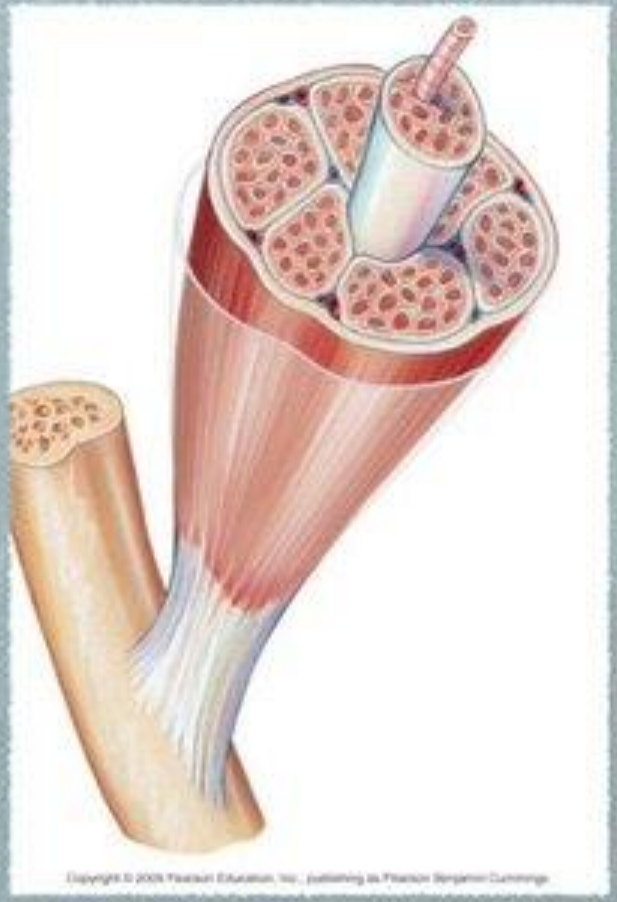
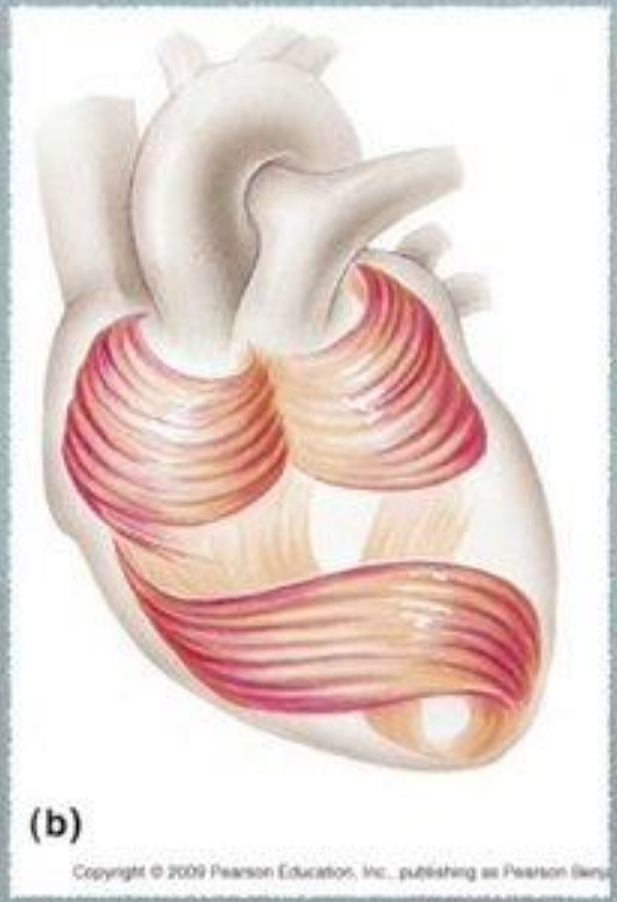
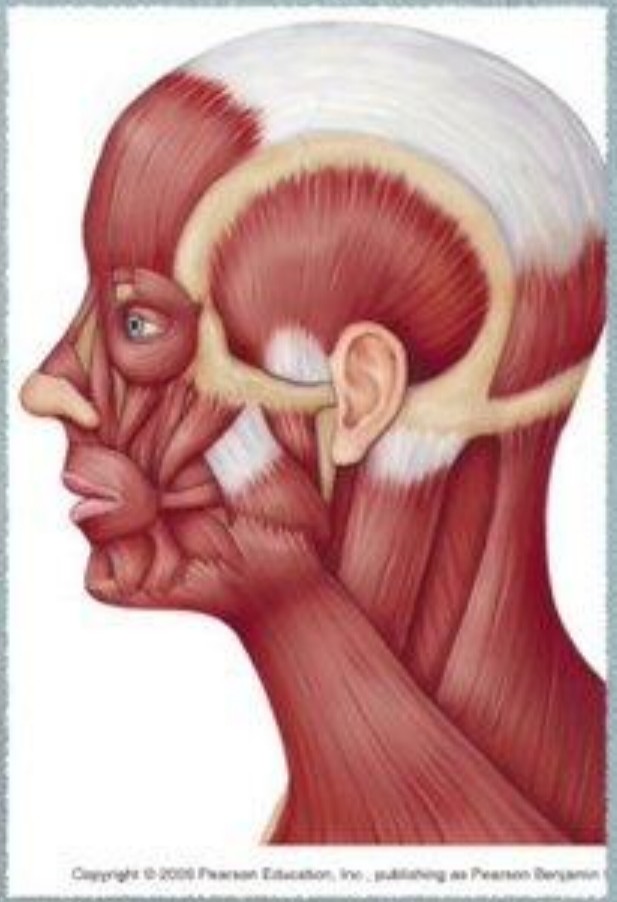






Muscular System

How does cause change in the physical world?

MUSCULAR SYSTEM

- The **muscular system** is the biological system of humans that produces movement.
- The muscular system, in vertebrates, is controlled through the nervous system, although some muscles, like cardiac muscle, can be completely autonomous.
- **Muscle** is contractile tissue and is derived from the mesodermal layer of embryonic germ cells.
- Its function is to produce force and cause motion, either locomotion or movement within internal organs.
- Much of muscle contraction occurs without conscious thought and is necessary for survival, like the contraction of the heart or peristalsis, which pushes food through the digestive system.

- Voluntary muscle contraction is used to move the body and can be finely controlled, such as movements of the finger or gross movements that of the biceps and triceps.
- There are approximately 640 skeletal muscles in the human.
- Contrary to popular belief, the number of muscle fibers cannot be increased through exercise; instead the muscle cells simply get bigger.
- It is however believed that myofibrils have a limited capacity for growth through hypertrophy and will split if subject to increased demand.
- There are three basic types of muscles in the body (smooth, cardiac, and skeletal).

근육의 종류

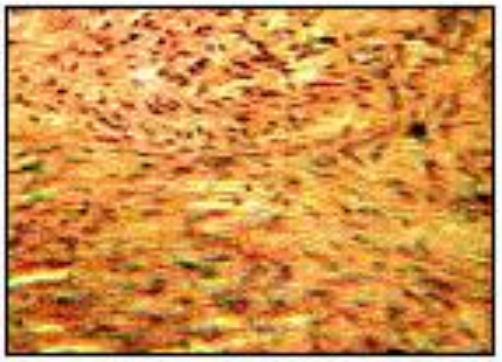
구조 분류

- 횡문근(striated muscle)
  - 골격근(skeletal muscle)
  - 심장근(cardiac muscle)
- 평활근(smooth muscle)
  - 다단위평활근(multi-unit smooth muscle)
  - 장기평활근(visceral smooth muscle)

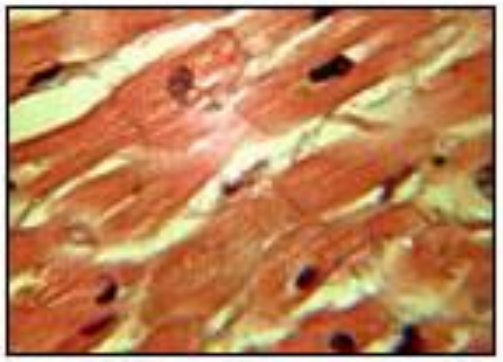
• **근육**

: 화학적 에너지를 **기계적 에너지**와 **열**로 변환시키는 하나의 TRANSDUCER

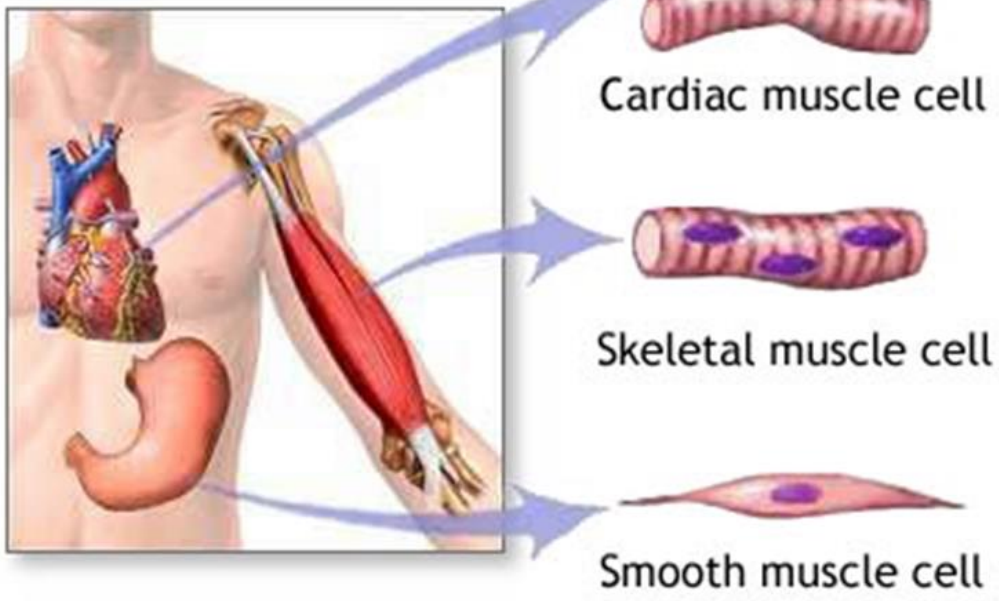
Skeletal muscle



Smooth muscle



Cardiac muscle



What is the main function of the muscular system?

- Locomotion or mobility, strength, heat production, shock absorption, shaping the body, maintaining posture, and respiration.
- In addition it plays a role in the digestive process by peristalsis to move the food through.
- It is also essential for pumping blood and plays a role in smooth muscles of the blood vessels to raise blood pressure during the stress response.
- Muscles help the body to have mobility through the environment, and motility inside the body for its processes.

근육의 발생

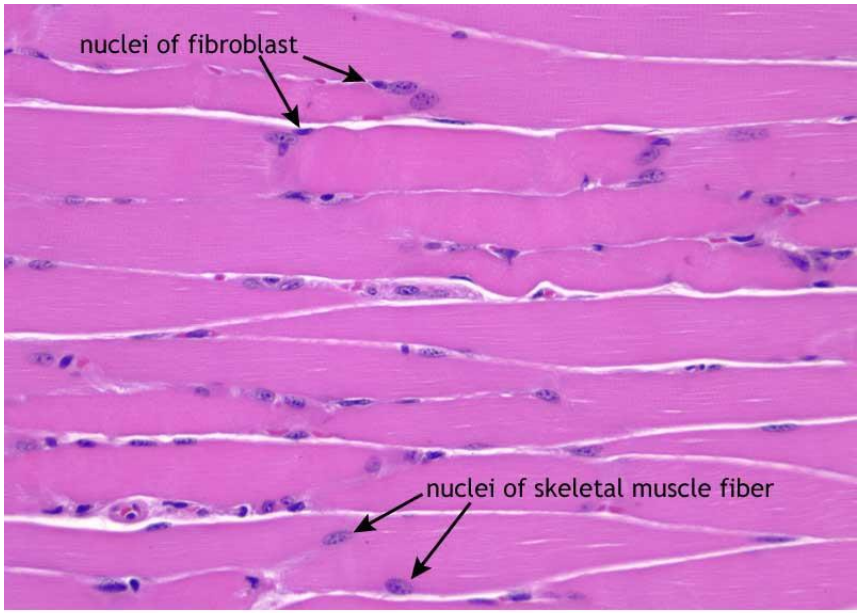
- 발생배엽: 중배엽 (mesoderm)
- 새궁(branchial arch):
  새절근(branchiomeric muscle)- 측두근, 교근, 익돌근,
  구륜근, 상안검거근 등
- 외배엽성 근: 한선의 평활근, 모양체근, 동공괄약근, 등..

근육계의 일반적 기능

- 신체운동
- 자세유지
- 호흡운동
- 배분, 배뇨
- 혈액순환
- 체열생산
- 음식물 이동

Skeletal muscle (voluntary muscle)

- is anchored by tendons to the bone
- is used to effect skeletal movement such as locomotion
- skeletal muscle cells are multinucleated with the nuclei peripherally located.
- skeletal muscle is called 'striated' because of the longitudinally striped appearance under light microscopy.



- a form of striated muscle tissue existing under control of the somatic nervous system i.e. it is voluntarily controlled.
- skeletal muscle is made up of individual components known as *muscle fibers*.
- these fibers are formed from the fusion of developmental myoblasts (a type of embryonic progenitor cell that gives rise to a muscle cell).
- the muscle fibers are long, cylindrical, multinucleated cells composed of myofibrils.
- the myofibrils are composed of actin and myosin myofibrils repeated as a sarcomere, the basic functional unit of the muscle fiber and responsible for skeletal muscle's striated appearance and forming the basic machinery necessary for muscle contraction.

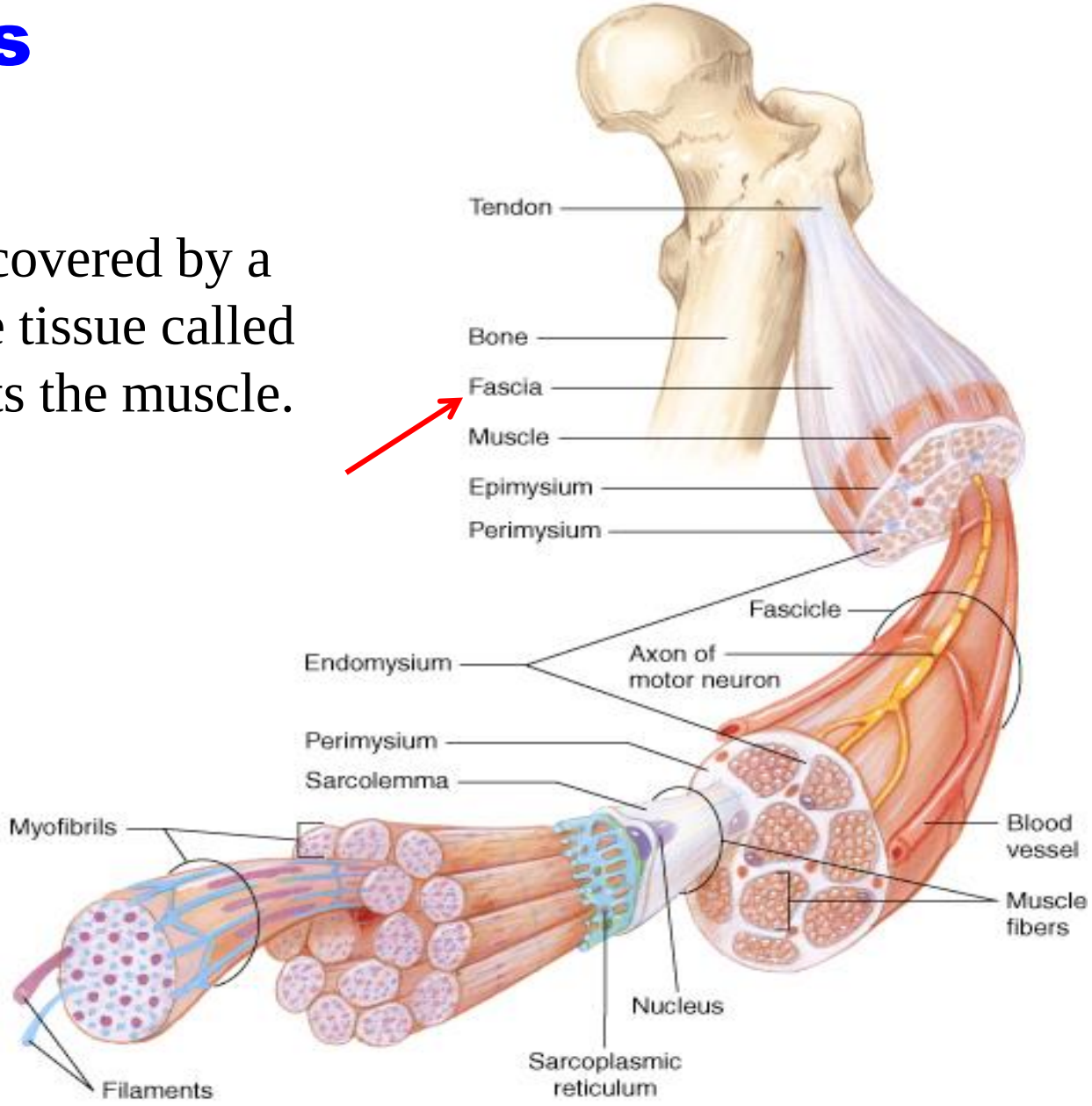
- Skeletal muscles have an abundant supply of blood vessels and nerves.
- Before a skeletal muscle fiber can contract, it has to receive an impulse from a neuron.
- Generally, an artery and at least one vein accompany each nerve that penetrates the epimysium of a skeletal muscle.
- Branches of the nerve and blood vessels follow the connective tissue components of the muscle of a nerve cell and with one or more minute blood vessels called capillaries.

- The cell membrane of a muscle cell is called the sarcolemma.
- This membrane, like that of neurons, maintains a membrane potential.
- So, impulses travel along muscle cell membranes just as they do along nerve cell membranes.
- However, the 'function' of impulses in muscle cells is to bring about contraction.
- To understand how a muscle contracts, you need to know a bit about the structure of muscle cells.

