabolites during harvest
  - Affects color, WHC, pH, others
- An understanding of muscle contraction is necessary to understand these processes

Contraction

- Begins with stimuli that arrive at the surface of the muscle fiber at the sarcolemma
- Nerve impulse starts in the brain and is transmitted via nerves to the muscle

Transmembrane Potentials

- Under resting conditions, an electric potential exists between the inside and outside of the cell
  - Fluids inside are negative
  - Fluids outside are positive
  - Results in a *resting membrane potential*

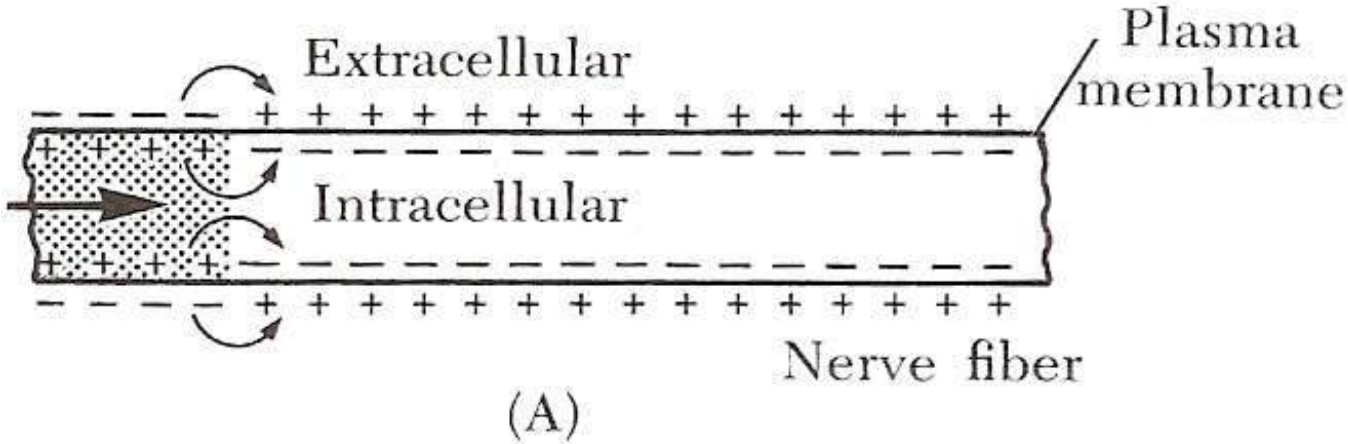

NERVE FIBER
Extracellular
Intracellular
Plasma membrane
Na+
(142 mEq/l)
Na+
(10 mEq/l)
K+
(5 mEq/l)
K+
(140 mEq/l)
Cl−
(100 mEq/l)
Cl−
(4 mEq/l)
A−
(5 mEq/l)
A−
(150 mEq/l)

Transmembrane Potentials

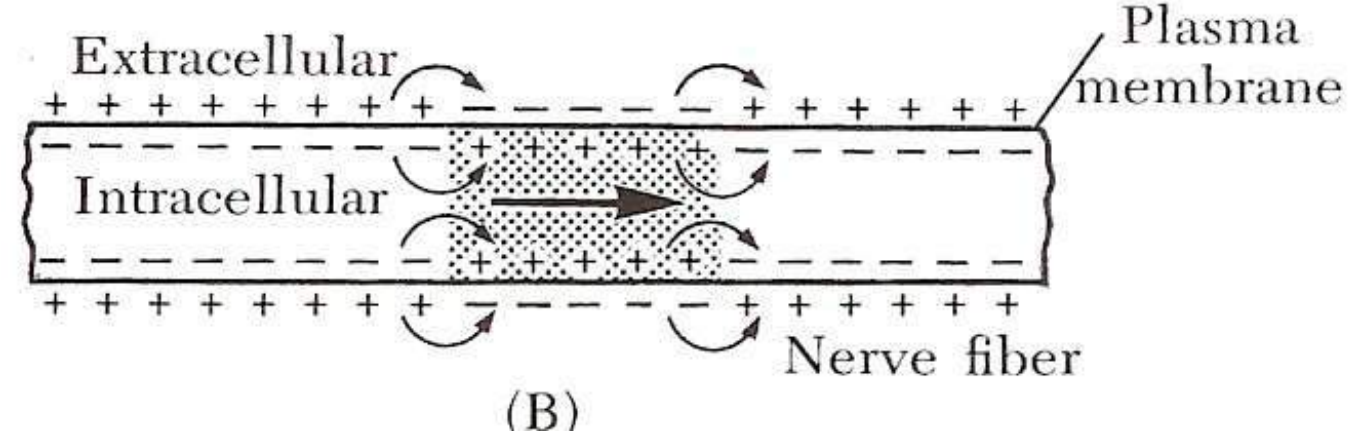
- Extracellular – Na^+ and Cl^-
- Intracellular – K^+ and A^-
- Na^+ and K^+ gradient maintained by a sodium-potassium pump.

Action Potential

- Transmits electric impulse to muscle
- Travels along the membrane surface of the nerve fiber by depolarization
  - Initiated by a dramatic increase in the permeability of Na+
  - Na+ rushes into cell to establish equilibrium; however K+ stays in cell causing a change in the net charge inside the cell to positive
    - Lasts only a millisecond (0.5 to 1 millisecond) before the permeability to Na+ is changed to resting state


Extracellular
Plasma membrane
Intracellular
Nerve fiber

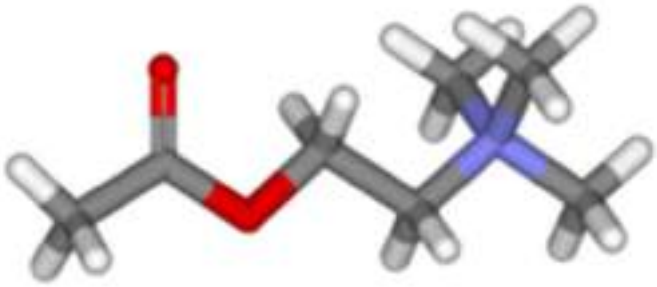
(A)