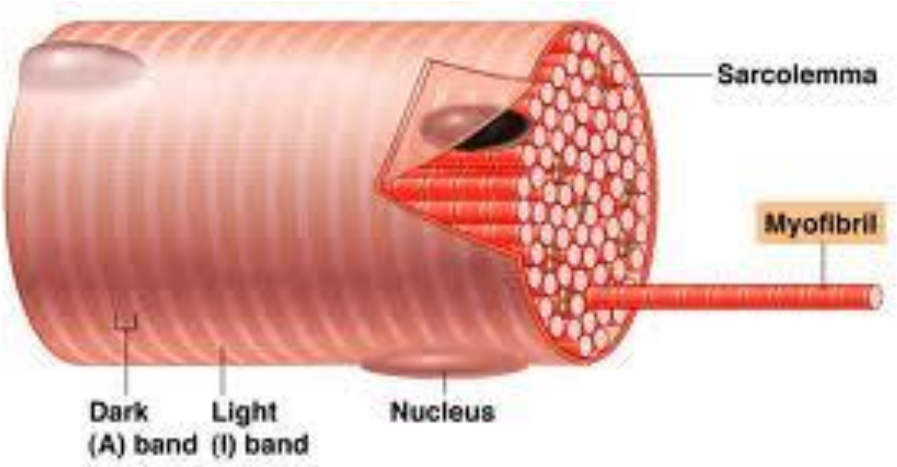
Structures

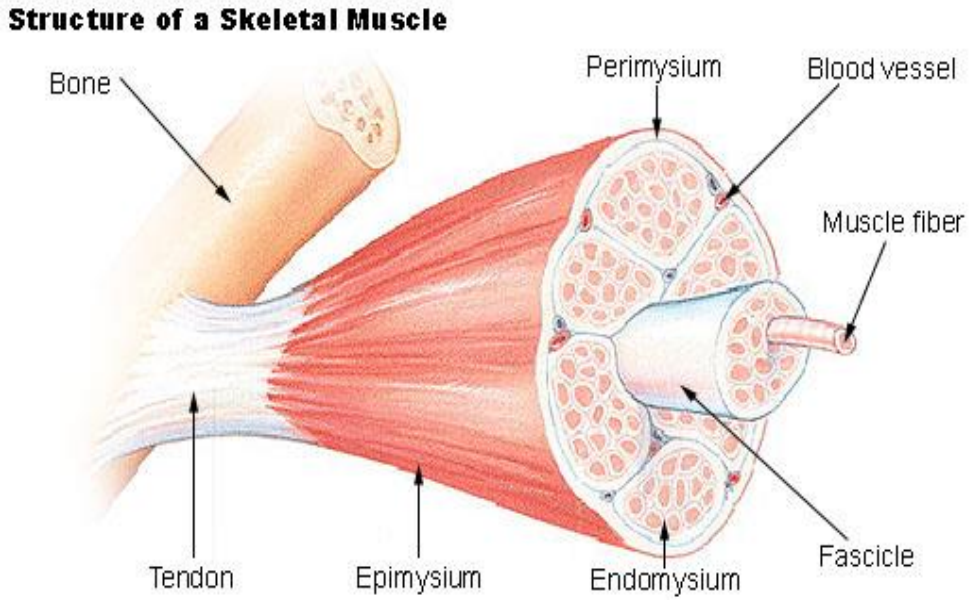
Muscles

Most muscles are covered by a band of connective tissue called fascia, that supports the muscle.



- 뼈에 근육이 붙어있는 상태로 수의근이며 줄무늬가 있다
- 근섬유는 길고 다핵이며 불규칙적으로 교차 되어 있다
- 기계적인 지지와 장력, 대사적 요구, 수축을 위한 자극을 위해 결합 조직, 혈관 및 신경조직 등이 관여한다
- 가로세관(T-tuble): 발달(A대와 I대 접합부)
- Ca^{2+} 유리: 근형질 세망(SR)
- 운동 시에 주로 사용하는 근이다





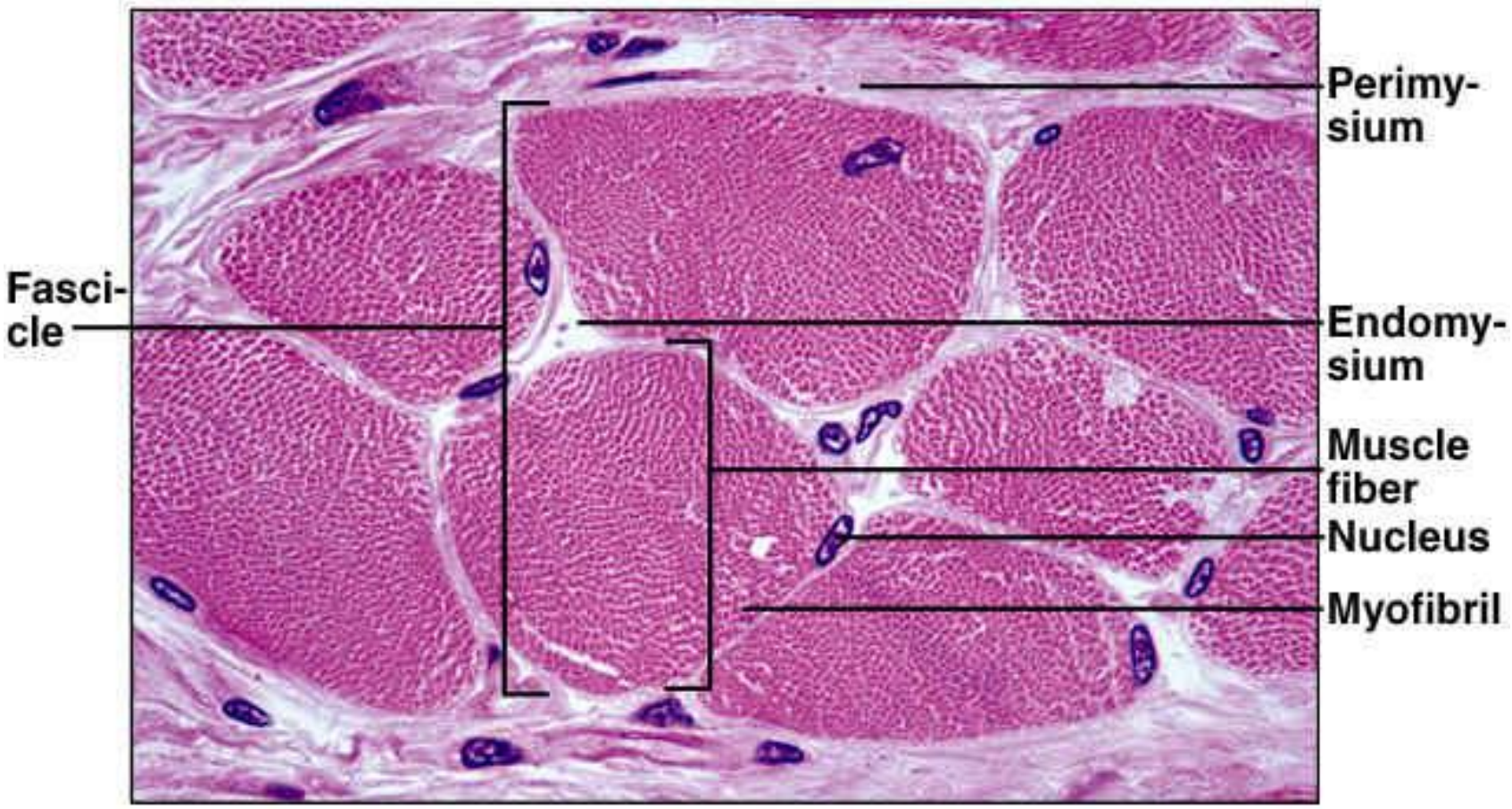
- Skeletal muscles may be made up of hundreds, or even thousands, of muscle fibers bundled together and wrapped in a connective tissue covering.
- Each muscle is surrounded by a connective tissue sheath called the epimysium

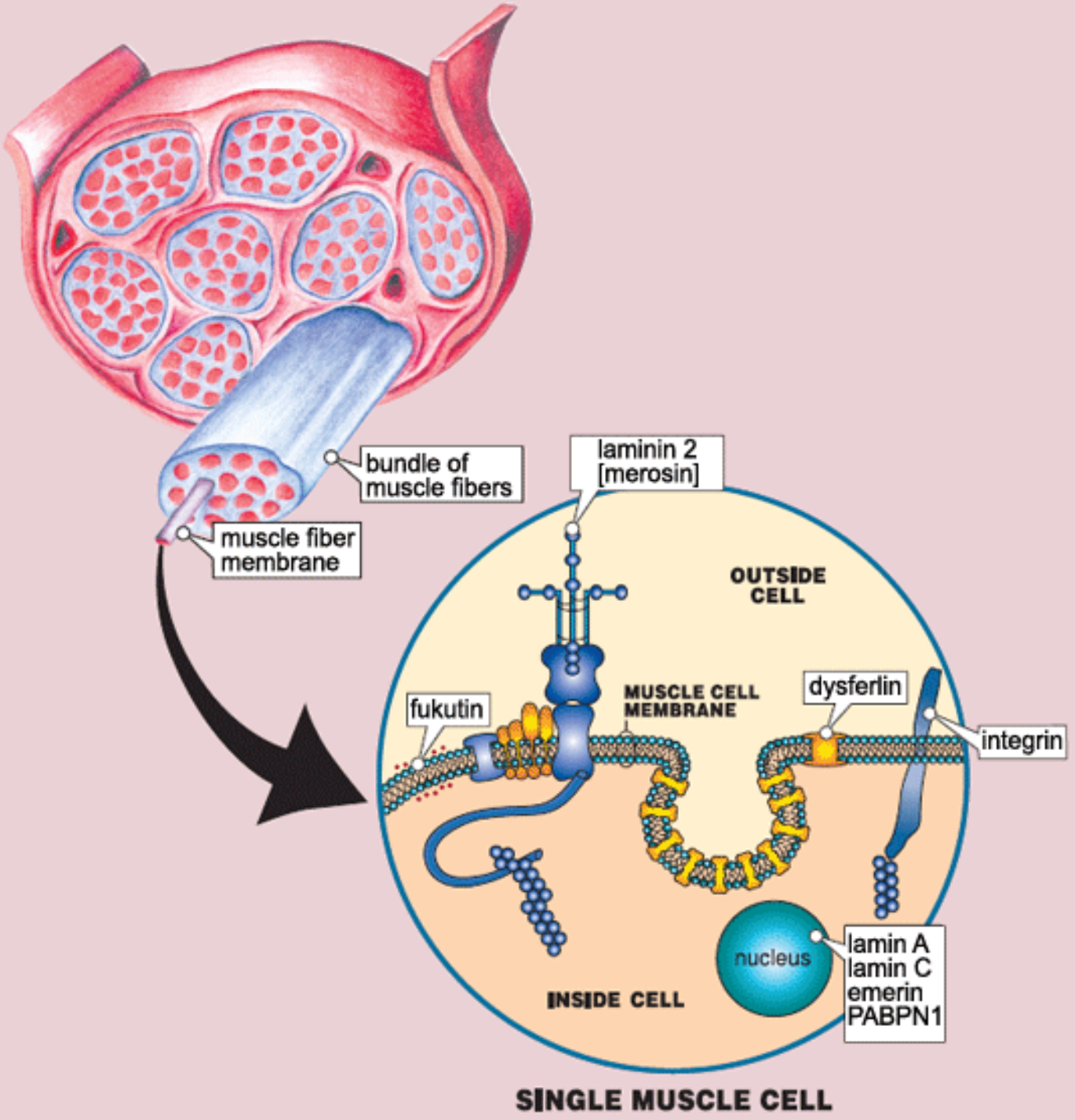
- Fascia, connective tissue outside the epimysium, surrounds and separates the muscles.

- Each bundle of muscle fiber is called a fasciculus and is surrounded by a layer of connective tissue called the perimysium.

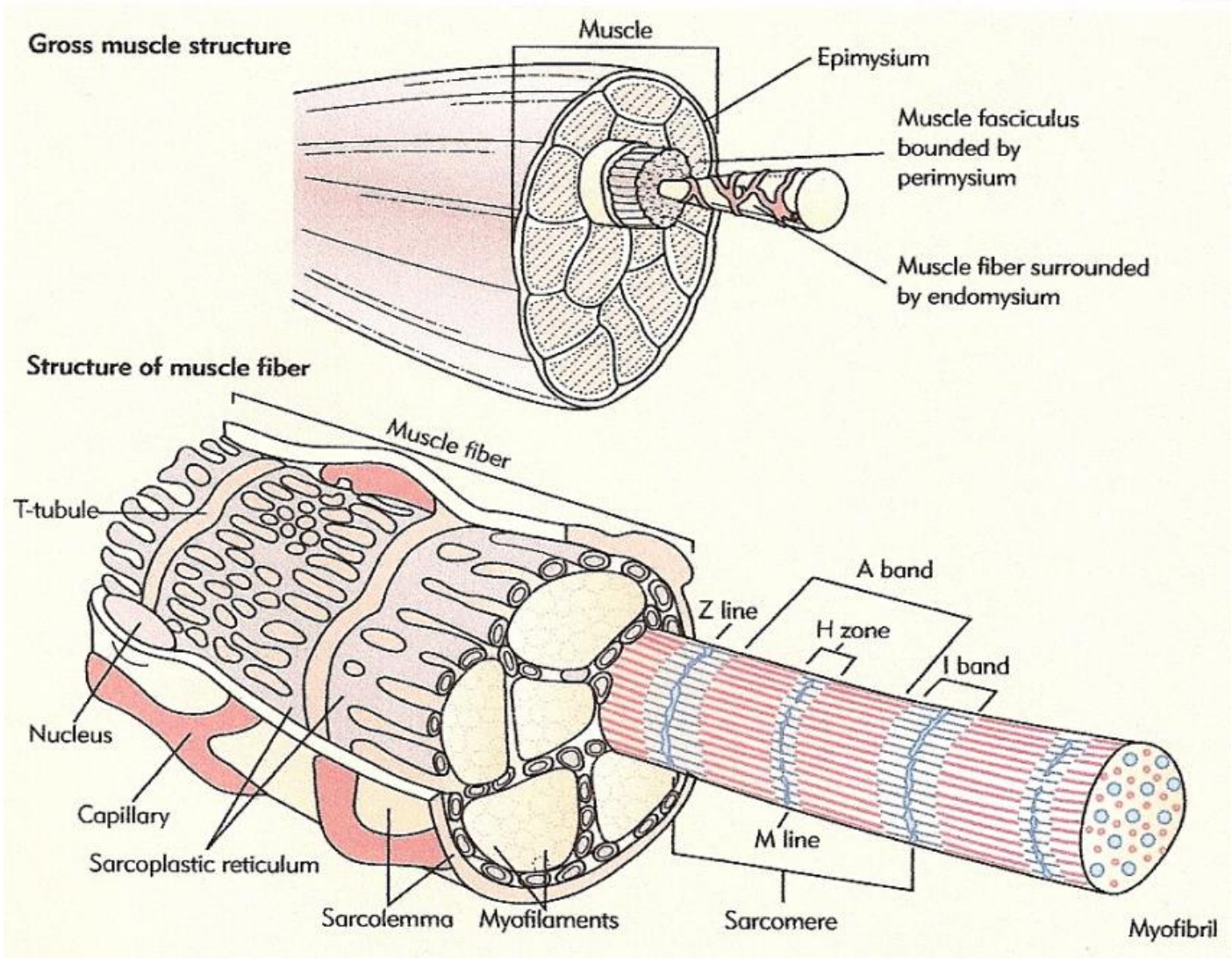
- Within the fasciculus, each individual muscle cell, called a muscle fiber, is surrounded by connective tissue called the endomysium.

Fascicle and Perimysium



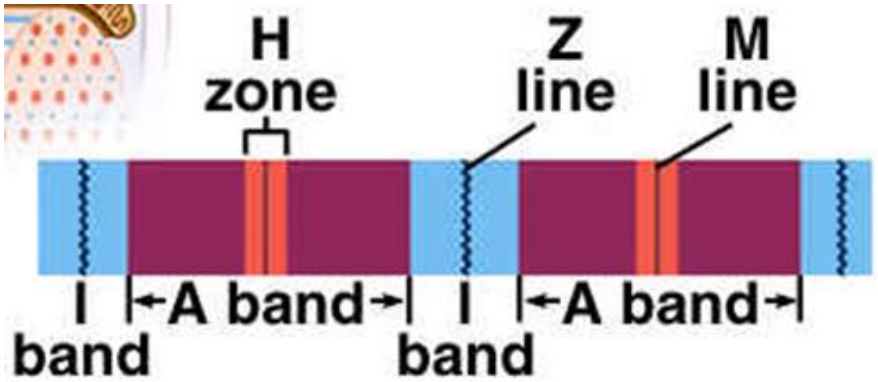


SINGLE MUSCLE CELL

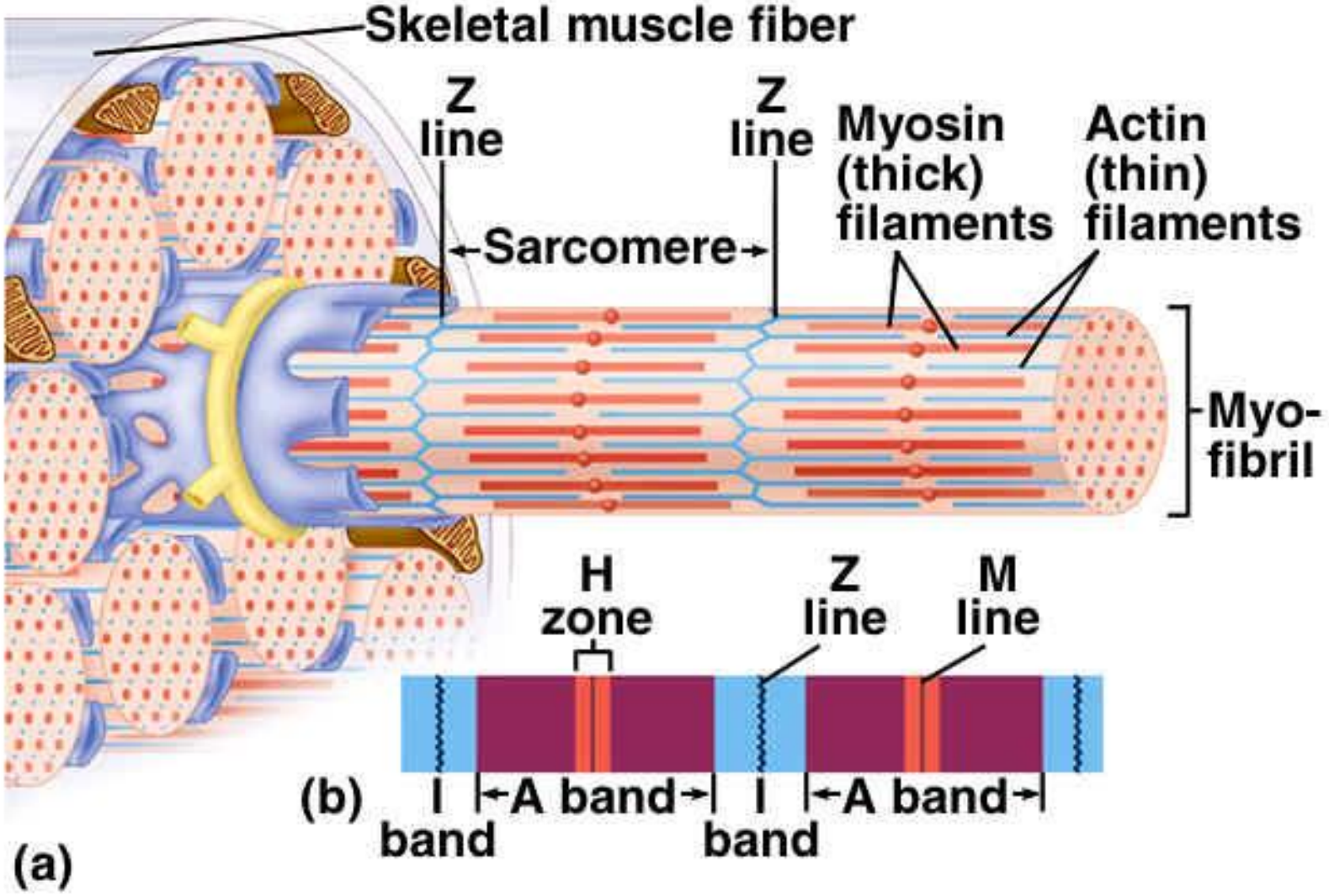

Gross muscle structure
Muscle
Epimysium
Muscle fasciculus bounded by perimysium
Muscle fiber surrounded by endomysium
Structure of muscle fiber
Muscle fiber
T-tubule
A band
Z line
H zone
I band
Nucleus
Capillary
Sarcoplastic reticulum
M line
Sarcolemma
Myofilaments
Sarcomere
Myofibril