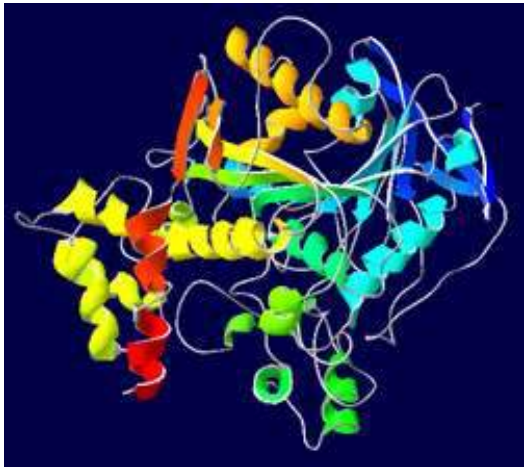

Extracellular
Plasma membrane
Intracellular
Nerve fiber

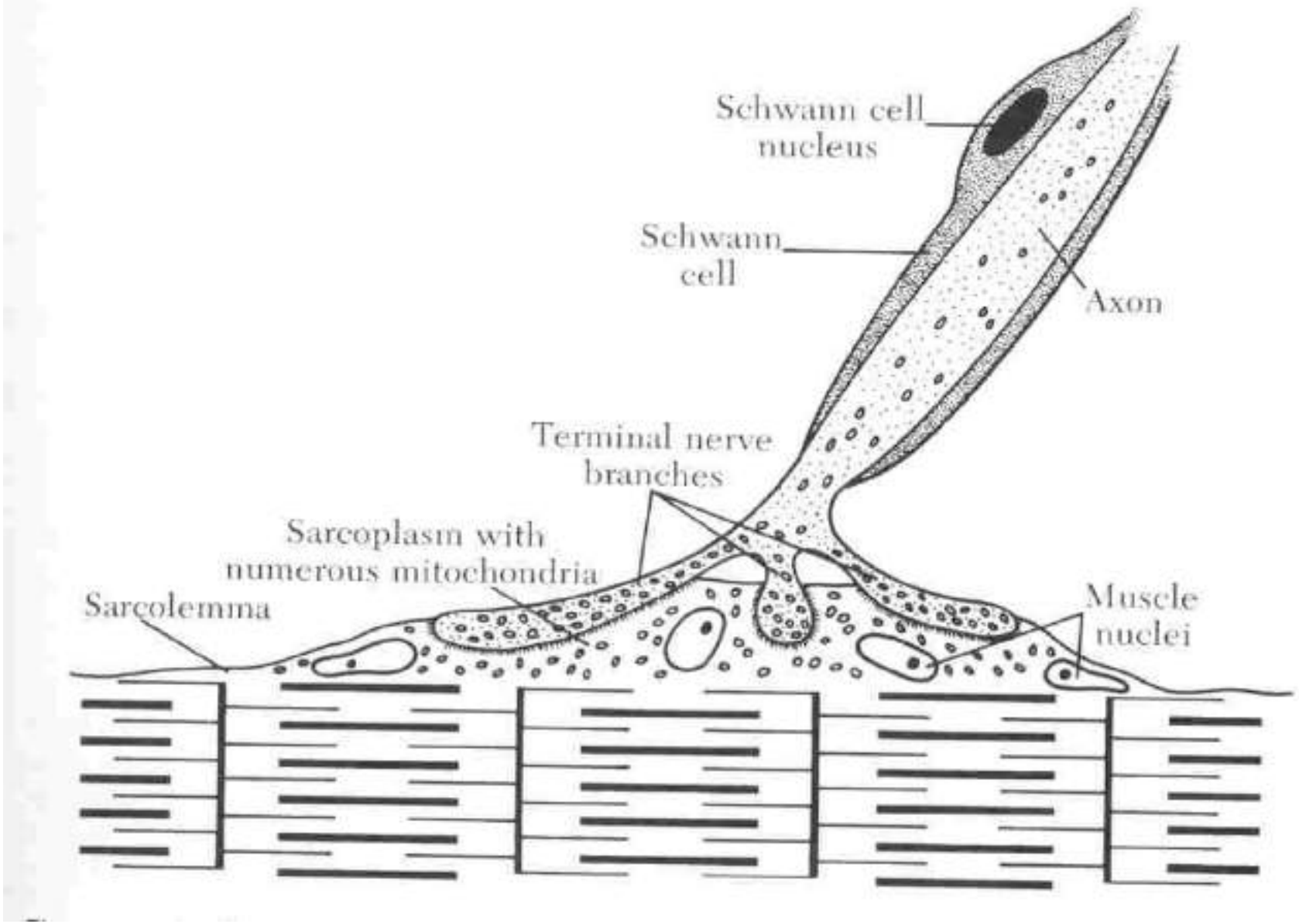
(B)

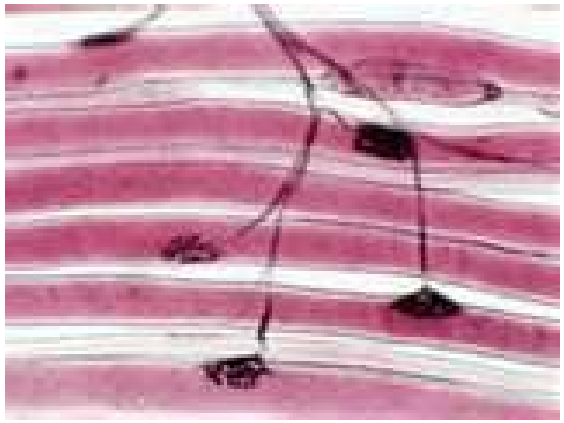
Myoneural Junction

- Action potential is not strong enough to elicit a response alone
- Uses a chemical transmitter called *acetylcholine* to be released.
  - Acetylcholinesterase is quickly released to neutralize the acetylcholine

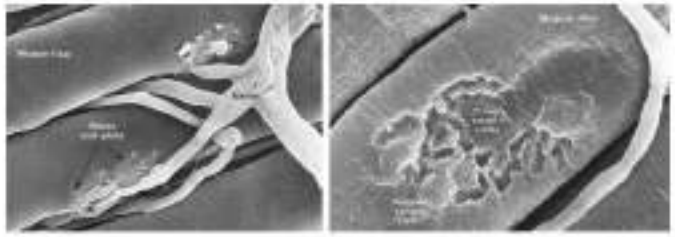




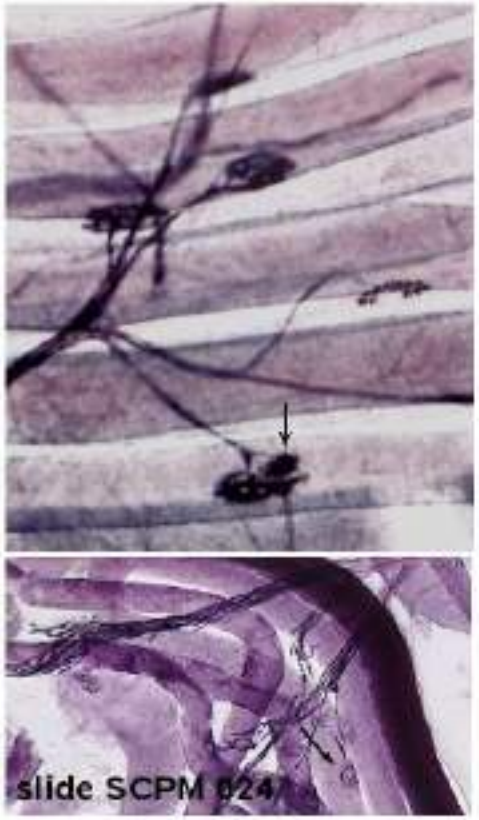

Schwann cell nucleus
Schwann cell
Axon
Terminal nerve branches
Sarcoplasm with numerous mitochondria
Sarcolemma
Muscle nuclei



Neuromuscular Junction (SEM)

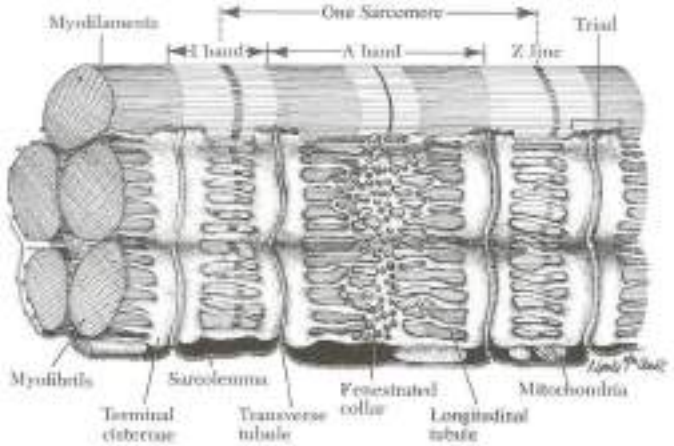


Motor End Plates: Structures of the neuromuscular junction



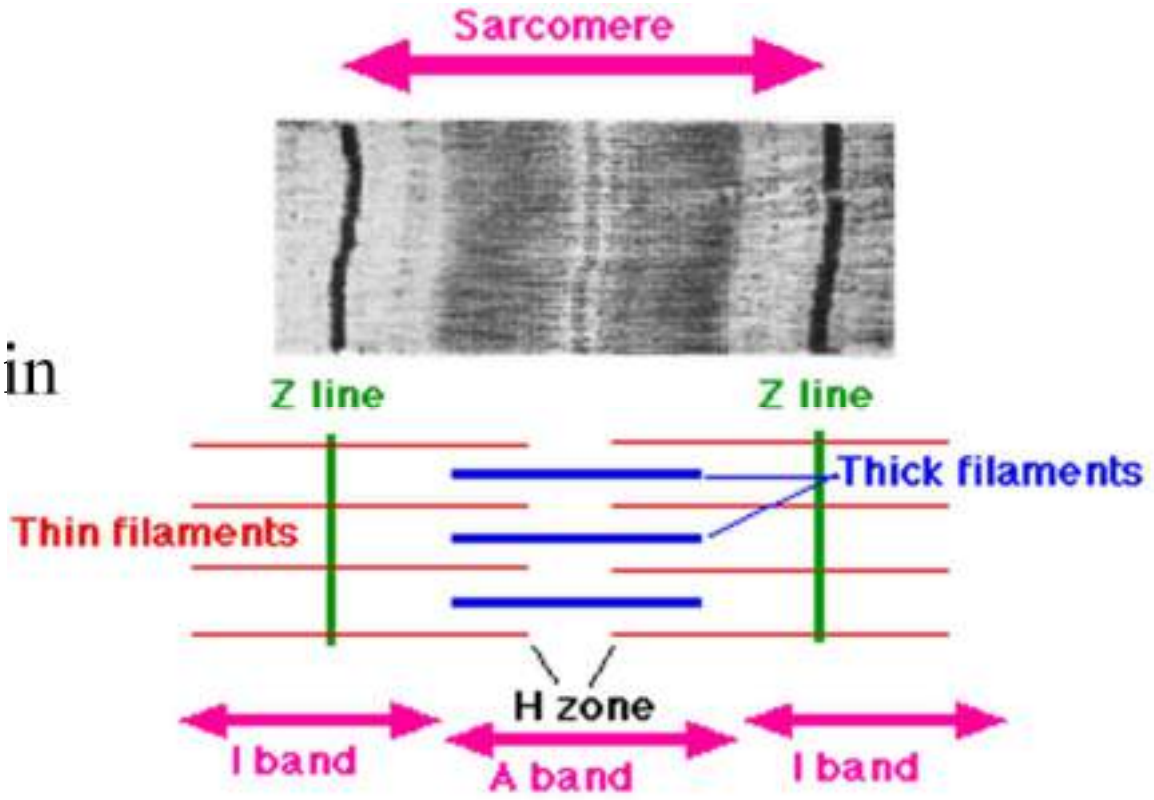
Muscle Action Potentials

- Same as the action potential for nerve fibers
- Communicated to the inner muscle cell via the T-tubule system
  - Action potential transverse a muscle fiber via the t-tubules and are ultimately responsible for the release of calcium from the SR



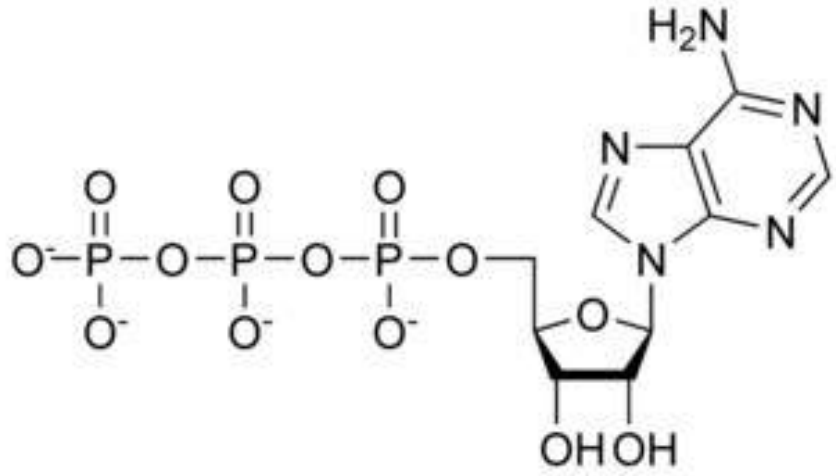
Sarcomere - Basic contractile unit of the muscle

1. Myosin
2. Actin
   a) Tropomyosin
   b) Troponin
3. Z lines



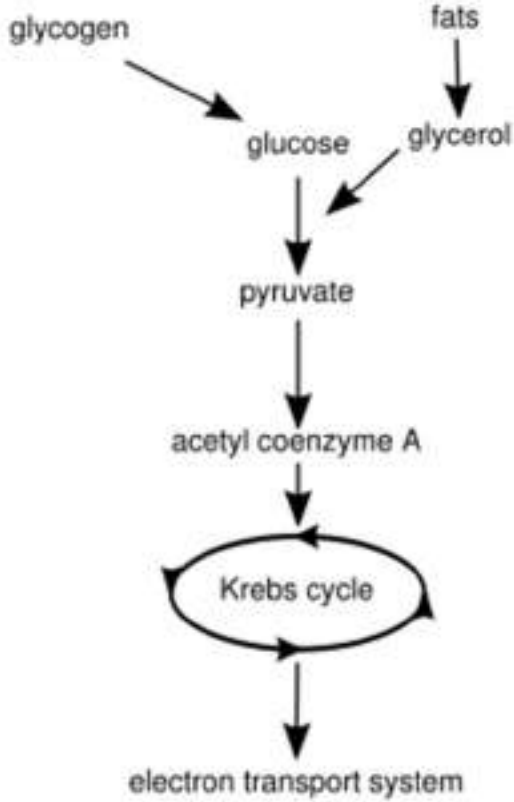
Elements required for muscle contraction and relaxation

1. Acetylcholine and Acetylcholinesterase
2. Calcium
3. Adenosine 5'-triphosphate (ATP)
   a) Derived from aerobic and anaerobic metabolism

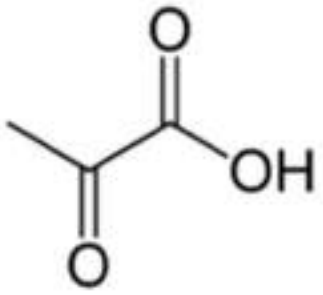


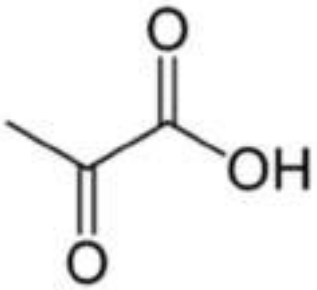
Sources of Energy for Muscle Contraction and Relaxation