근원섬유(myofibrils)의 배열

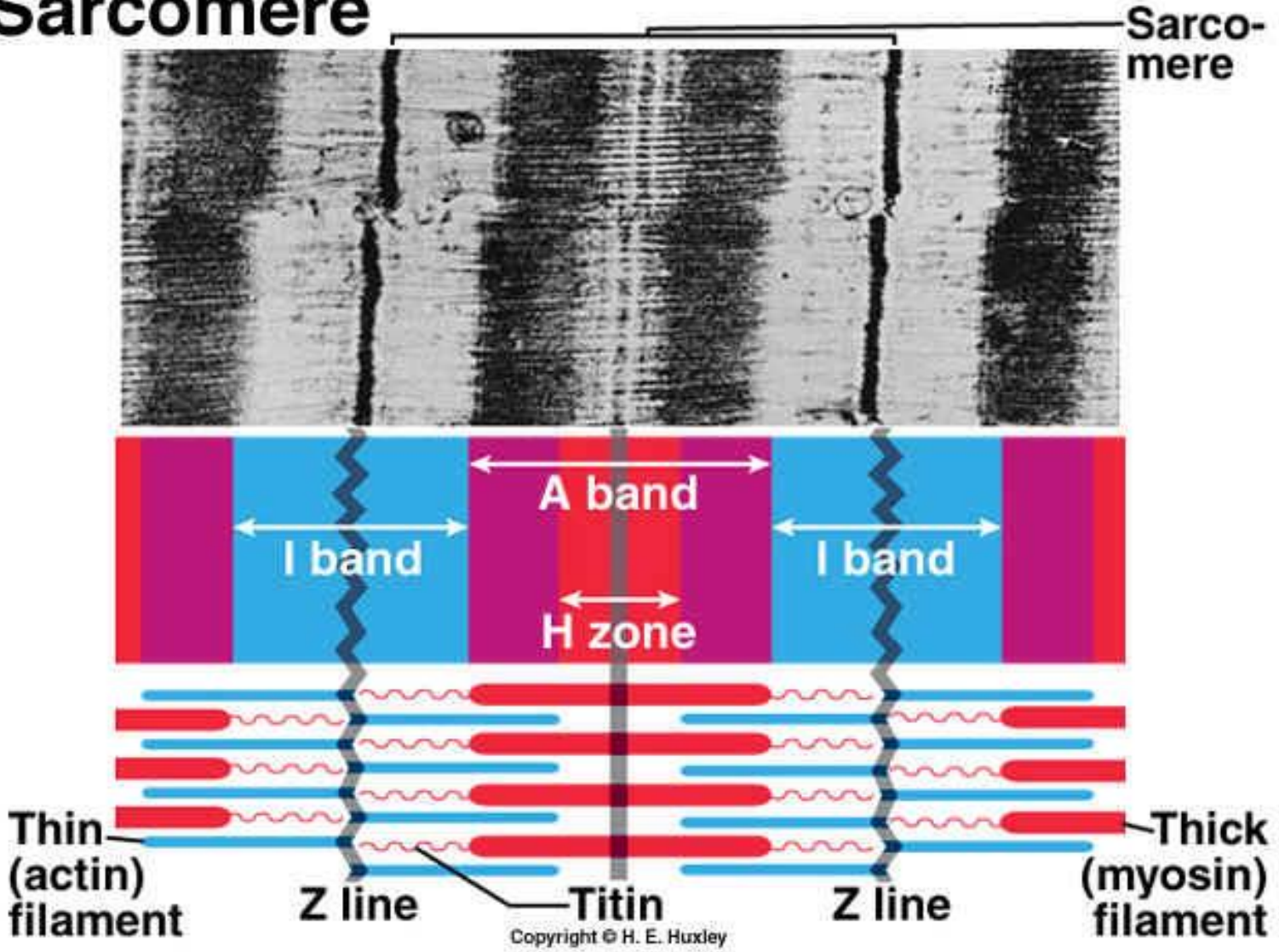
a. A-band(암대): myosin filament와 actin filament 가 겹쳐 있는 곳
b. I-band(명대): actin filament 만 있는 곳
c. H-zone: 암대(A band) 중앙의 밝은 부위- myosin filament만 있는 곳
d. M-line: myosin filament가 부푼 곳
e. Z-line: 명대(I-band) 중앙의 어두운 선
f. Z~Z 사이 : 근절 (sarcomere) – 골격근의 기본 단위

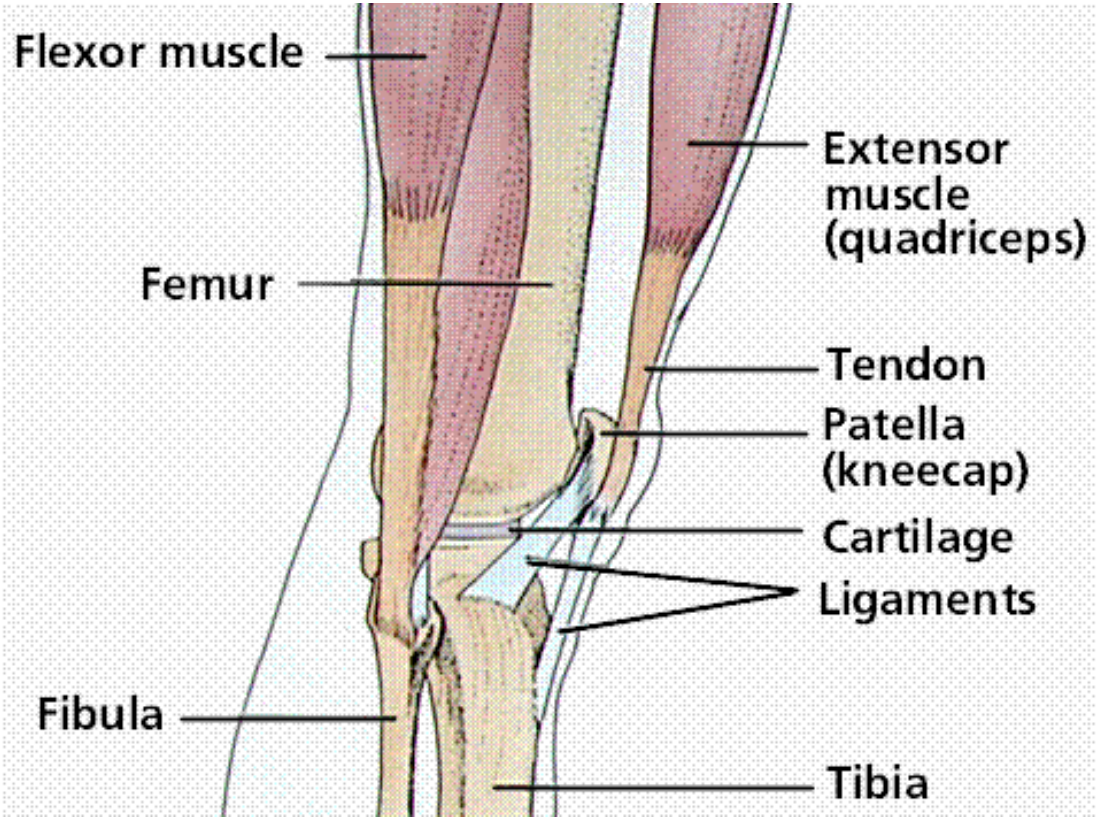


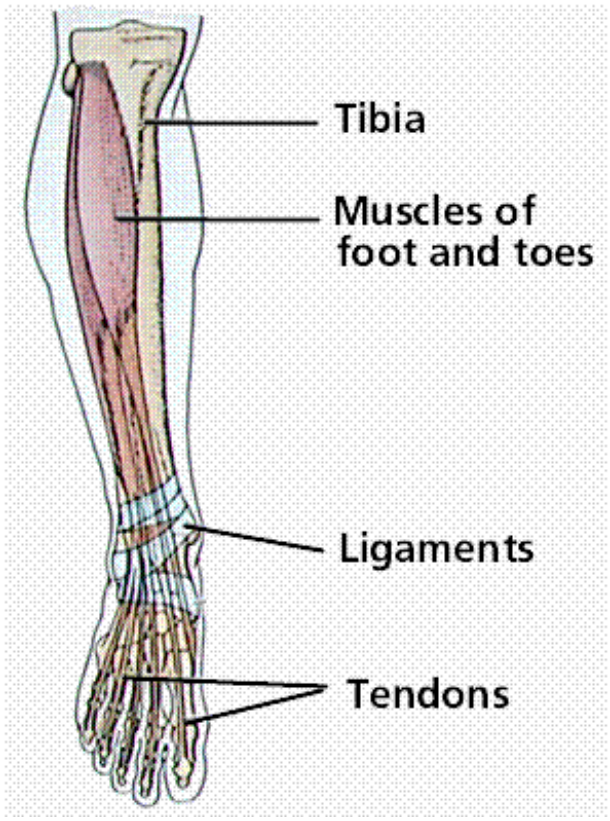
Skeletal Muscle Fiber



Sarcomere


Sarco-
mere
A band
I band
I band
H zone
Thin
(actin)
filament
Z line
Titin
Z line
Thick
(myosin)
filament
Copyright © H. E. Huxley


Flexor muscle
Extensor muscle (quadriceps)
Femur
Tendon
Patella (kneecap)
Cartilage
Ligaments
Fibula
Tibia

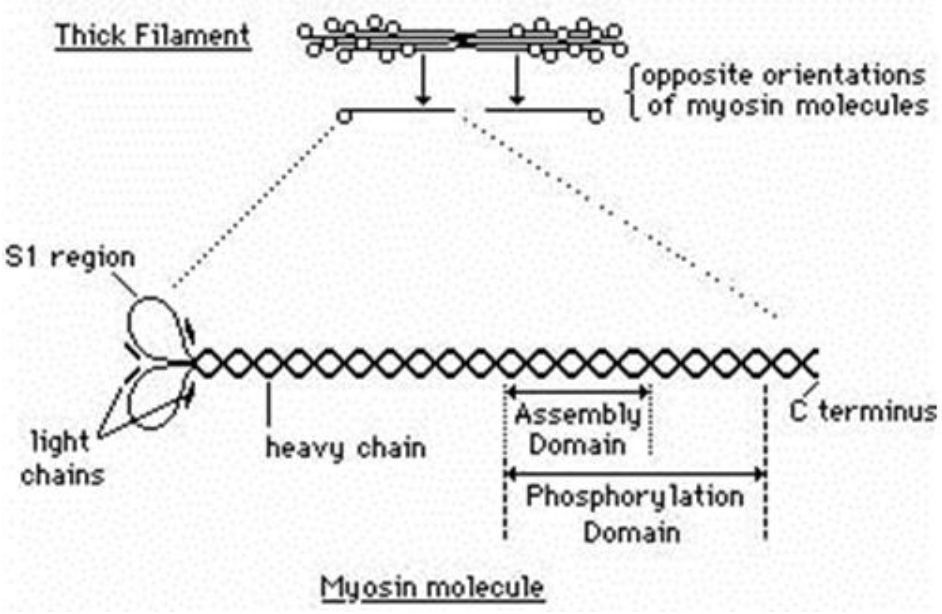

Tibia
Muscles of foot and toes
Ligaments
Tendons

골격근의 미세구조

근원섬유(myofibrils)의 구성

1. 마이오신근세사 (myosin filament) : 굵은 섬유

- 구성단백질: myosin (분자량 500,000)
- 특징 - 이중나선구조
  - 2개의 큰 사슬(heavy chain)과 2쌍의 작은 사슬 (light chain)로 구성
  - 머리에 ATP 가수분해 촉매부가 있음



2. 액틴근세사 (actin filament) :가는 섬유

구성단백질:

a. actin (분자량 45,000)

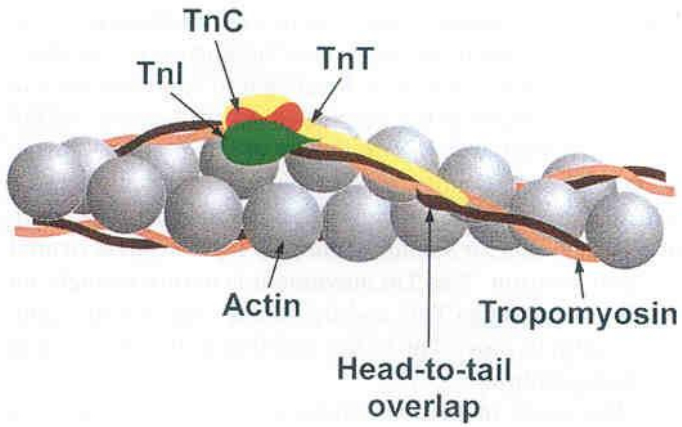
- ✓ 이중나선구조 **(F-actin),** 액틴근세사 틀 형성
- ✓ **myosin** 머리와 결합하는 활성부가 있음

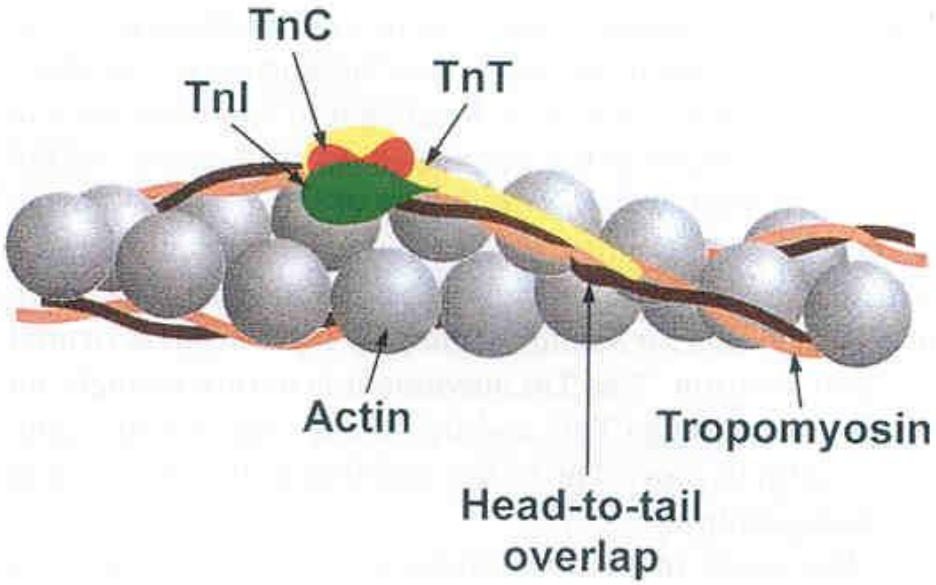
b. tropomyosin –분자량 70,000

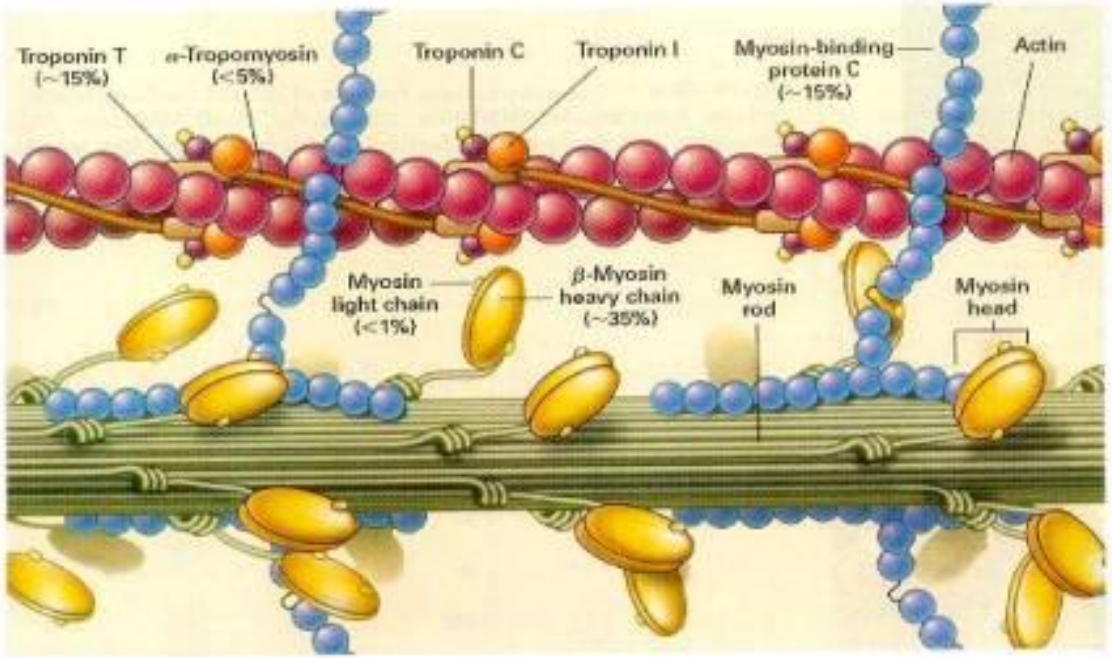
- ✓ 긴 단백질 중합체, 액틴의 나선구조 사이에 부착
- ✓ **myosin**과 **actin**의 결합을 저해함

c. troponin- 분자량 69,000

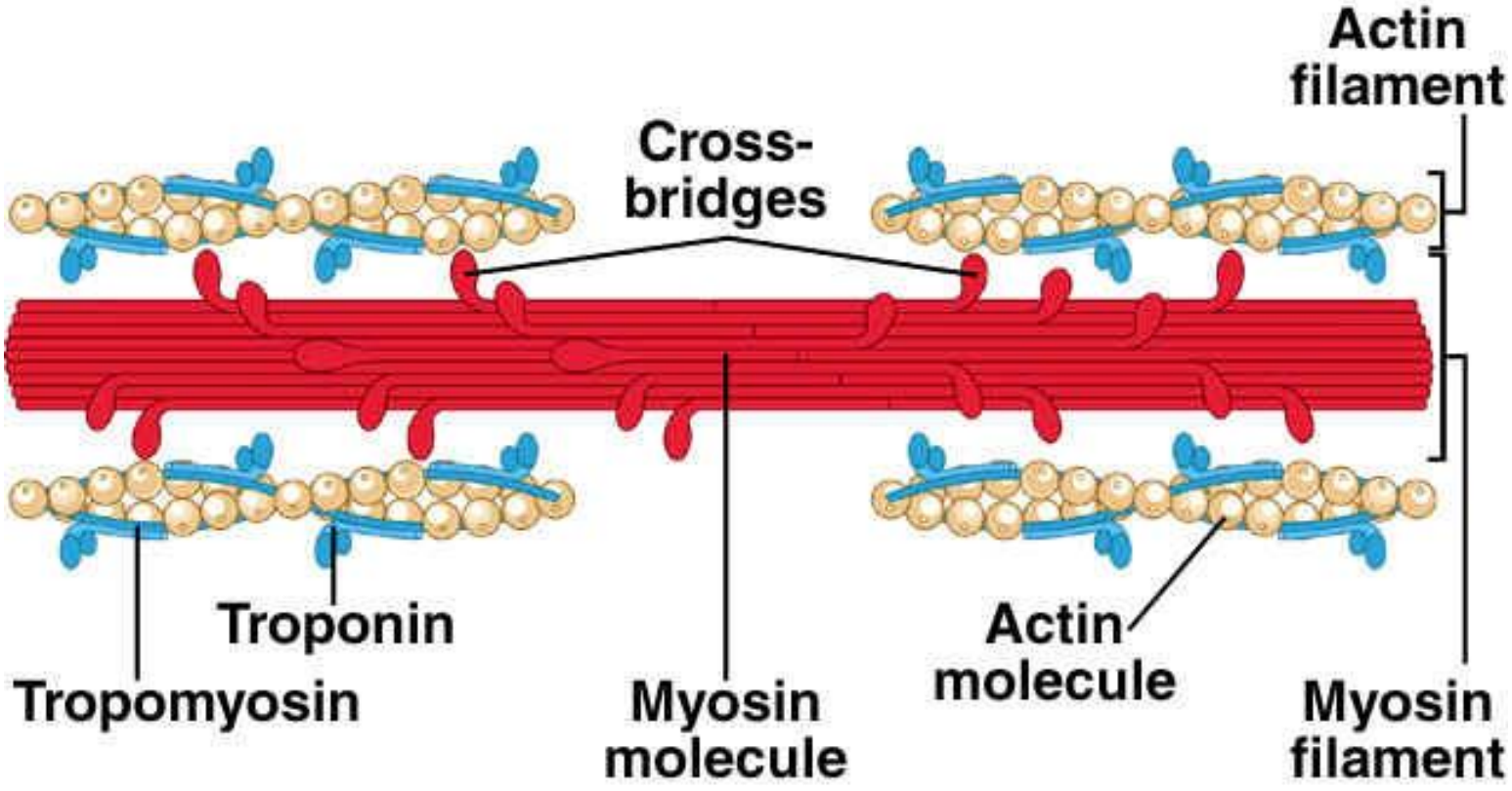
- ✓ **Tropomyosin** 끝에 부착된 Ca^{2+} 친화성의 구형 단백질
- ✓ **Tn-C, Tn-T, Tn-I** 이라는 **3**개의 **subunit**로 구성
- ✓ **Tn-C:** 세포질 내 Ca^{2+}과 결합하는 부위가 있음