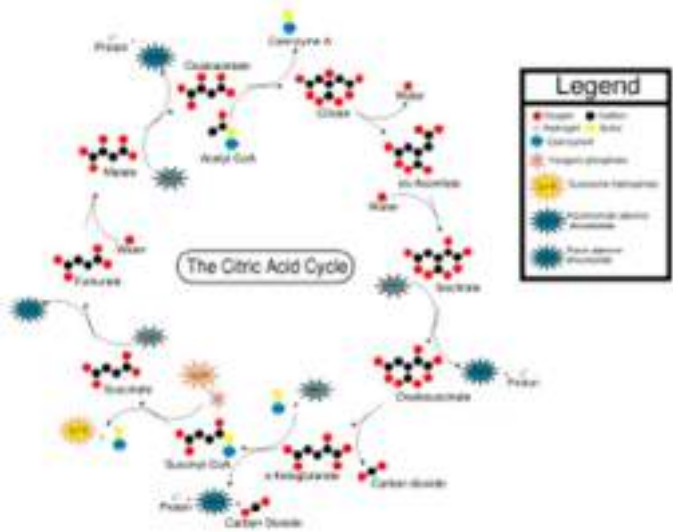
Energy

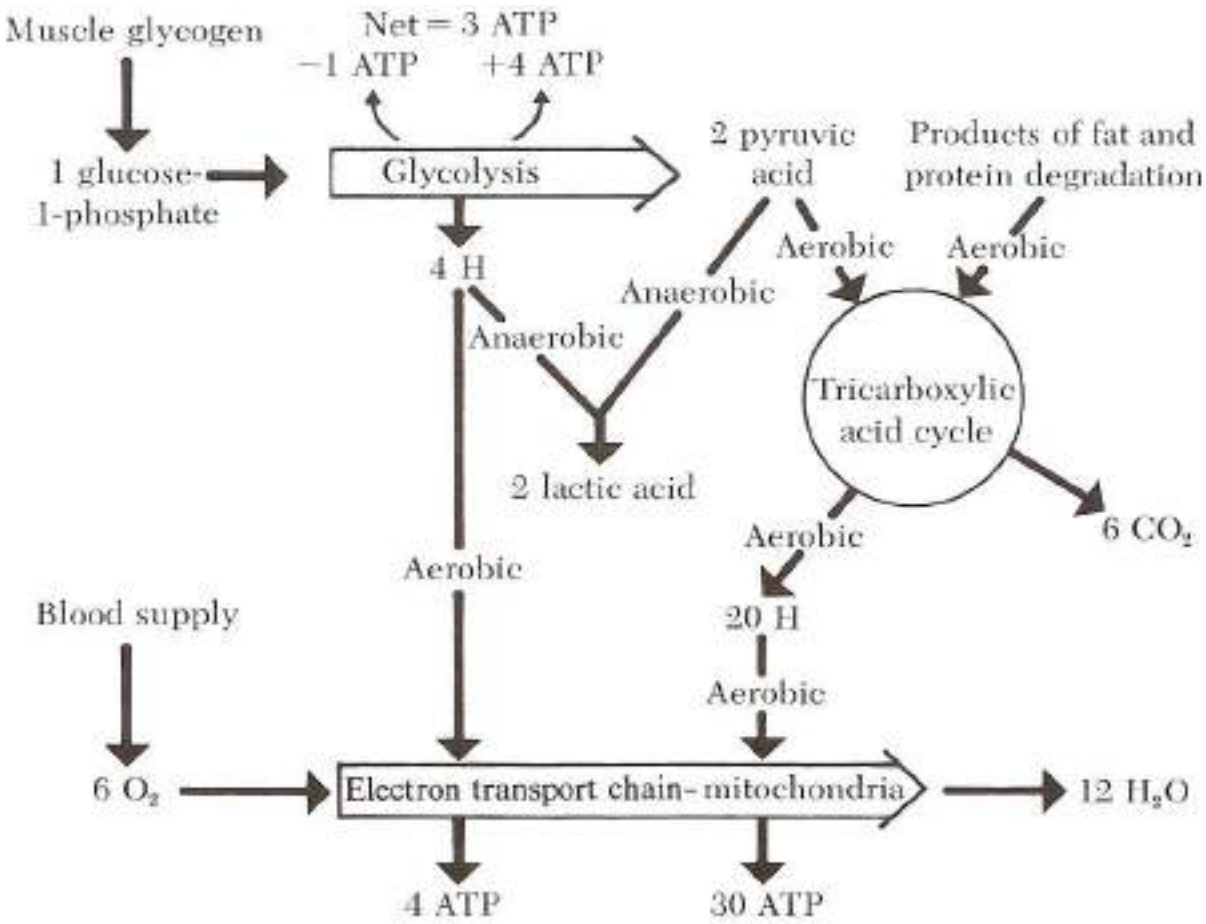


- Aerobic
  - Glycolysis
  - TCA cycle
  - Electron transport chain
- Anerobic
  - Excess Hydrogen is used to reduce pyruvic acid to lactic acid, which permits glycolysis to proceed at a rapid rate
  - Easily fatigued