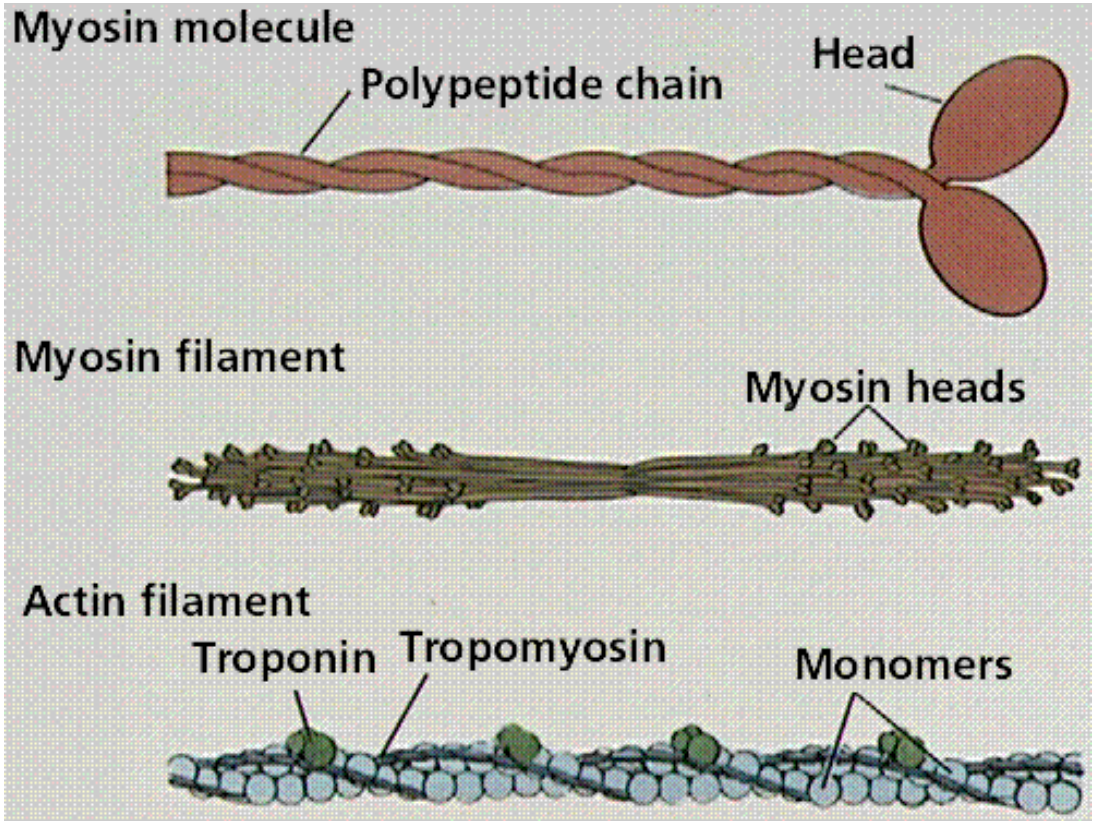


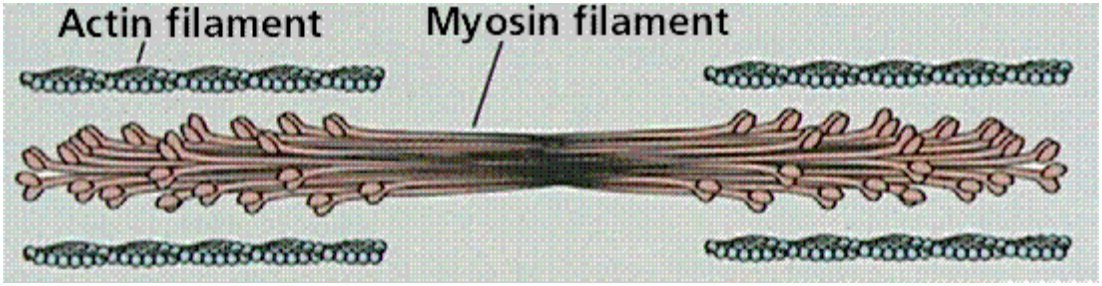

TnC
TnI
TnT
Actin
Tropomyosin
Head-to-tail
overlap


Troponin T
(~15%)
α-Tropomyosin
(<5%)
Troponin C
Troponin I
Myosin-binding
protein C
(~15%)
Actin
Myosin
light chain
(<1%)
β-Myosin
heavy chain
(~35%)
Myosin
rod
Myosin
head

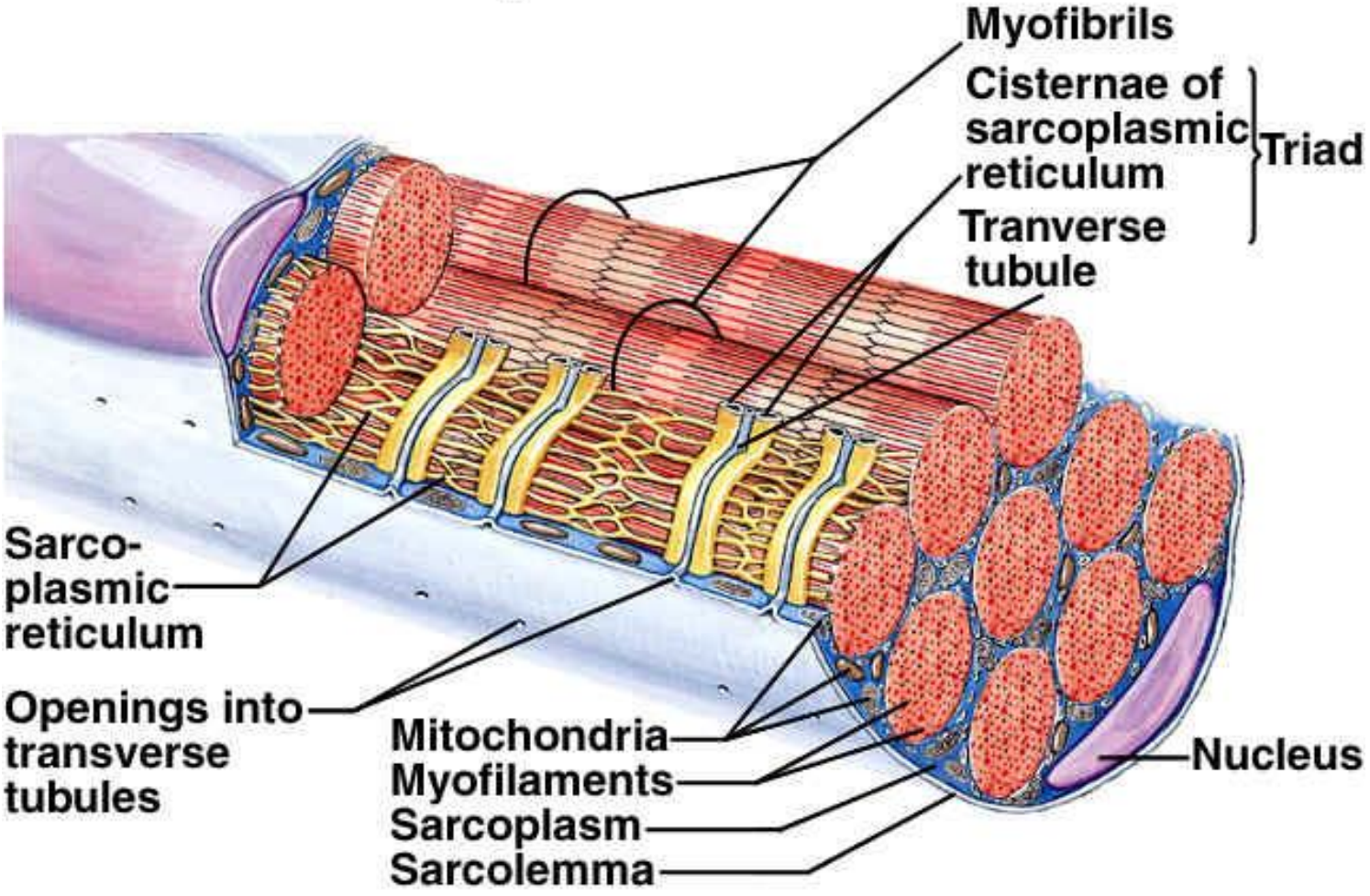
Thick Filaments

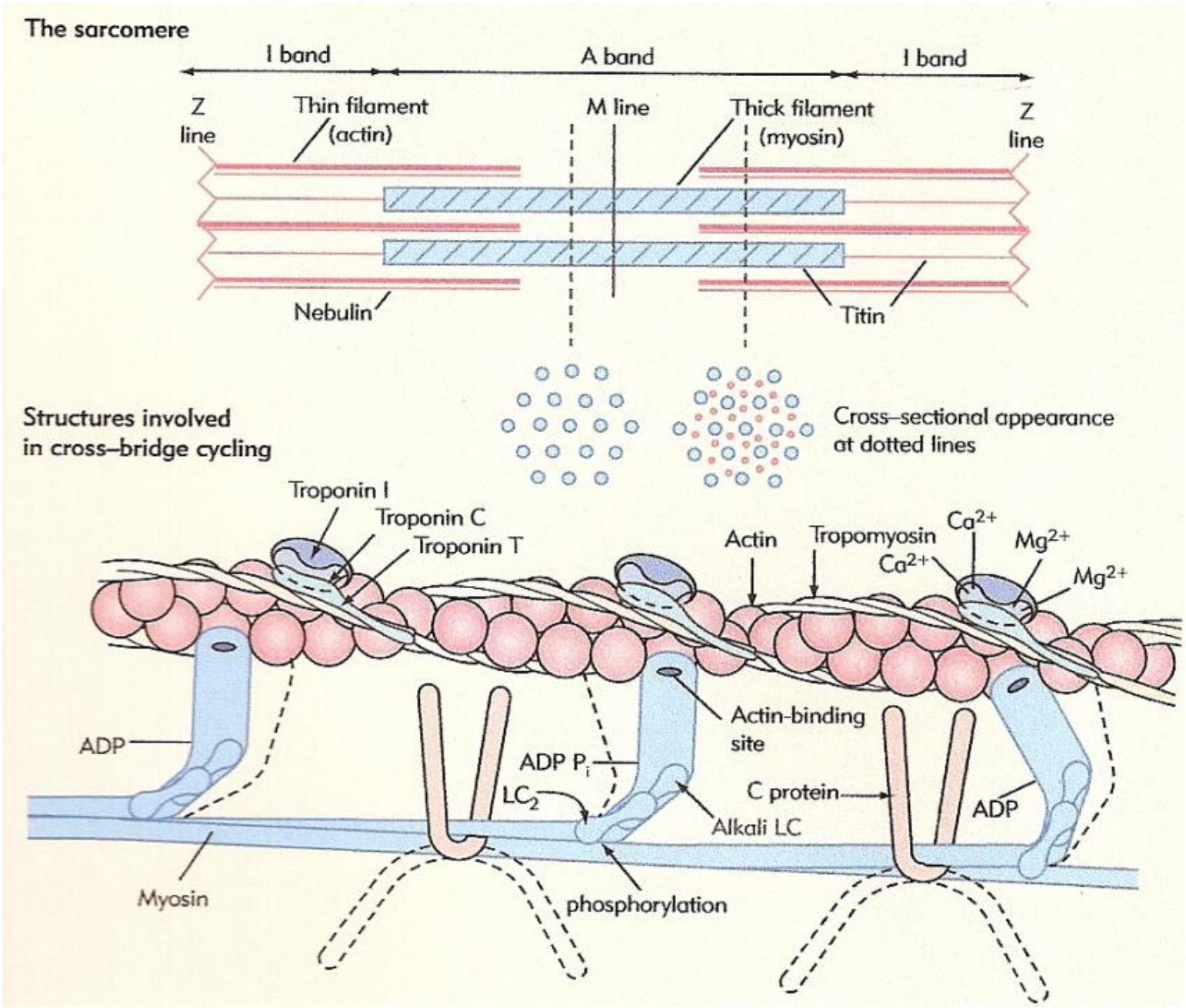



Myosin molecule
Polypeptide chain
Head
Myosin filament
Myosin heads
Actin filament
Troponin
Tropomyosin
Monomers


Actin filament
Myosin filament

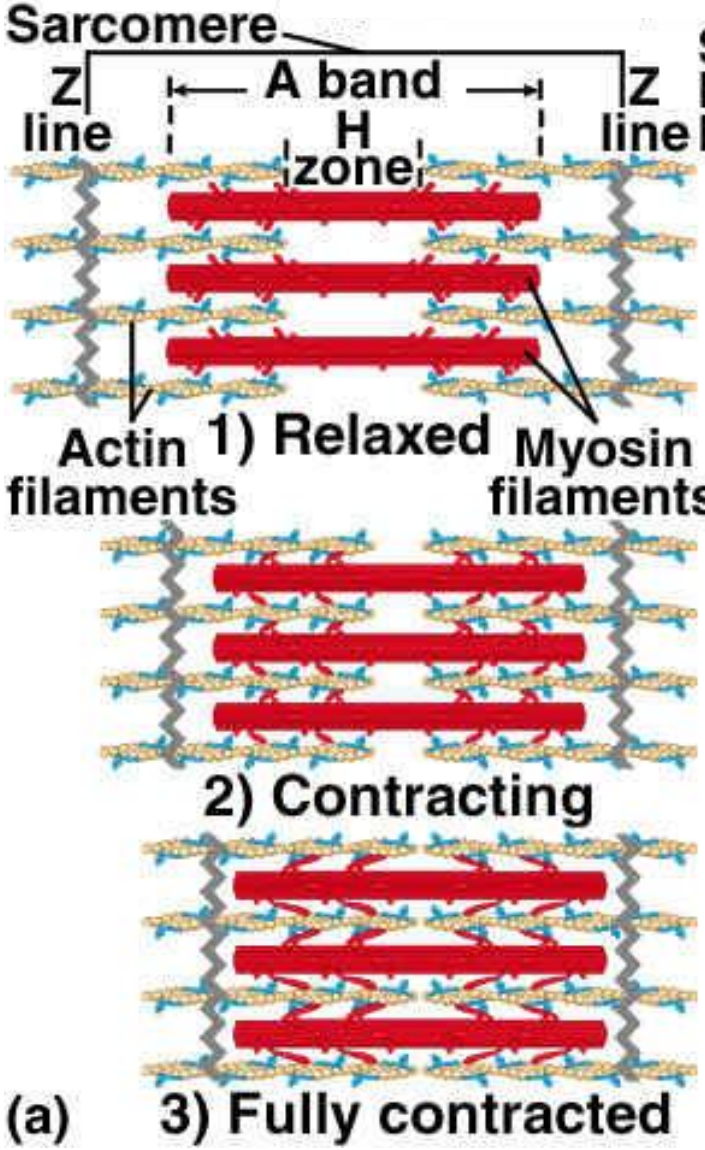
Sarcoplasm Contents

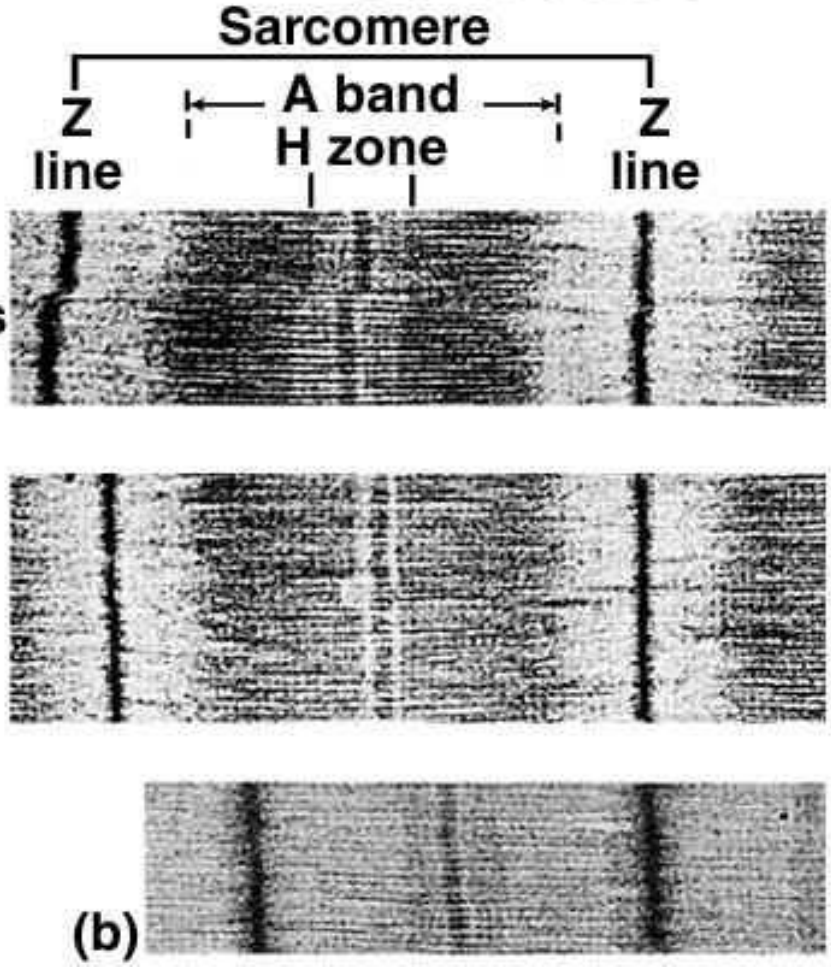



The sarcomere
I band
A band
I band
Z line
Thin filament (actin)
M line
Thick filament (myosin)
Z line
Nebulin
Titin
Cross–sectional appearance at dotted lines
Structures involved in cross–bridge cycling
Troponin I
Troponin C
Troponin T
Actin
Tropomyosin
Ca^{2+}
Mg^{2+}
Ca^{2+}
Mg^{2+}
Actin-binding site
ADP
ADP P_i
LC_2
C protein
ADP
Alkali LC
Myosin
phosphorylation