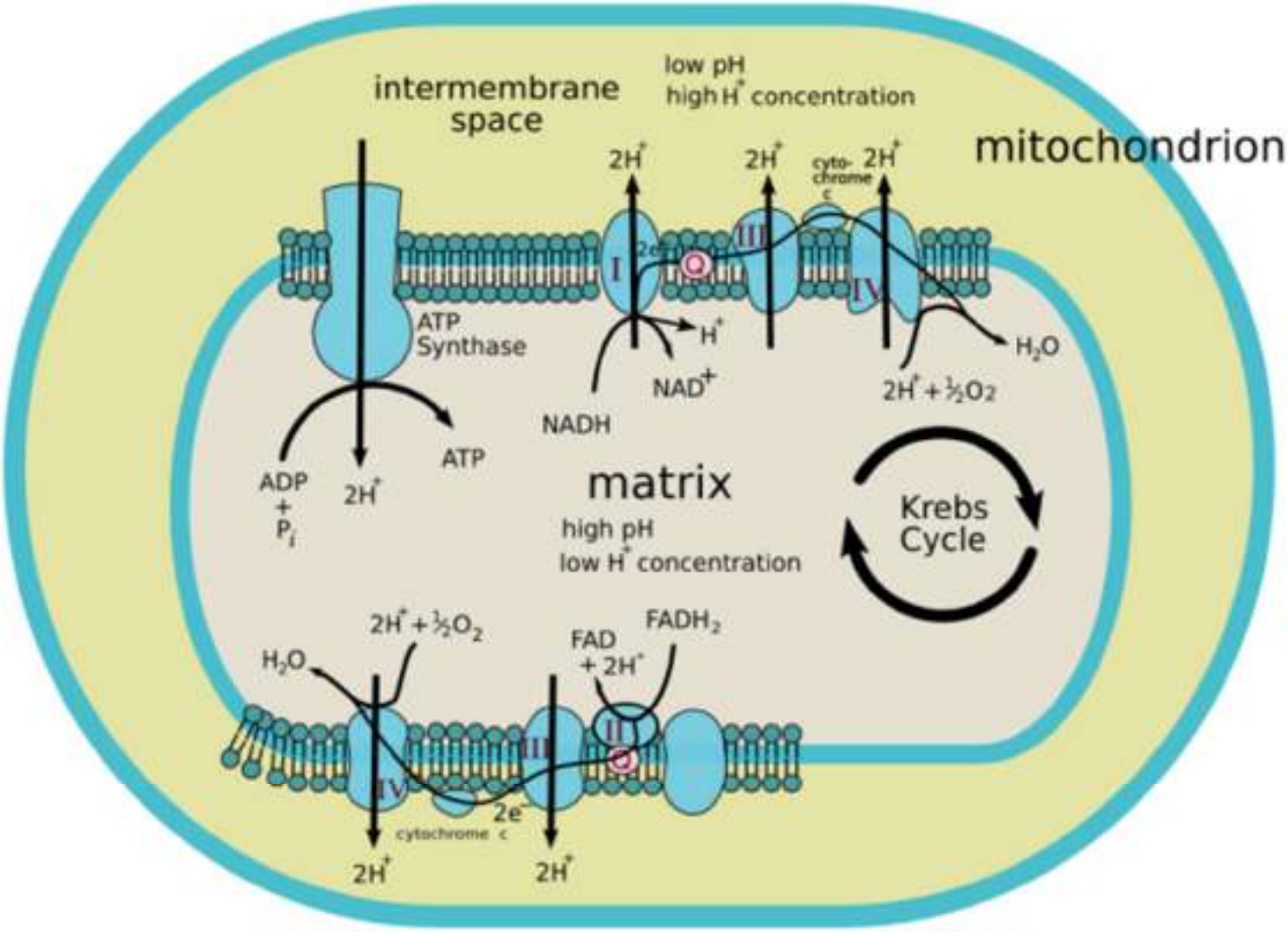



O
OH
O


Legend
The Citric Acid Cycle


Muscle glycogen
Net = 3 ATP
−1 ATP
+4 ATP
1 glucose-1-phosphate
Glycolysis
2 pyruvic acid
Products of fat and protein degradation
Aerobic
Aerobic
4 H
Anaerobic
Anaerobic
Tricarboxylic acid cycle
2 lactic acid
6 CO_2
Aerobic
Aerobic
Blood supply
20 H
Aerobic
6 O_2
Electron transport chain–mitochondria
12 H_2O
4 ATP
30 ATP

Mitochondrial Electron Transport Chain



Contraction Phase

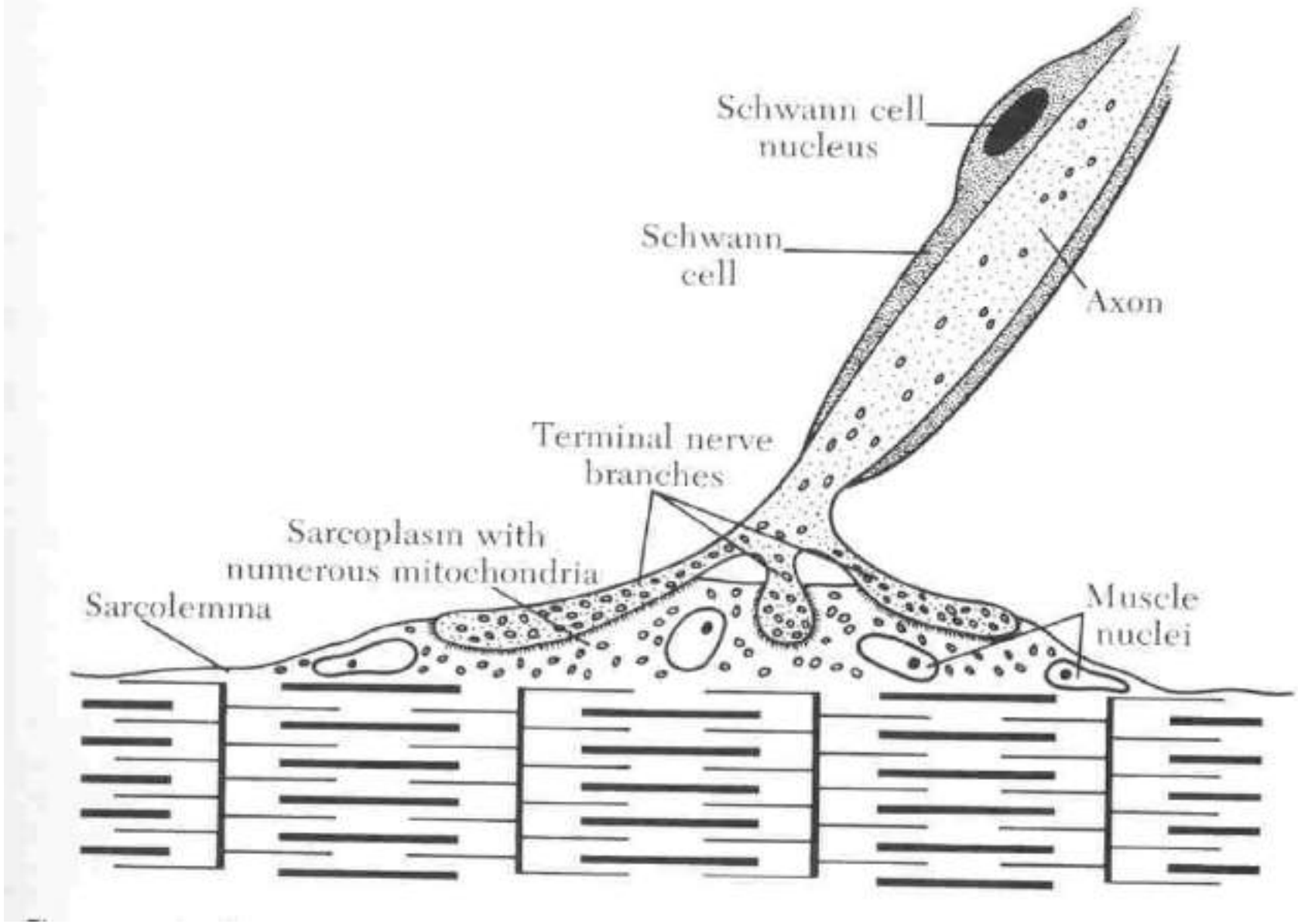
1. Nerve pulse/impulse transmitted through action potential

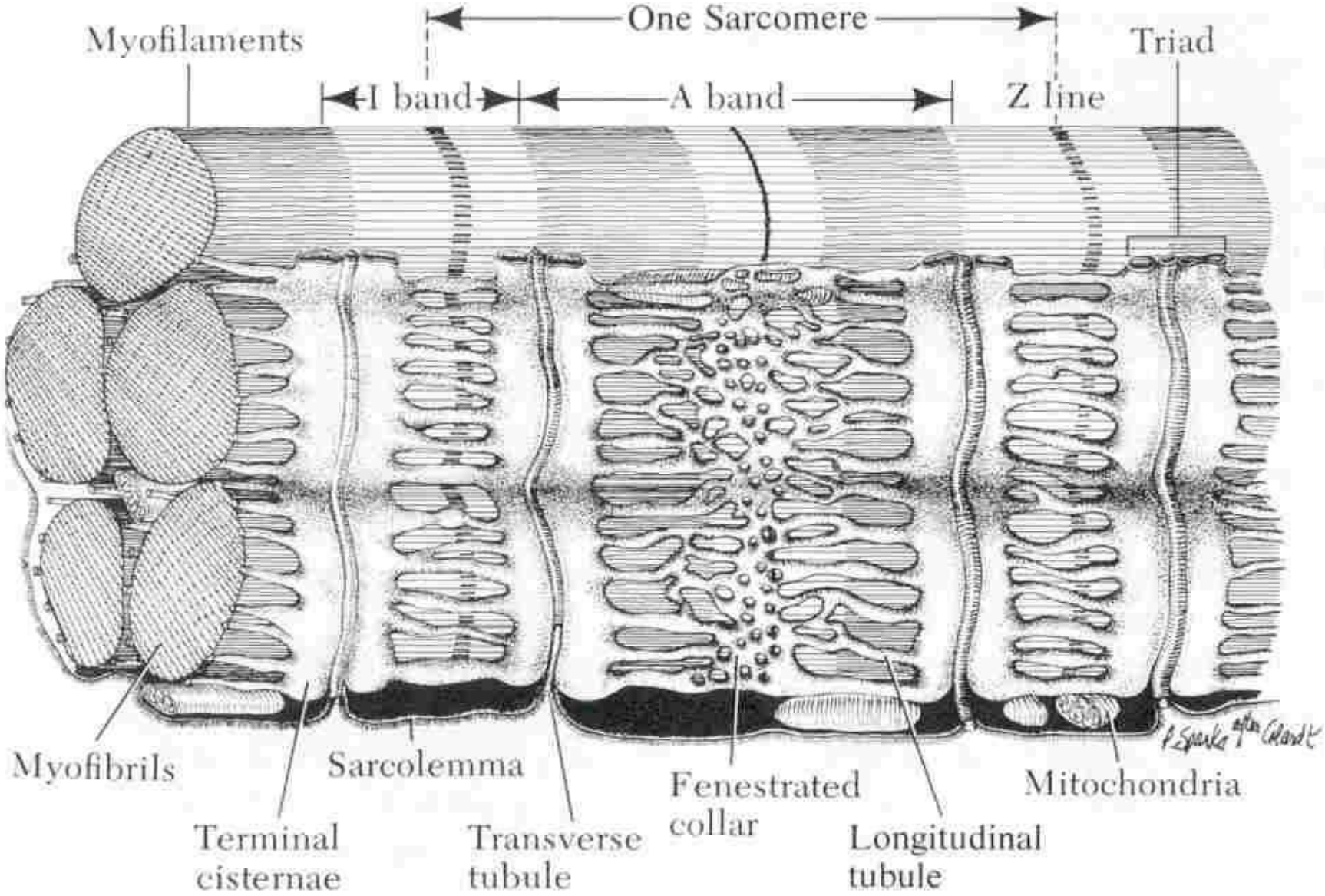
↓

2. Acetylcholine is released at neural juncture

↓

3. Action potential transmitted to muscle fiber via the T-tubles to the sarcoplasmic reticulum (SR)


Schwann cell nucleus
Schwann cell
Axon
Terminal nerve branches
Sarcoplasm with numerous mitochondria
Sarcolemma
Muscle nuclei


One Sarcomere
Myofilaments
Triad
I band
A band
Z line
Myofibrils
Sarcolemma
Fenestrated collar
Mitochondria
Terminal cisternae
Transverse tubule
Longitudinal tubule