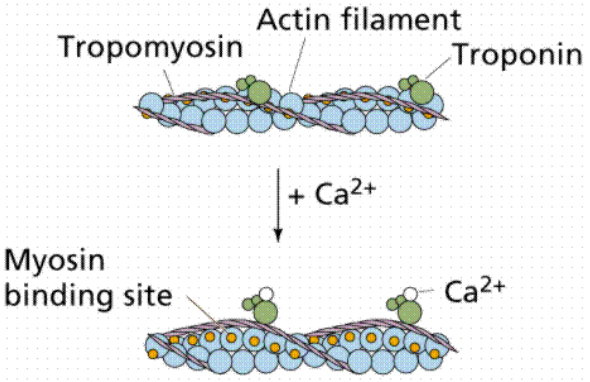
Skeletal Muscle Contraction

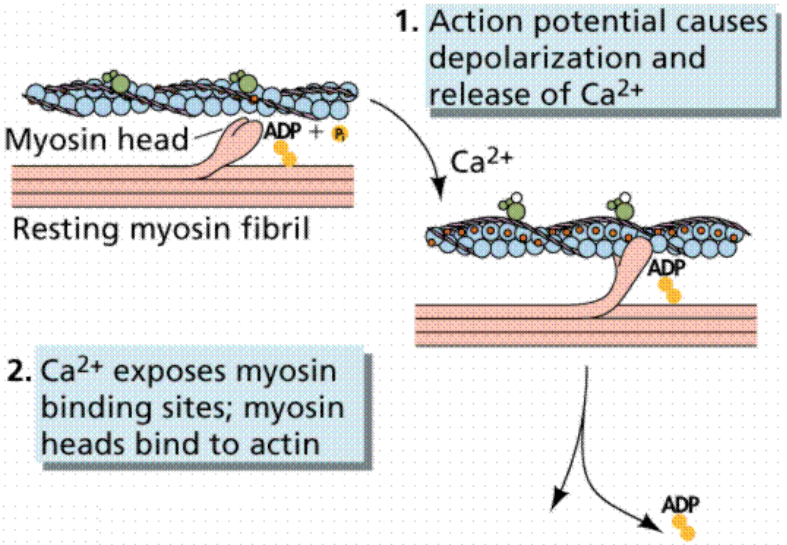
SLIDING FILAMENT MODEL

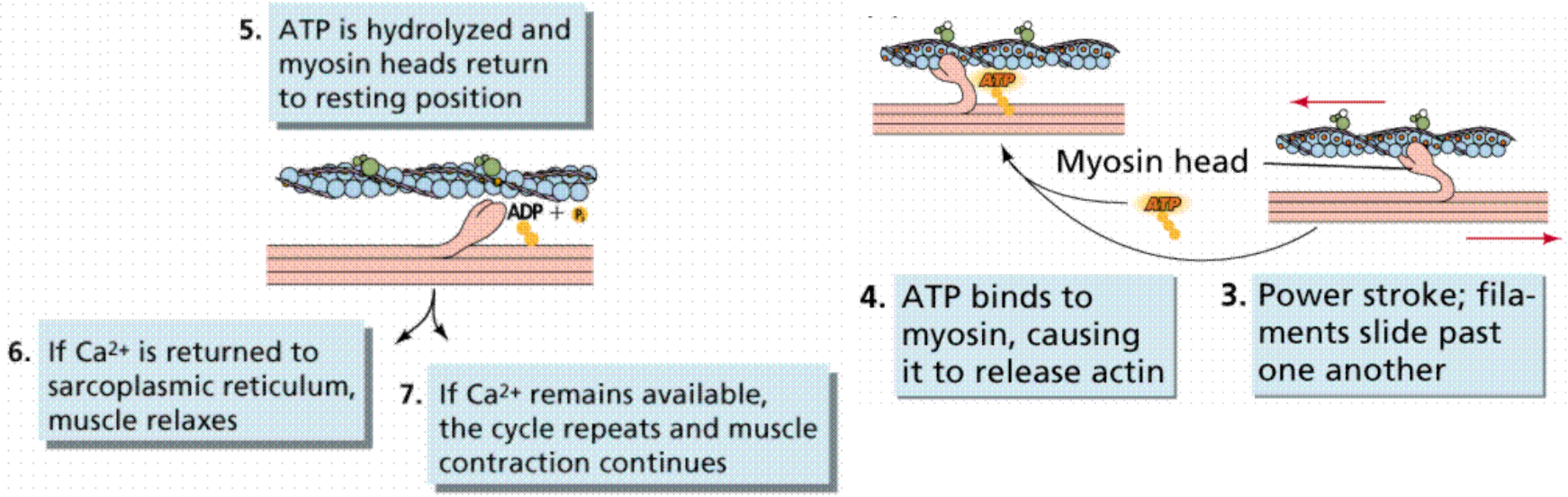




근수축 sliding filament theory







근 수축기전

1. 근섬유의 활동전압

- 골격근 세포의 안정막 전압: -90 mV
- 골격근 단일 섬유는 실무율 원리에 따름

2. Ca2+의 수축 조절기전

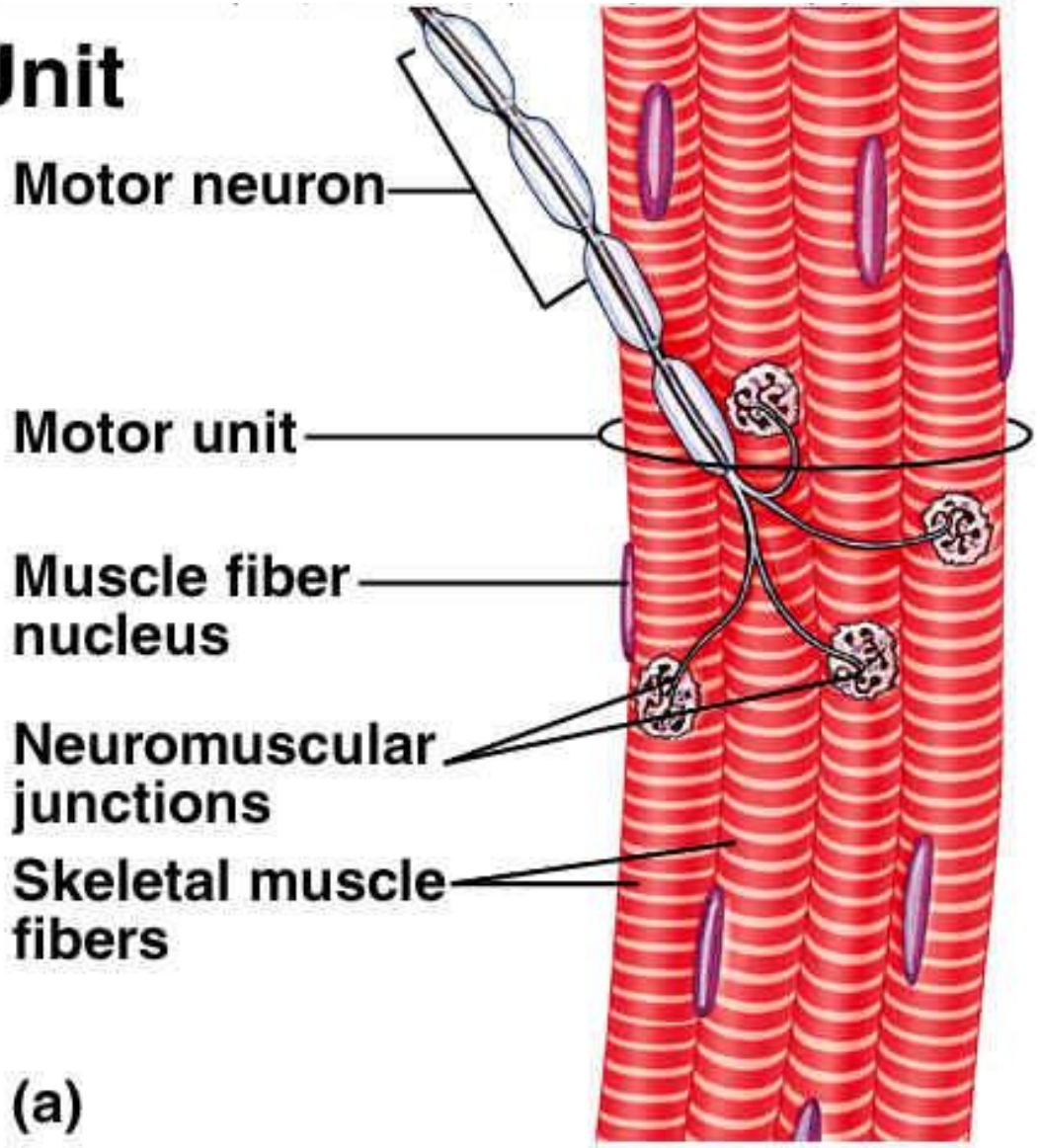
- 횡문근 : Ca^{2+} 이 troponin C에 부착→
  Tropomyosin 구조변화 → 횡교형성
- 평활근 : Ca^{2+} 이calmodulin과 결합 → MLCK를 활성화
  → MLC 인산화

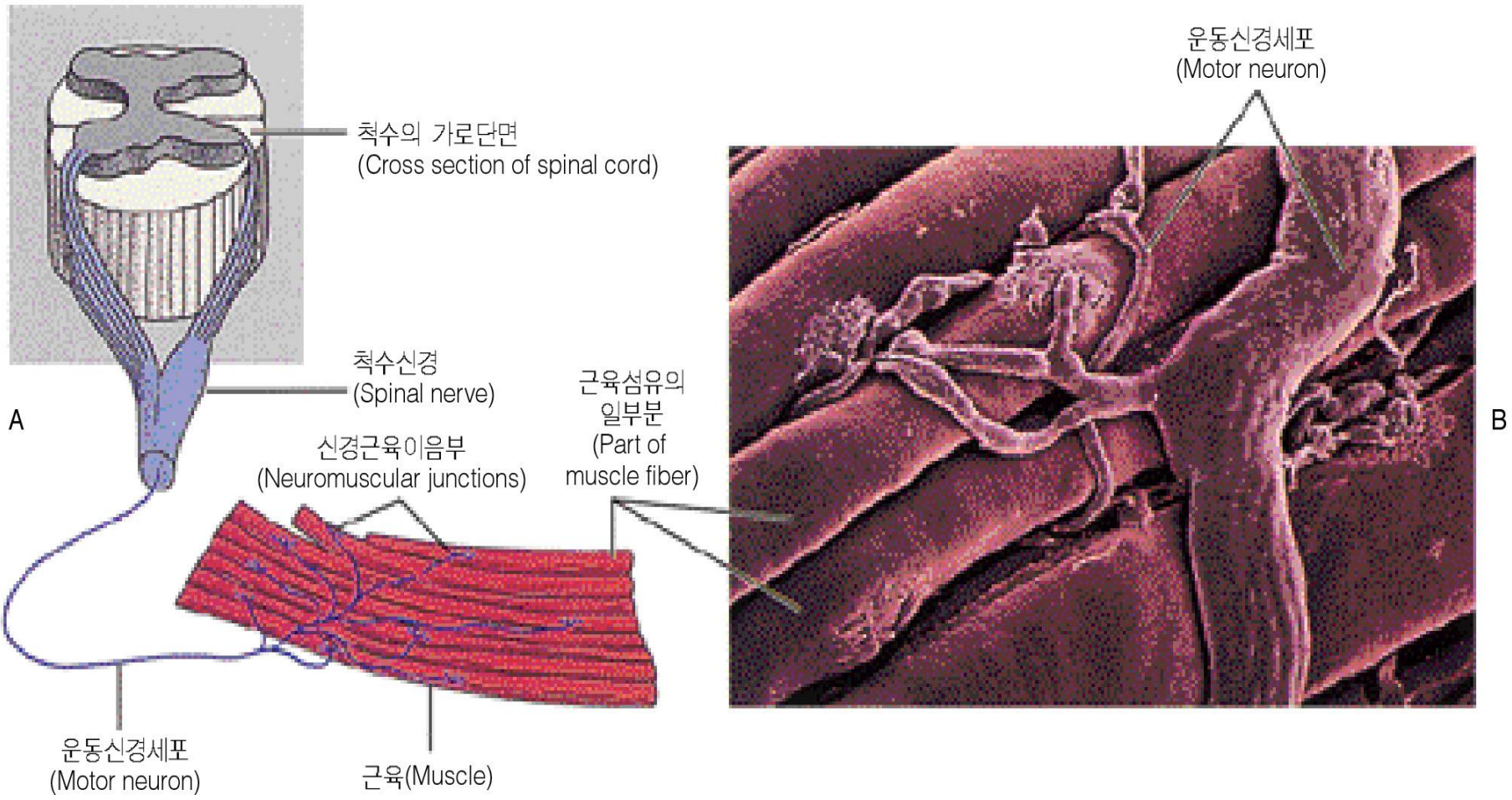
Myosin light chain kinase

골격근 수축의 단계별 진행과정

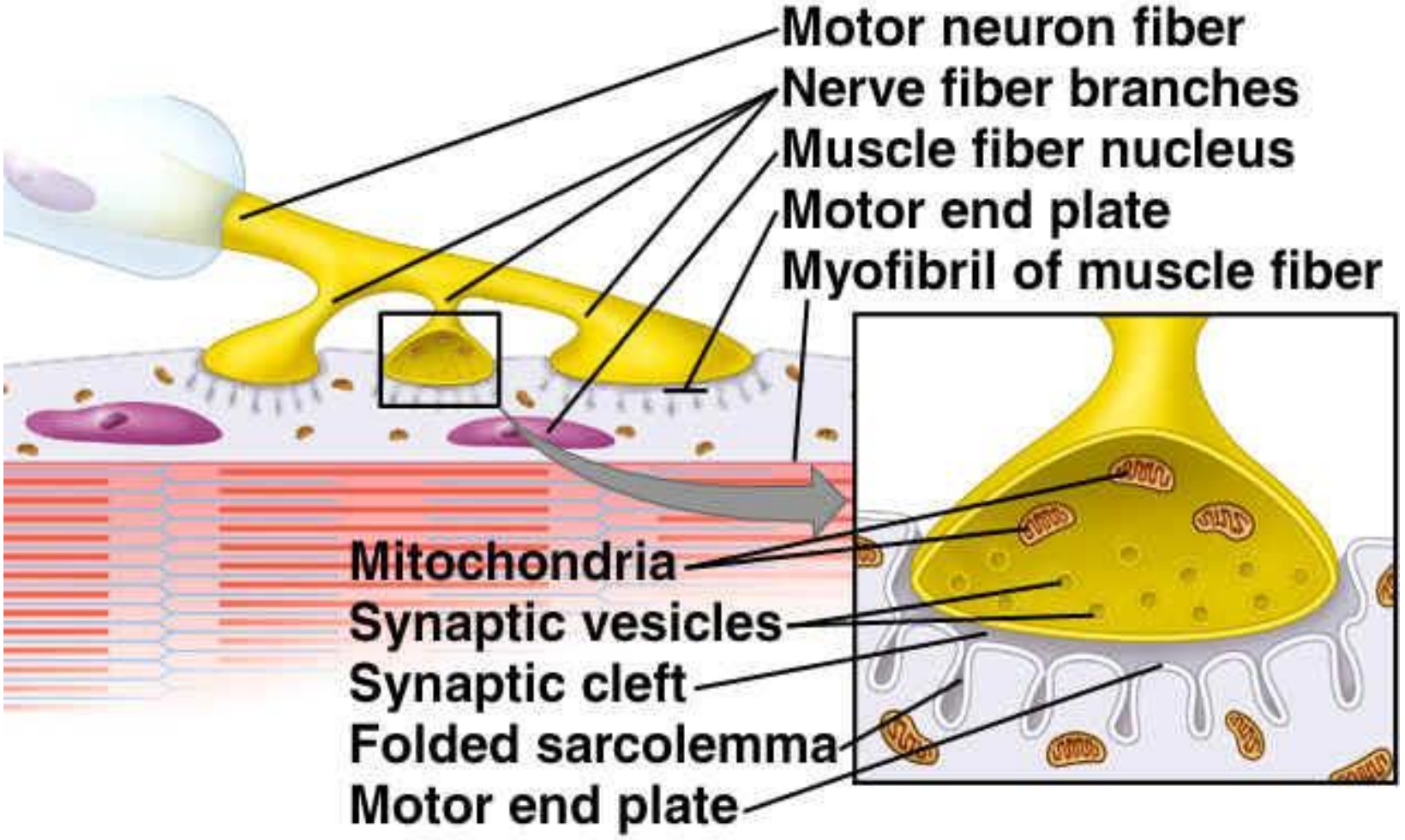
단계별	진행과정
신경근 연접 흥분전달	• 흥분이 도달하면 시냅스종말의 전압의존성 Ca^{2+} 통로들이 열림 • 세포외액의 Ca^{2+} 이 시냅스종말 내로 들어와 소포들의 Ach 유리 촉발 • Exocytosis에 의해 시냅스 간격내로 Ach 유리 • Ach은 확산되어 근초표면의 Ach 수용체와 결합
흥분-수축 연결	• Ach-수용체결합이 근초의 Na+통로들을 활동시켜 활동전압 유발 • 활동전압은 가로세관을 경유해 삼조체에 도달 • 근형질세망 종말 수조의 투과성을 증대시켜 Ca^{2+} 의 유리를 촉진
수축과정	• Ca^{2+} 은 troponin과 결합하고 troponin-tropomyosin complex의 위치가 변화 • Actin 분자의 활성부(active site)가 노출됨 • 횡교(cross-bridge)형성, 선회(pivoting), 횡교분리의 과정이 진행 ↓ • Ach이 AchE에 의해 분해 되면서 근 수축 주기가 중지됨 • 세포질 내 ca 이 능동수송에 의해 근형질 세망으로 회수됨 • Ca^{2+} 농도가 낮아지고 troponin-tropomyosin complex의 위치가 복구됨

Motor Unit

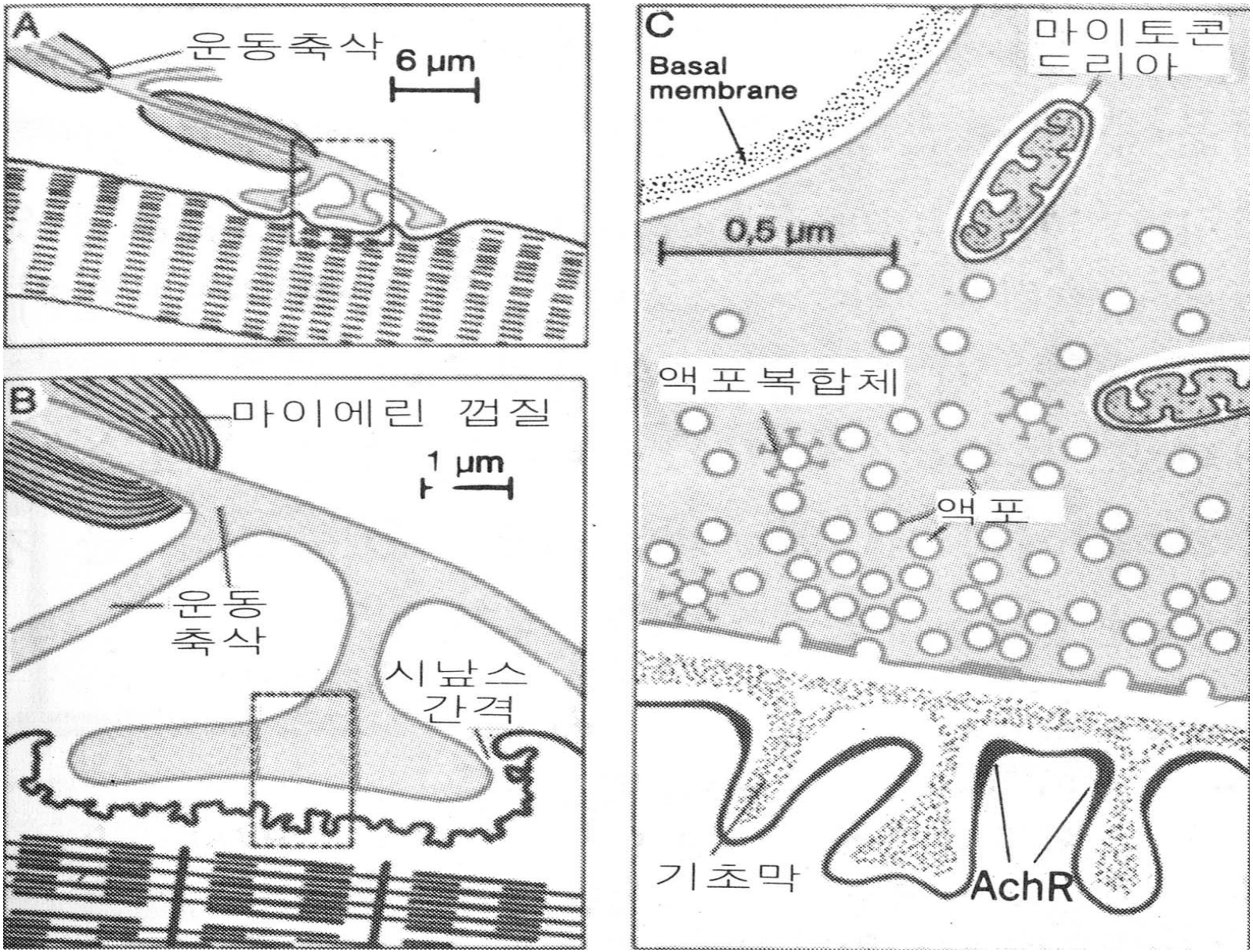

Motor neuron
Motor unit
Muscle fiber nucleus
Neuromuscular junctions
Skeletal muscle fibers
(a)