Contraction phase

4. Calcium is released from SR into sarcoplasm

↓

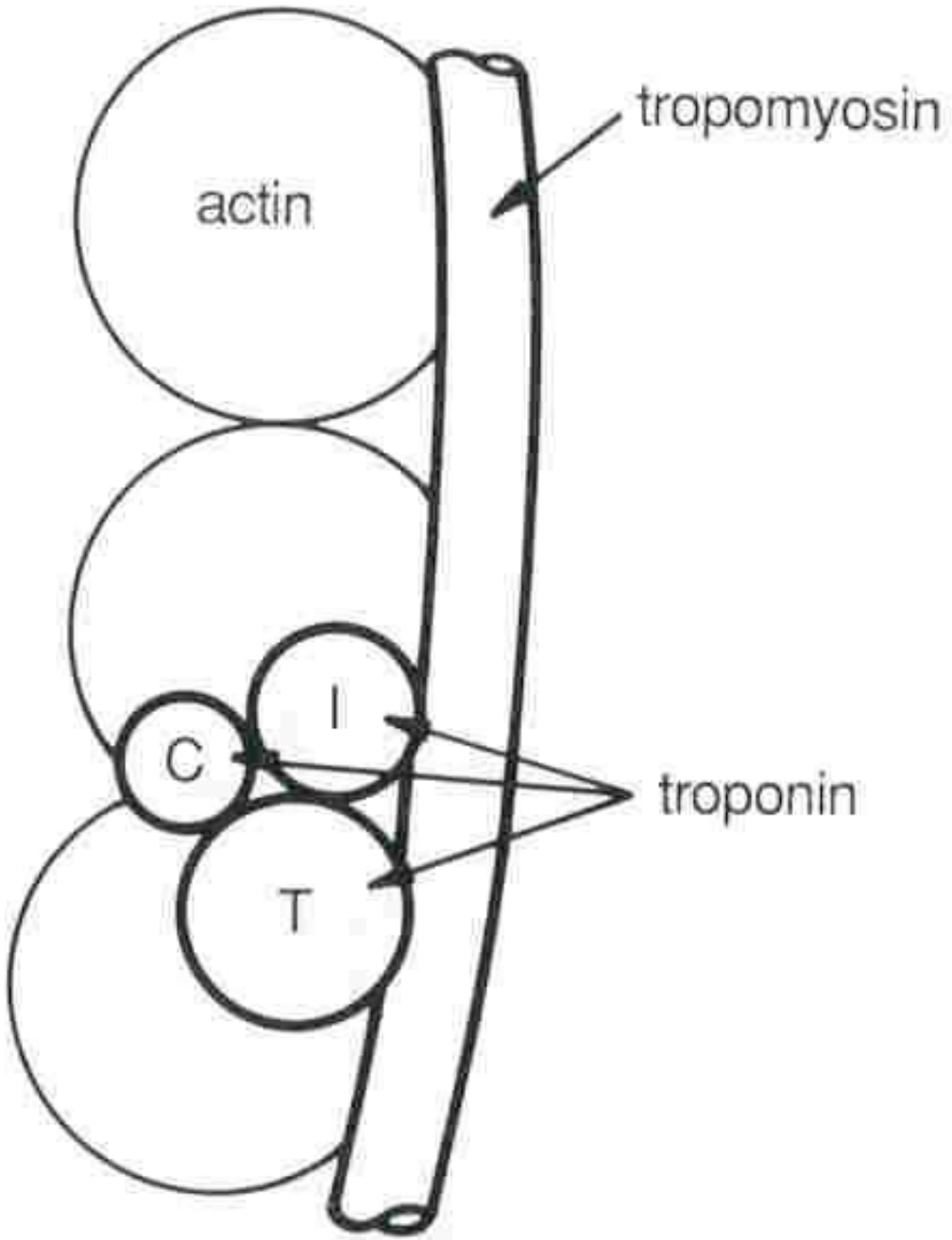
5. Calcium binds to troponin

↓

6. ATP is hydrolyzed (burned)

↓

7. Energy causes a shift in tropomyosin and actin binding site is exposed


tropomyosin
actin
I
C
troponin
T

Contraction phase

8. Actin-myosin cross bridge forms (cross bridge is termed actomyosin)

↓

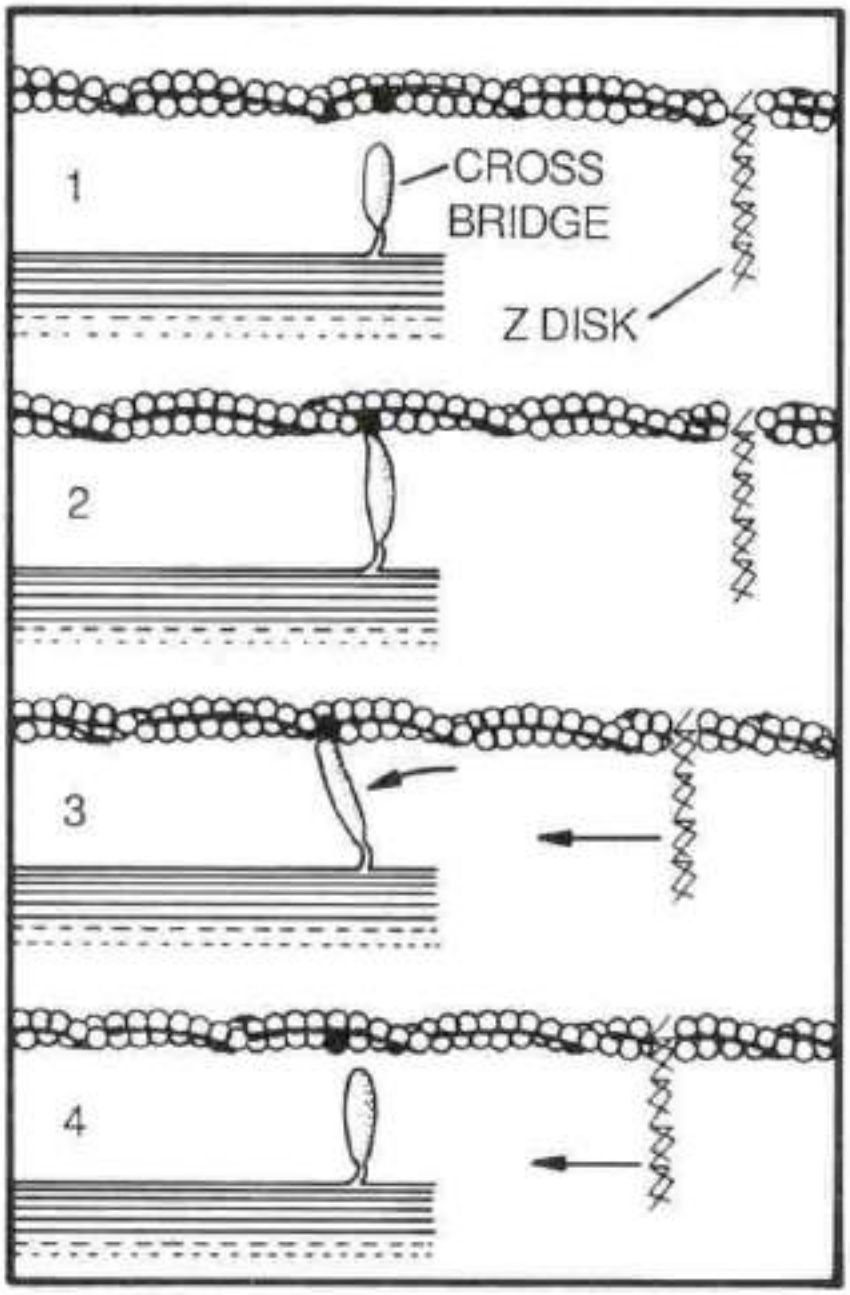
9. ATP hydrolyzed

↓

10. Myosin head rotates

↓

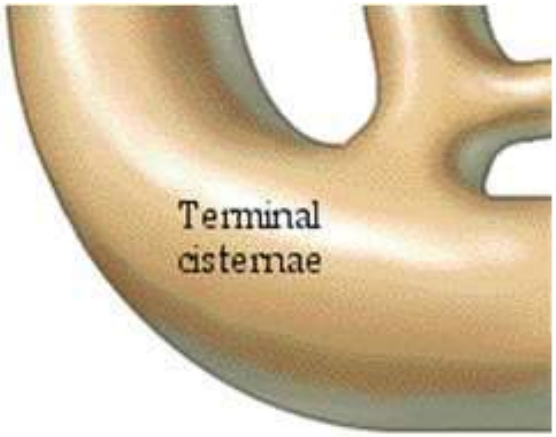
11. Repeated over and over; filaments slide causing shortening of sarcomere