척수의 가로단면
(Cross section of spinal cord)
척수신경
(Spinal nerve)
A
신경근육이음부
(Neuromuscular junctions)
근육섬유의
일부분
(Part of
muscle fiber)
운동신경세포
(Motor neuron)
근육(Muscle)
운동신경세포
(Motor neuron)
B

Neuromuscular Junction

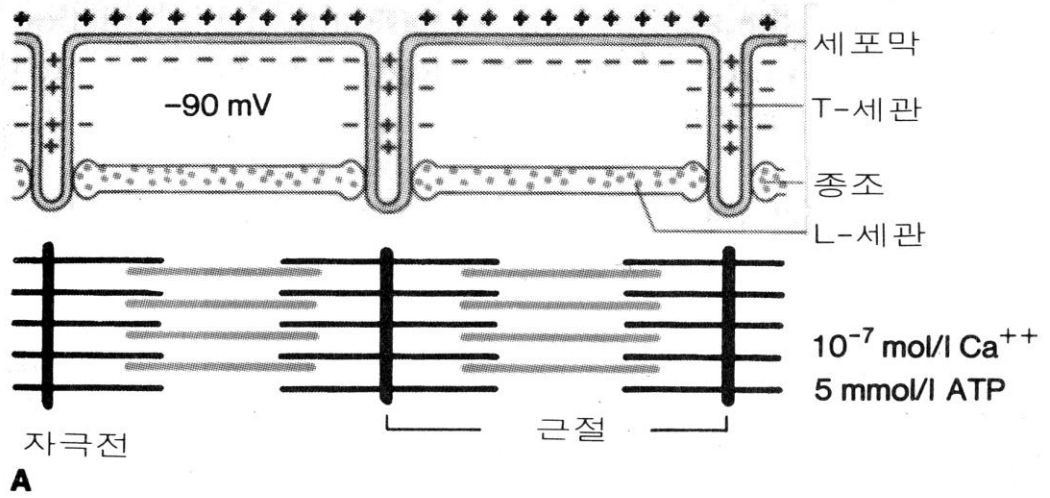


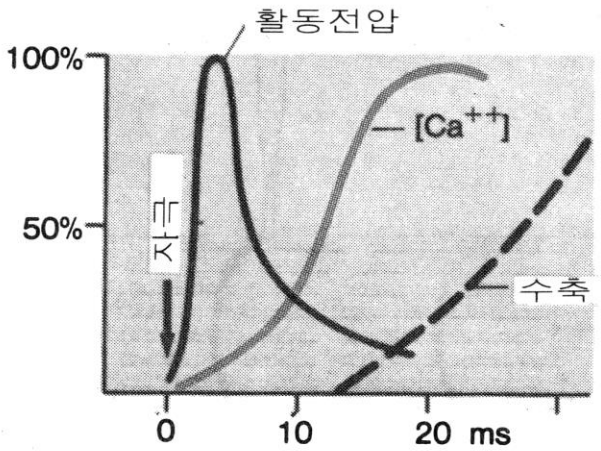
Nueromuscular Junction

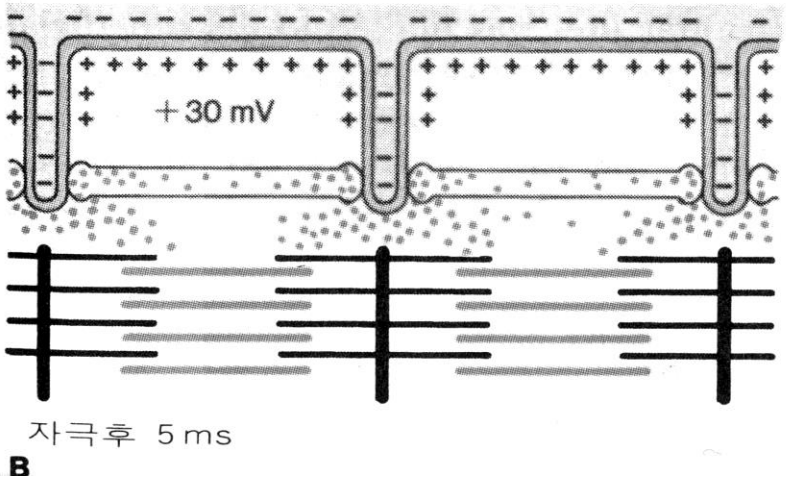


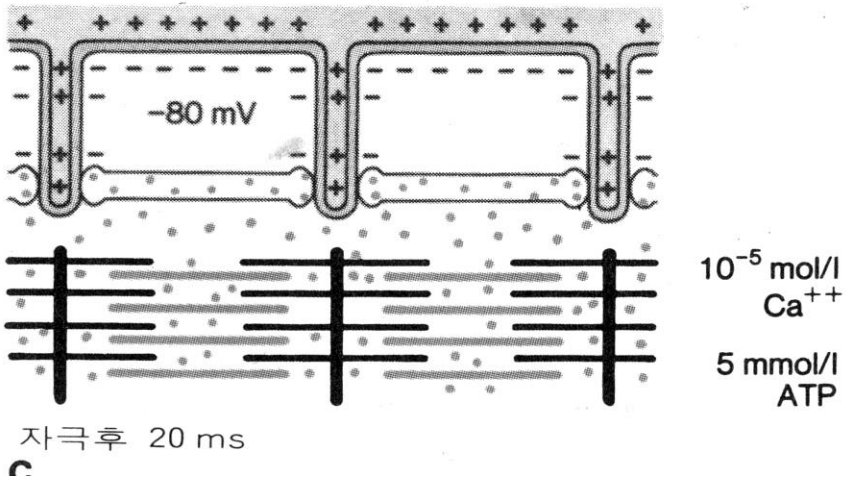
[**신경-근 연접부위**. B: A의 점선 부분 확대. C: B의 점선 부분 확대.]

❖근 수축기구



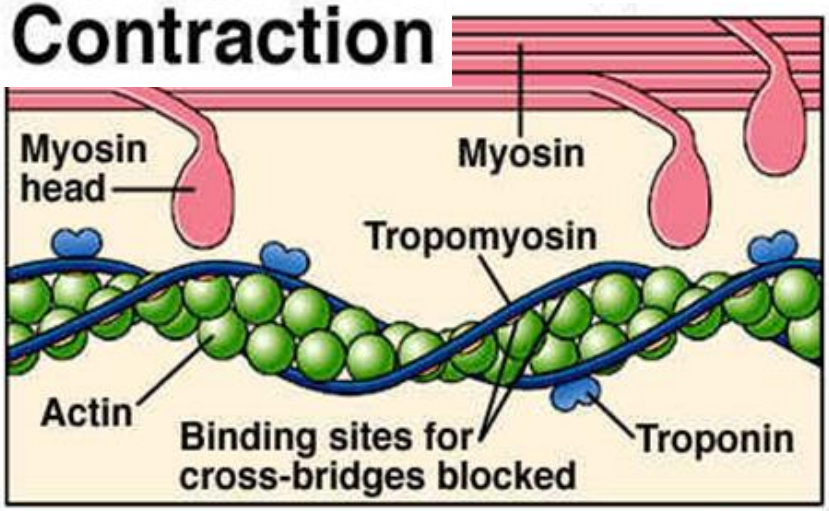


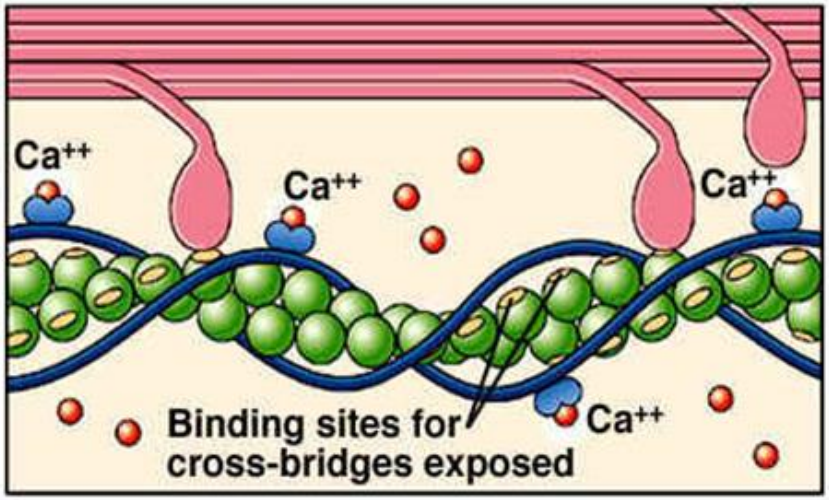




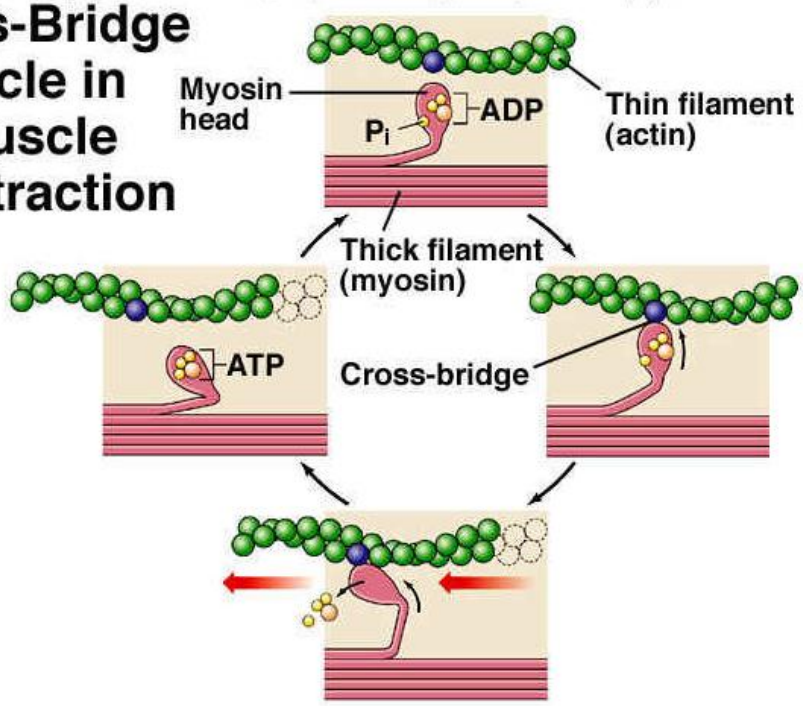
[근 수축시의 Ca^{++}의 유리.
A: 자극 전의 Ca^{++} 저장장소 및 농도. B: 자극 후 5msec에 Ca^{++} 유리과정. C: 자극 후 20msec에 유리된 Ca^{++} 농도. 그래프: 활동전압이 진행되는 중, Ca^{++} 농도 증가현상 및 수축곡선의 상호관계.]

Role of Calcium in Muscle Contraction





Cross-Bridge Cycle in Muscle Contraction



근 수축 에너지

1. $ATP + H_2O \rightarrow ADP + H_2PO_4 + 12{,}000$ calories
2. Phosphocreatine + ADP → creatine + ATP

3. Glucose + 2ATP (or glycogen + 1ATP)

$$\xrightarrow{\text{염기성 포도당 분해}}$$ 2 lactic acid + 4ATP

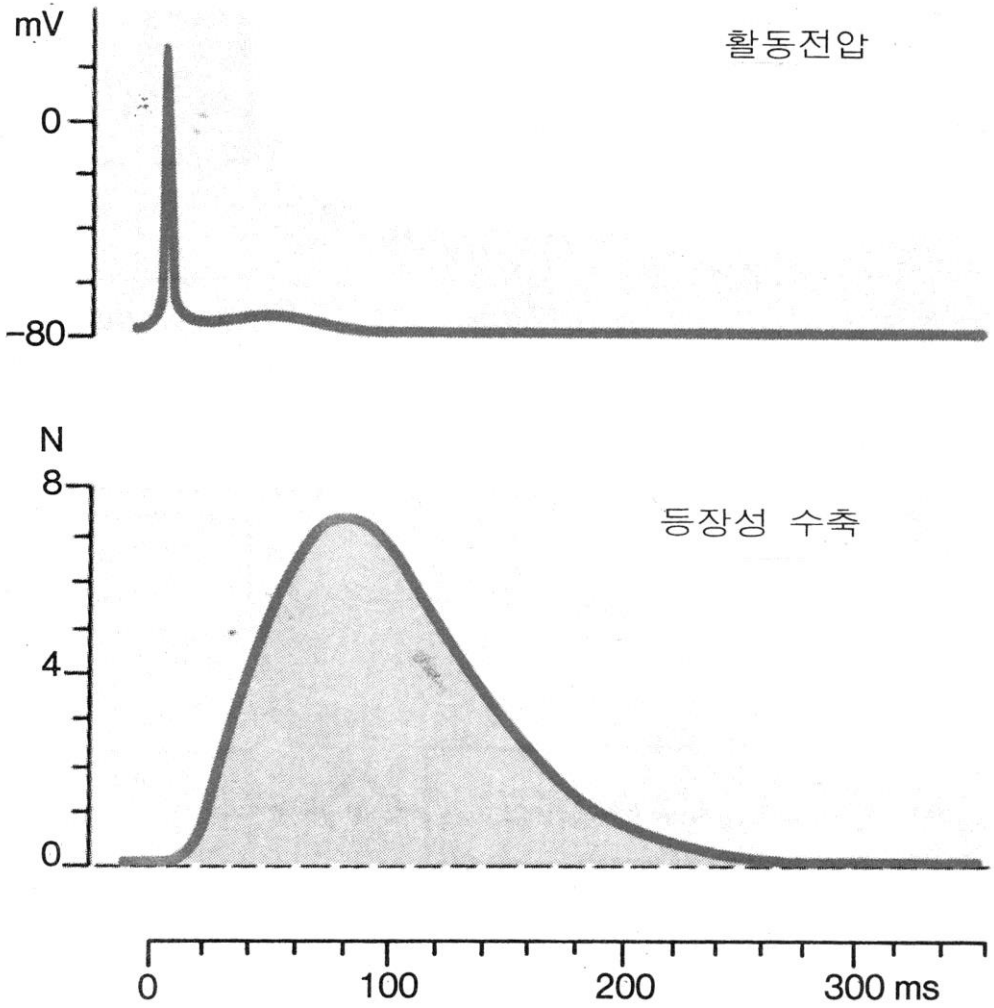
4. Glucose + 2ATP (or glycogen + 1ATP)

$$\xrightarrow{O_2}$$ $6CO_2 + 6H_2O + 40ATP$

5. Free fatty acid $\xrightarrow{O_2}$ CO_2 + ATP

❖근 수축의 종류

형태에 따른 분류



[**활동전압과 연축 곡선.** O: 자극을 준 시간.]

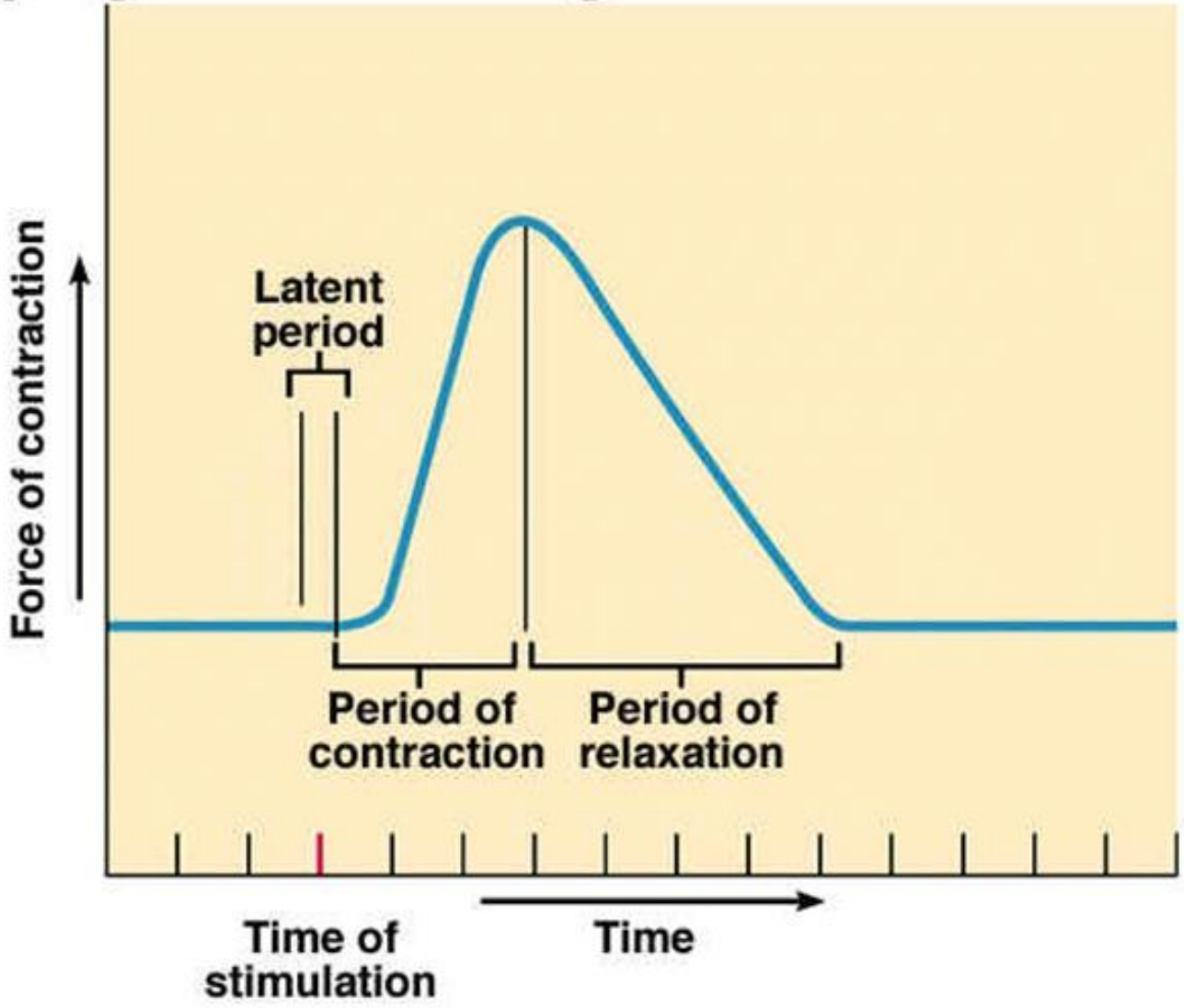
- 연축(twitch): 신경섬유 위에 하나의 전기적 역치 자극을 가하면 일어나는 근육의 급속한 하나의 수축
- 기간: 0.1초

  (잠복기 0.01초

  → 수축기 0.04초

  → 이완기 0.05초)

Myogram — Single Muscle Twitch



A). Muscle twitch is the response of a muscle to a single brief threshold stimulus.

B). Phases

1). Latent Period
Muscle tension is beginning.

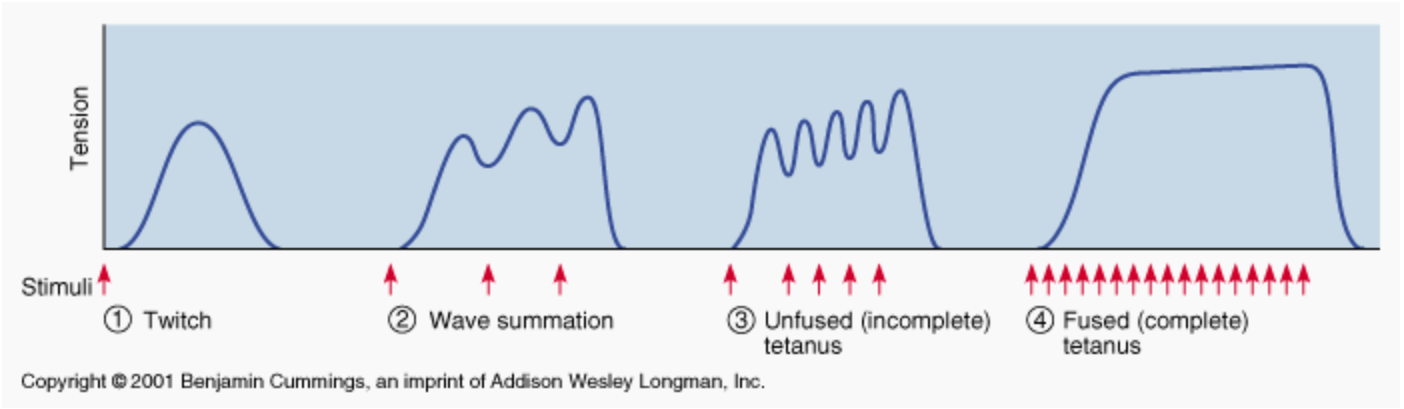
2). Period of Contraction
Muscle fibers shorten.

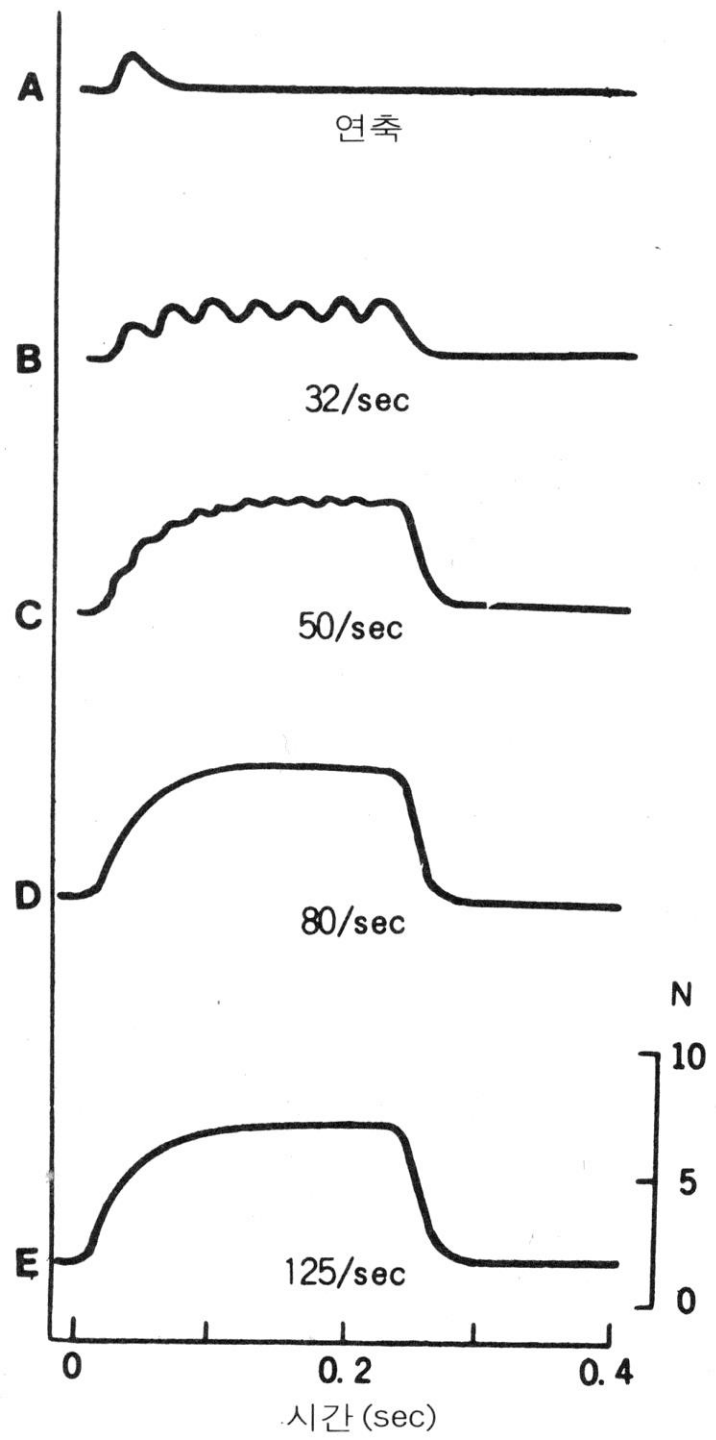
3). Period of Relaxation
Ca++ reenters the sarcoplasmic reticulum

ii). **Incomplete Tetanus**

The amount of Ca++ increases in the cytoplasm results in a quivering response

iii). Complete Tetanus





- 강축(tetanus): 짧은 시간 간격으로 반복하여 자극을 가하면 발생하는 연축 때보다 크고 지속적인 수축
- 긴장(tonus): 근육의 부분적인 수축을 지속하고 있는 것

  근육에 있는 여러 운동단위 중에서 일부분이 서로 번갈아 가면서 연축을 일으키기 때문
- 강직(contracture): 비가역적인 강축현상, 병적 상태에서 활동전압이 유발되지 않고서도 강축 발생

[**강축곡선**. A: 연축곡선. B~E: 자극 빈도를 증가시킴으로써 일어난 수축곡선. C: 불완전한 강축, E~D: 완전 강축.]

장력의 길이와 변화에 따른 분류

1. 등력성 수축 (isotonic contraction)

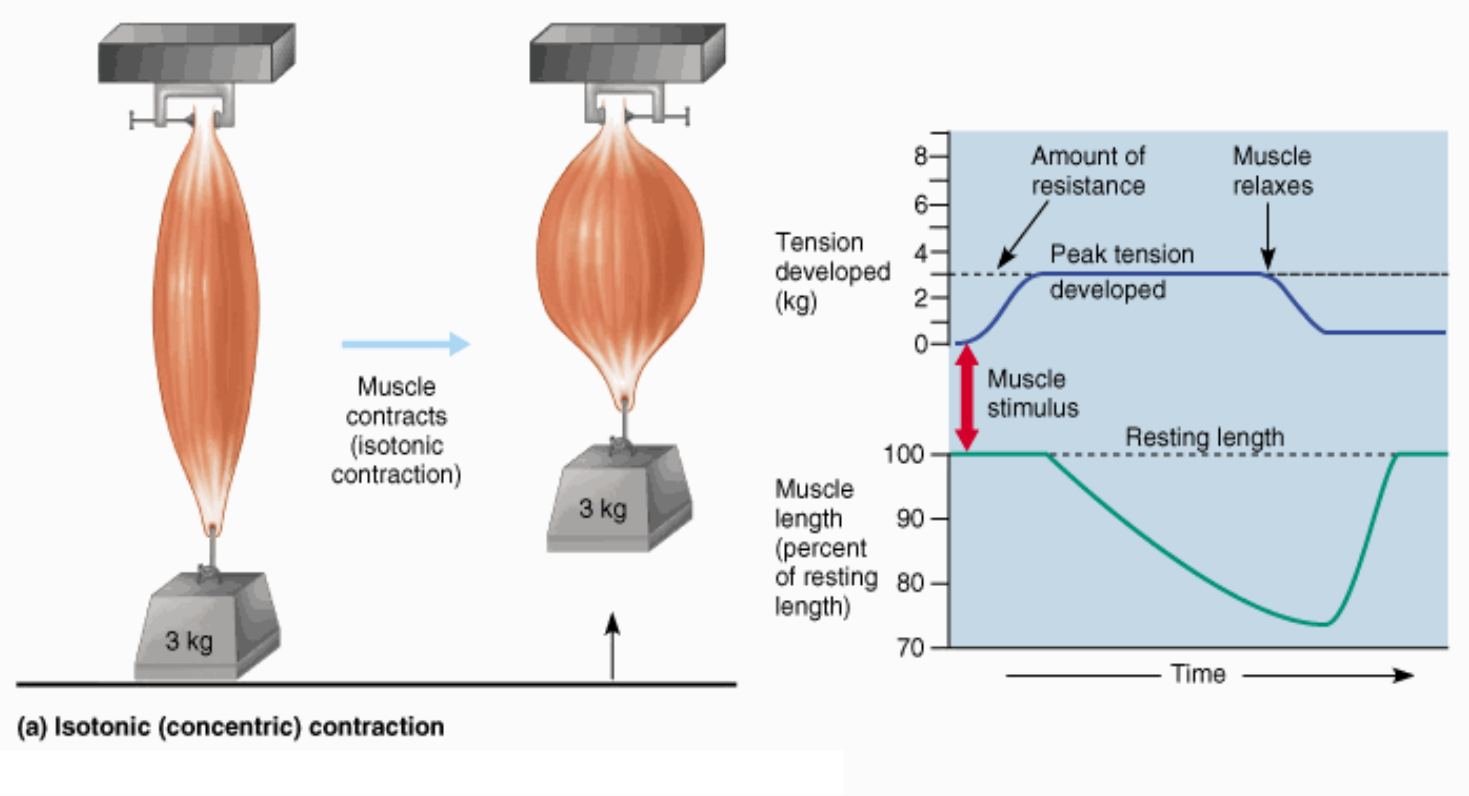
- 장력은 변화 없이 근의 길이가 짧아지는 수축
- 동적 수축- 순발력, 신체운동

2. 등장성 수축 (isometric contraction)

- 근의 길이는 변화가 없으나 장력은 변화가 있는 수축
- 정적 수척-근력

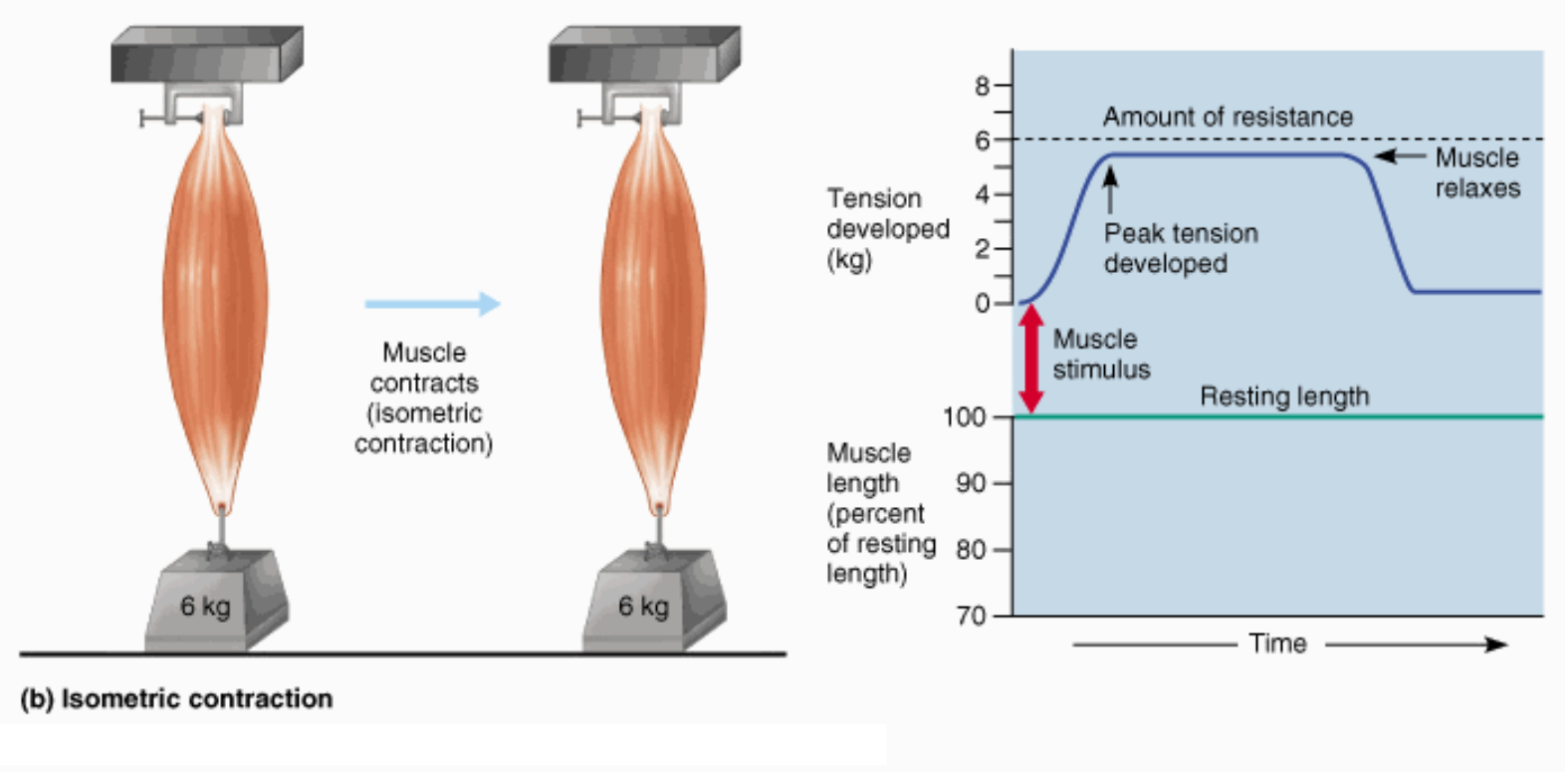
Isotonic contraction (등력성 수축)

- The muscle changes length and moves a load.
- Isotonic contractions the thin actin filaments are sliding across the myosin

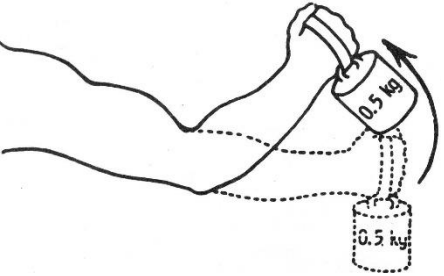


Isometric contraction (등장성 수축)

- Tension in the muscle increases but the muscle neither shortens or lengthens.
- Isometric contractions the cross bridges are forming and pulling but the actin filament is not moving



(b) Isometric contraction

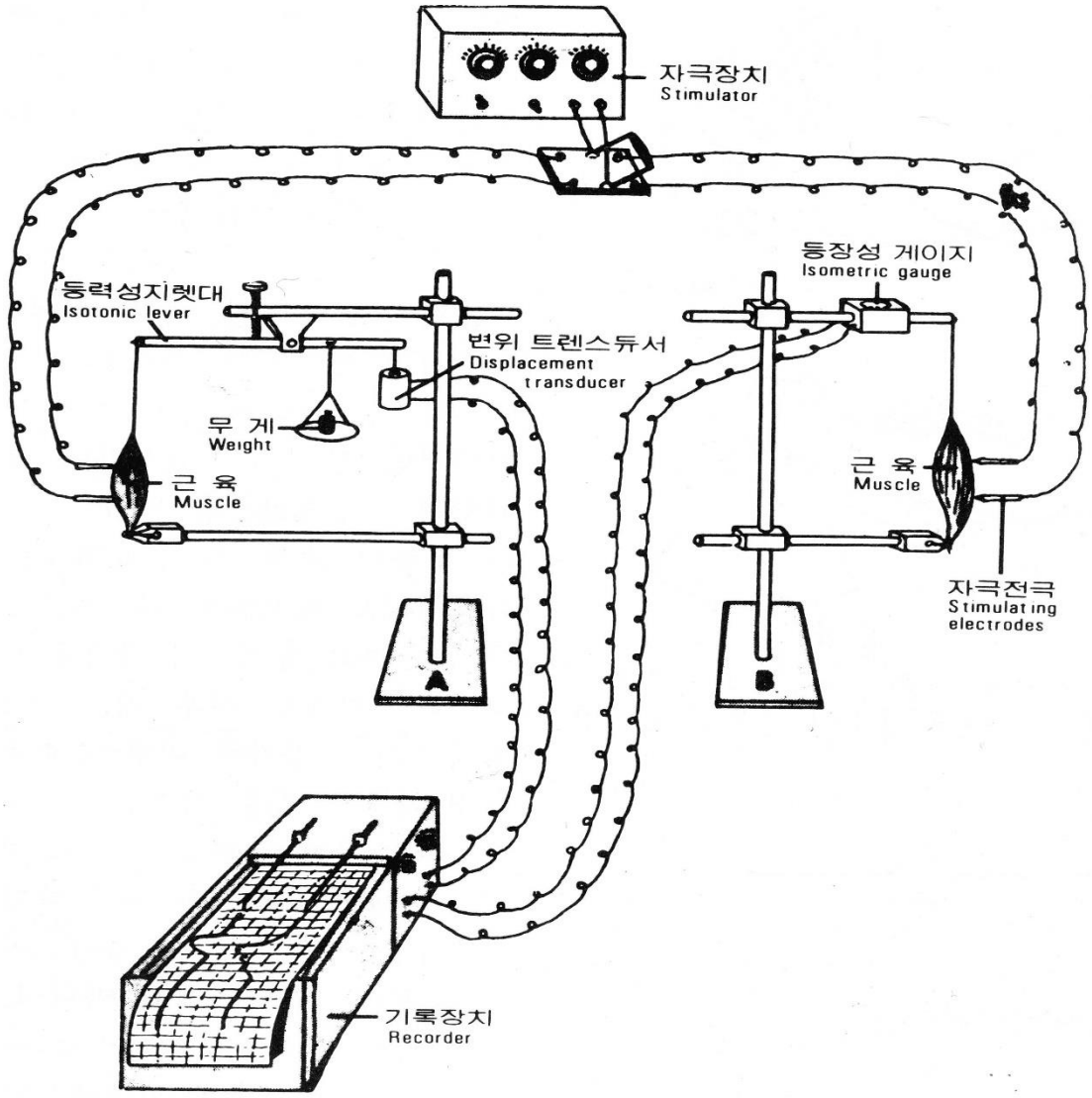


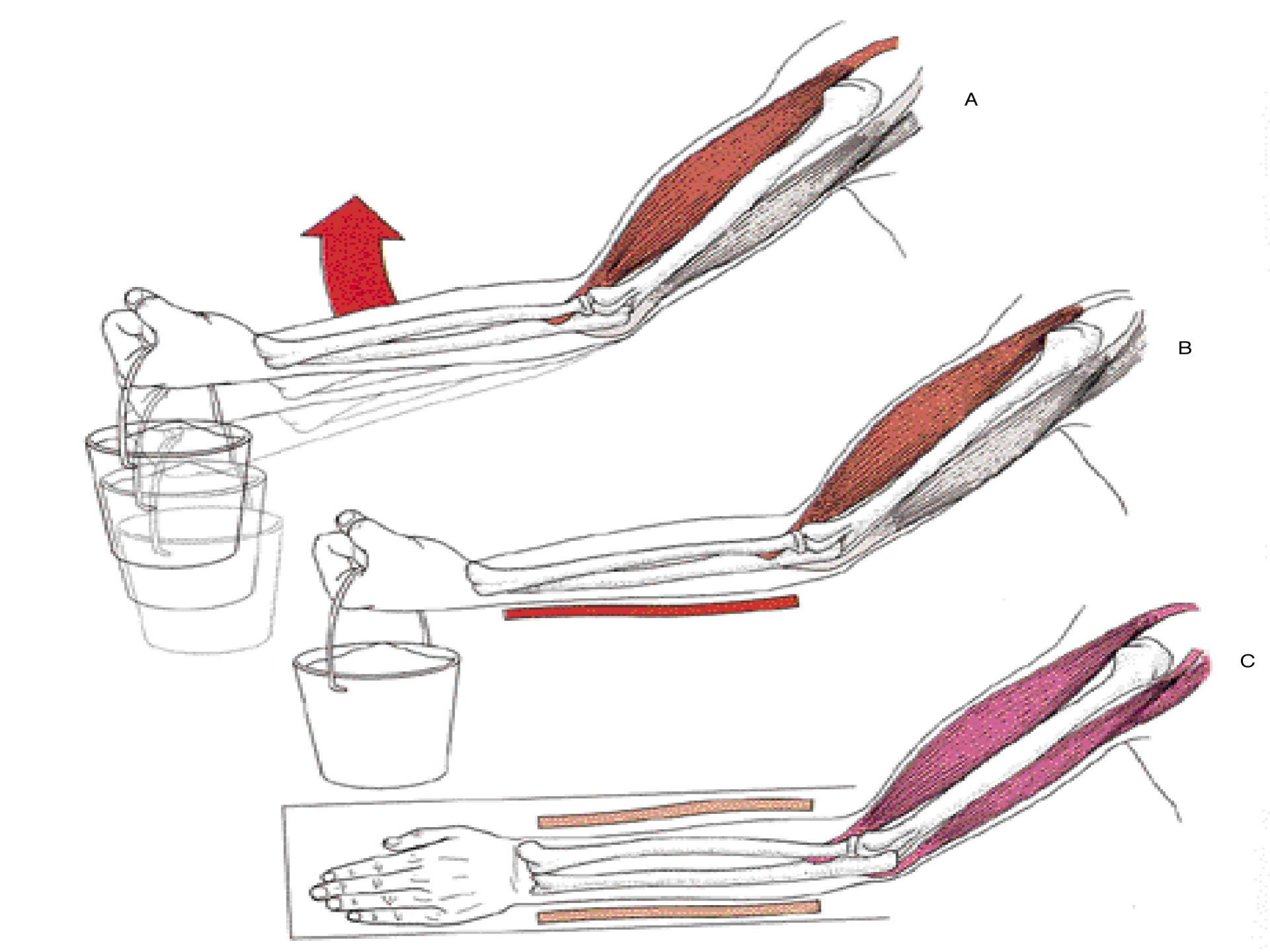
등력성 수축(isotonic contraction)
등장성 수축(isometric contraction)