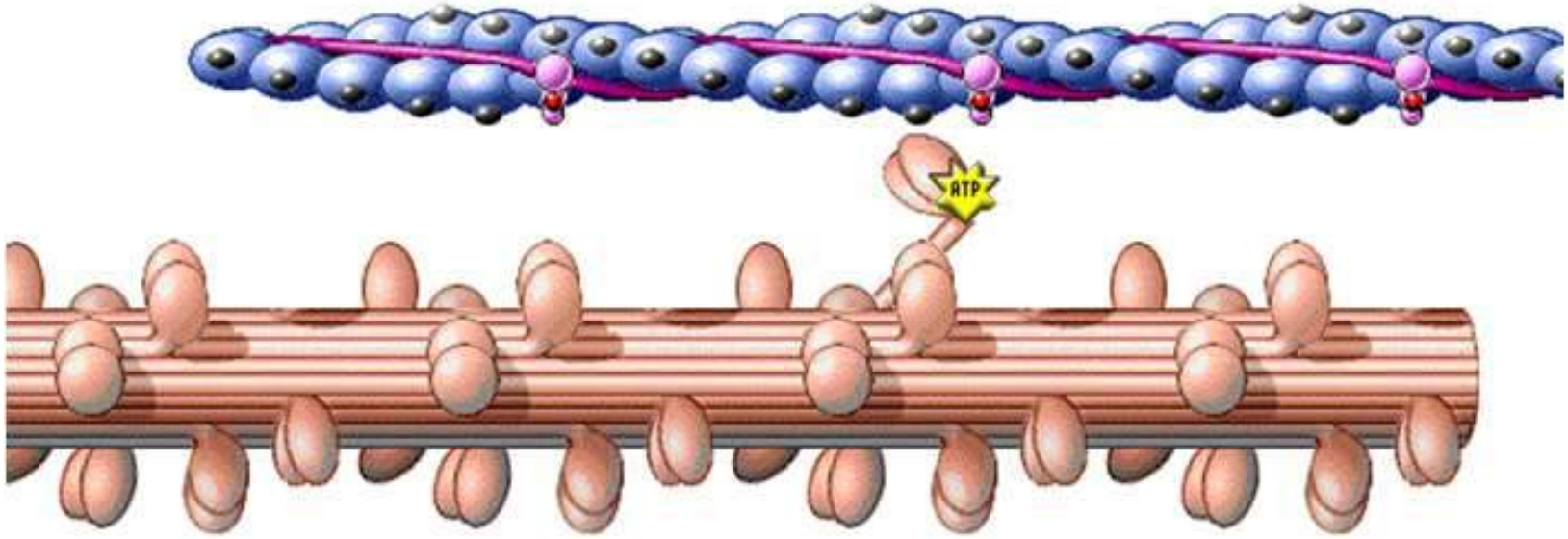

1
CROSS
BRIDGE
Z DISK
2
3
4

Contraction

Disconnecting the Cross Bridge from Actin

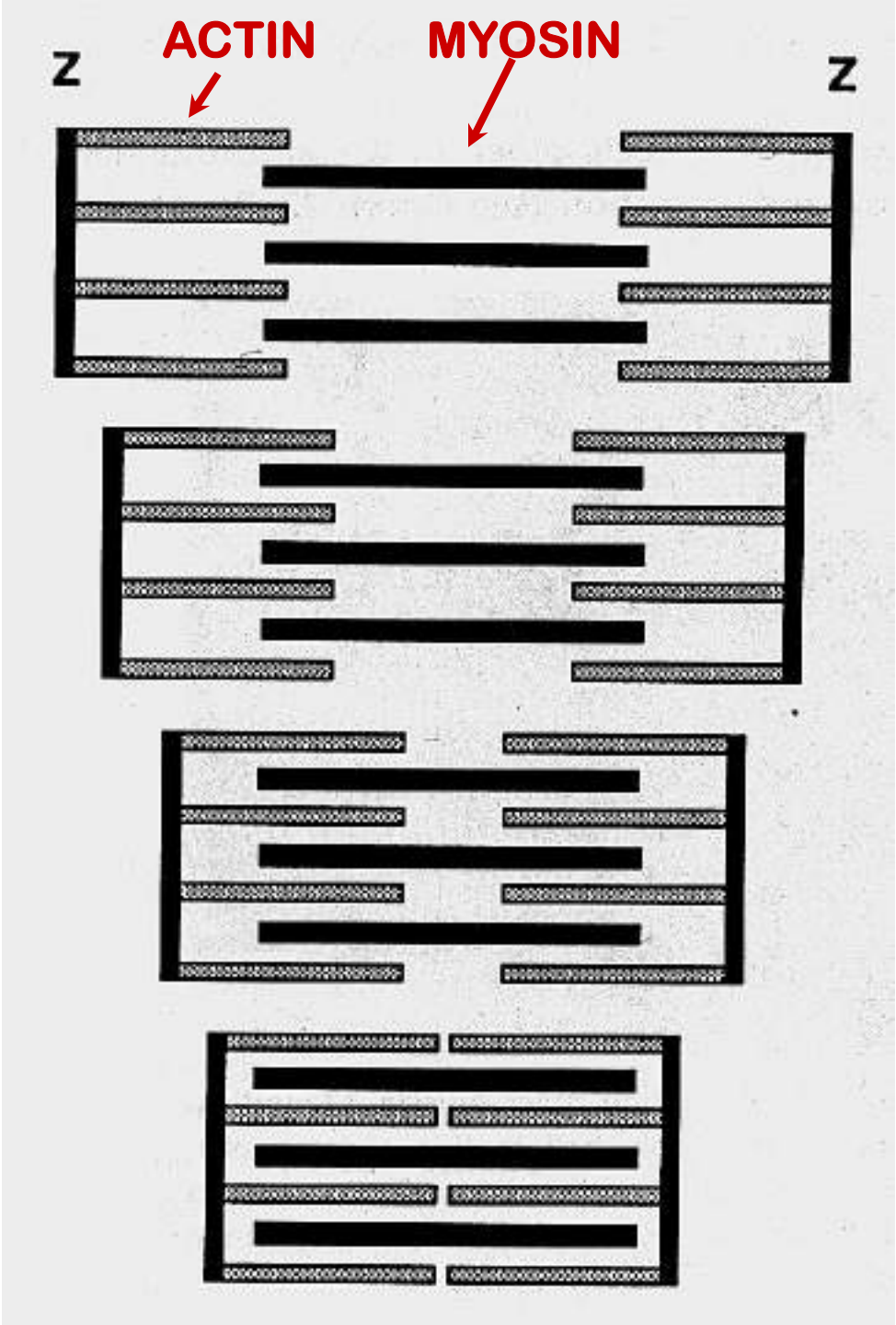
In order to disconnect the cross bridge from actin, an ATP molecule must bind to its site on the myosin cross bridge.





A sarcomere contracting

Notice that neither filament changes length



Relaxation phase

1. Acetylcholinesterase is released (neutralizes acetylcholine)

↓

2. Calcium pump activated by SR to sequester calcium

↓

3. Actin-myosin cross bridge terminated

↓

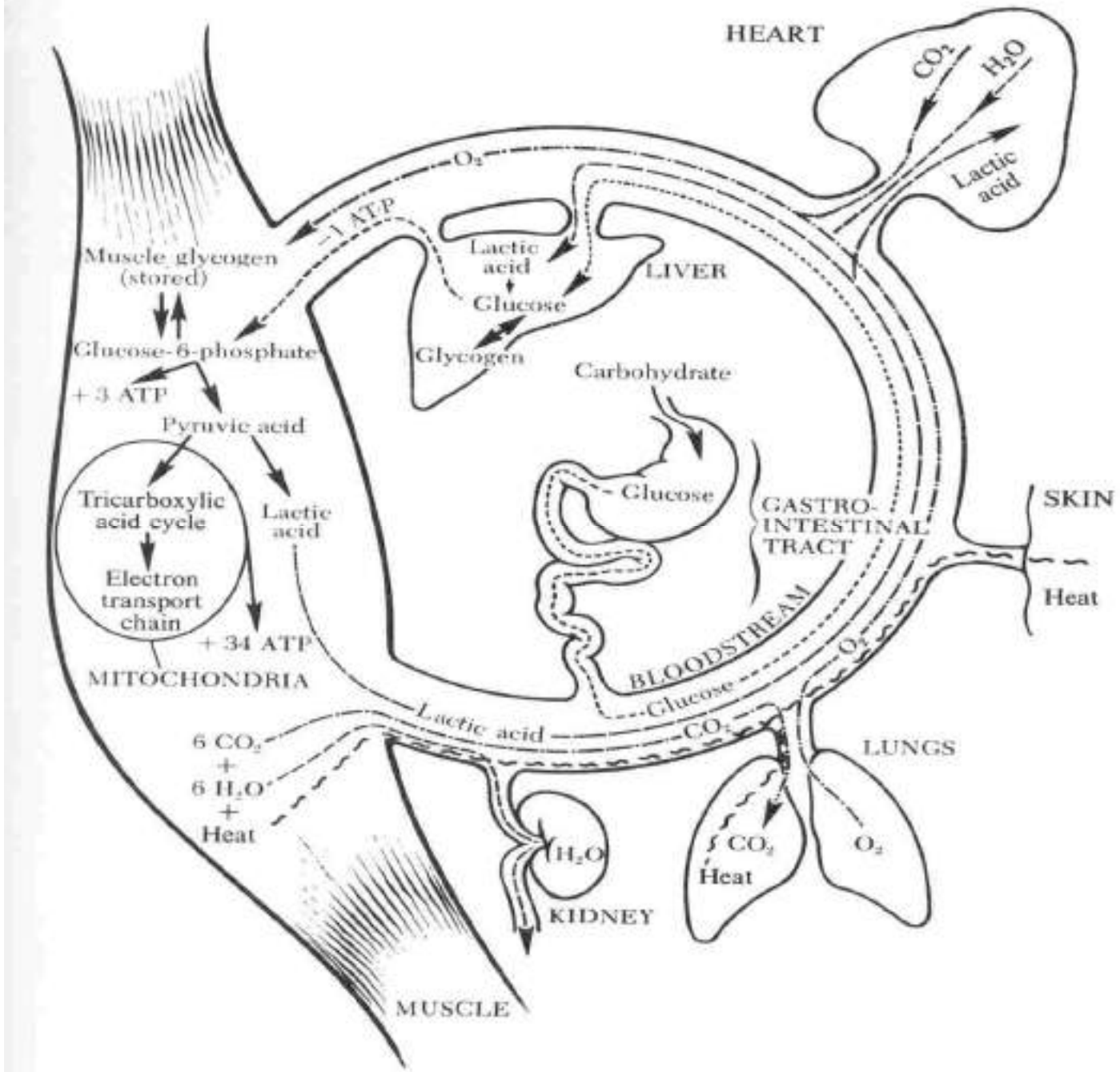
4. Tropomyosin shifts covering the binding site on actin

Relaxation phase

5. Passive sliding of filaments

↓

6. Sarcomere returns to resting state


HEART
CO_2
H_2O
Lactic acid
O_2
-1 ATP
Muscle glycogen (stored)
Lactic acid
LIVER
Glucose
Glycogen
Glucose-6-phosphate
+ 3 ATP
Pyruvic acid
Carbohydrate
Glucose
GASTRO-INTESTINAL TRACT
SKIN
Heat
Tricarboxylic acid cycle
Electron transport chain
Lactic acid
+ 34 ATP
MITOCHONDRIA
BLOODSTREAM
Glucose
O_2
Lactic acid
CO_2
LUNGS
6 CO_2 + 6 H_2O + Heat
H_2O
KIDNEY
CO_2
Heat
O_2
MUSCLE

Thankyou for your patience