[골격근의 연축곡선 기록장치]

A: 등력성 수축 곡선 기록 장치

B: 등장성 수축곡선 기록장치

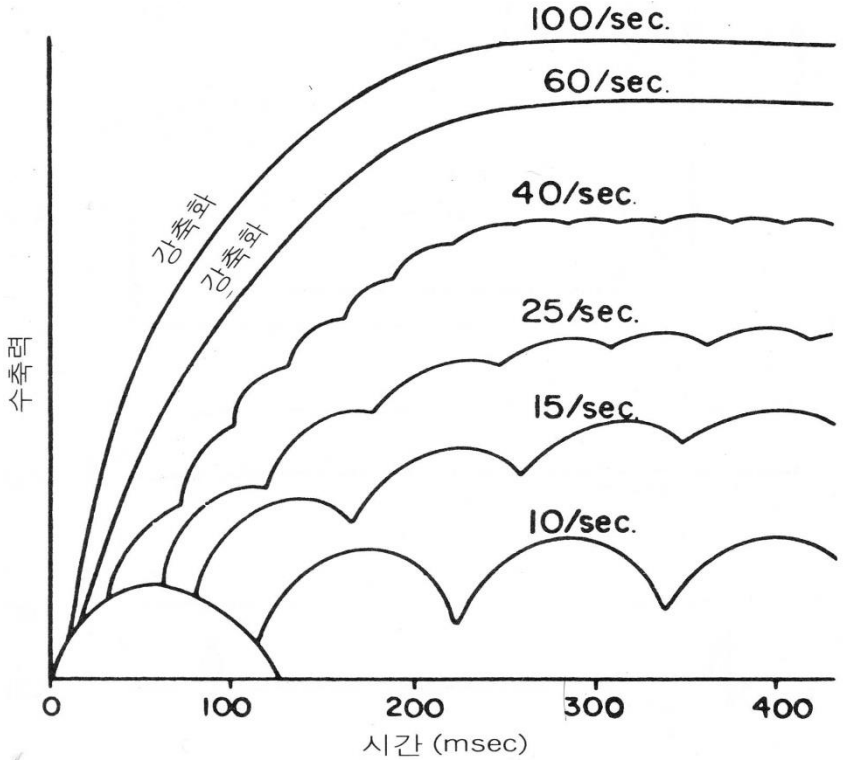



A
B
C

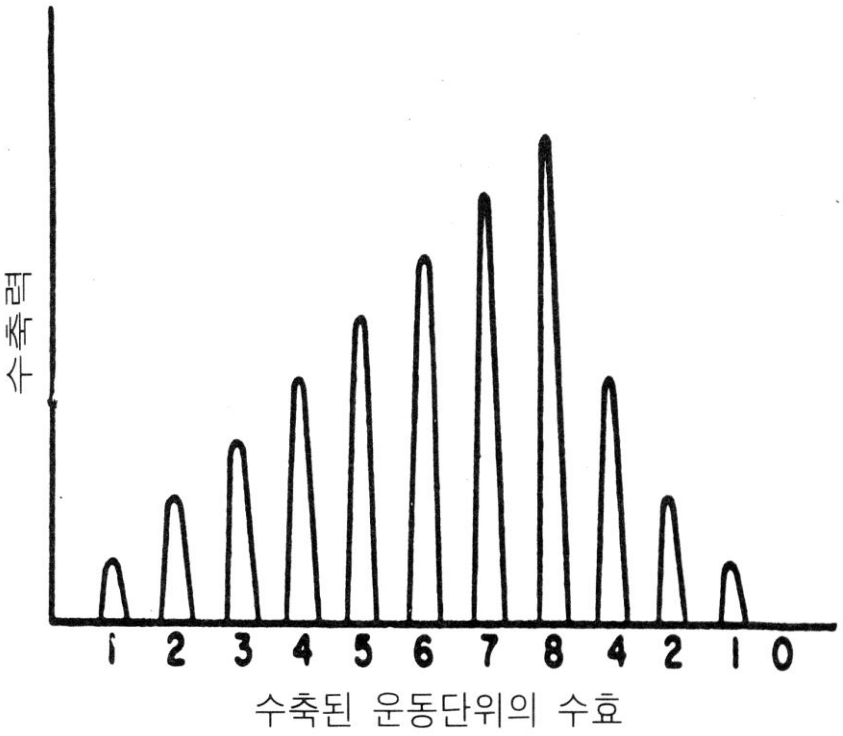
근육의 성질

- 불응기: 골격근이 흥분을 일으켰을 때 그 직후의 제2 자극으로 흥분이 일어나지 않는 기간
  - 하나의 유효자극이 가해진 후 약 0.005초 동안
- 실무율: 자극의 종류나 역치 이상의 자극에서 강도에 관계없이 언제나 일정한 연축 크기를 보임
  - 역치 미만의 자극에 대하여는 무반응

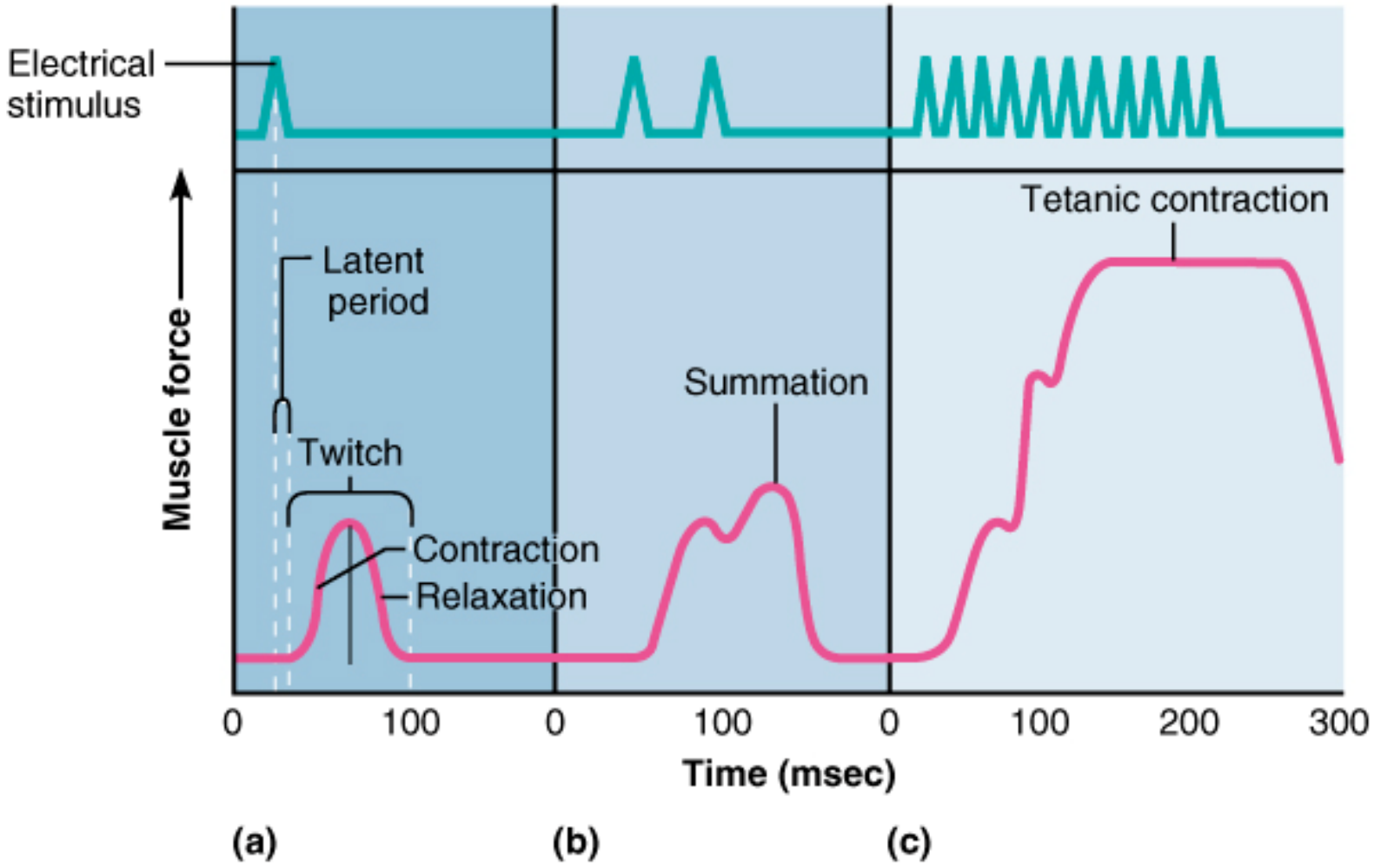
- 가중(summation): 먼저 자극으로 생긴 수축 때문에 발생된 근내의 장력에 나중 자극으로 발생된 근내의 장력이 합쳐져서 나타남

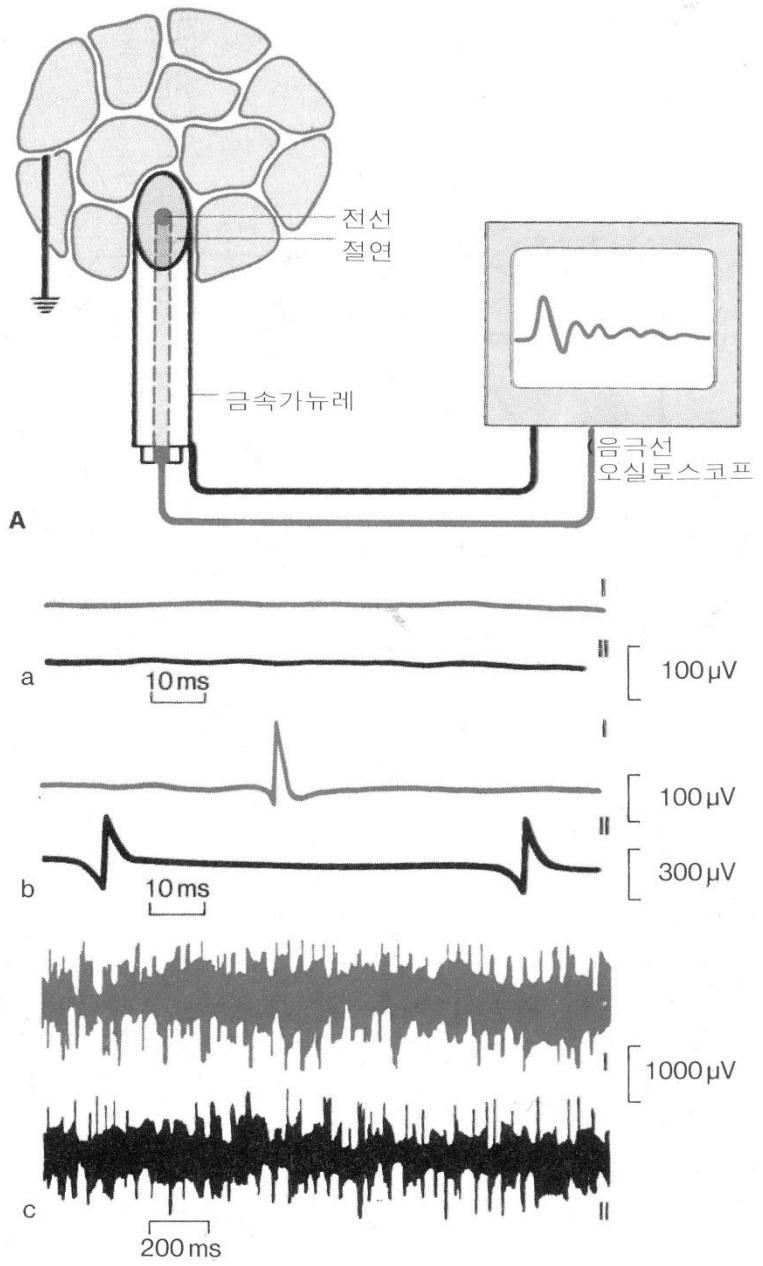


[파형성 가중 및 강축곡선]



[섬유성 가중]


Electrical stimulus
Muscle force
Latent period
Twitch
Contraction
Relaxation
Summation
Tetanic contraction
0
100
0
100
0
100
200
300
Time (msec)
(a)
(b)
(c)



- 근전도 (electromyography; EMG): 마취하지 않은 사람의 근육을 덮고 있는 피부 위에 pickup전극 또는 주사침 전극 같은 작은 금속판을 이용해 근의 활동 중에 나타나는 전기적 변동

[**근전도**. A: 근전도 기록장치. B: 근전도. a: 이완근, b: 약한 수의적 수축, c: 강력한 수의적 수축.]

Definition

Electromyography is a test that measures and records the activity of contracting muscles in response to electrical stimulation. It checks the health of the muscles and the nerves that control the muscles. EMG is performed using an instrument called electromyogaph, to produce a record called an electromyogram.

Purpose of EMG

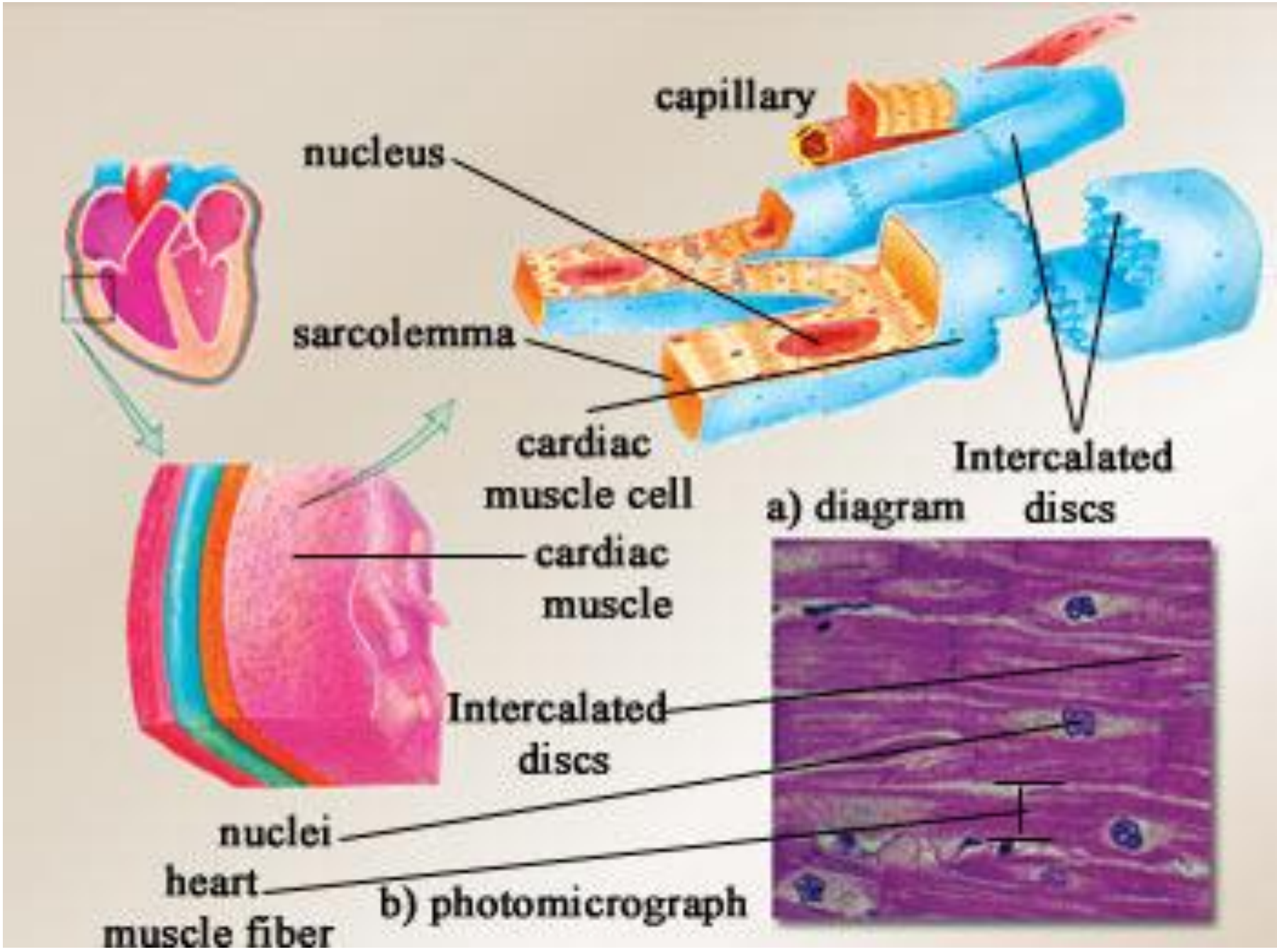
- EMGs are useful in determining the presence of a neuromuscular disorder and neuropathies.
- Helps to distinguish weakness due to neuropathy (functional or pathologic changes in the peripheral nervous system) from weakness due to other causes.
- It helps differentiate muscle disease from motor neuron dysfunction.

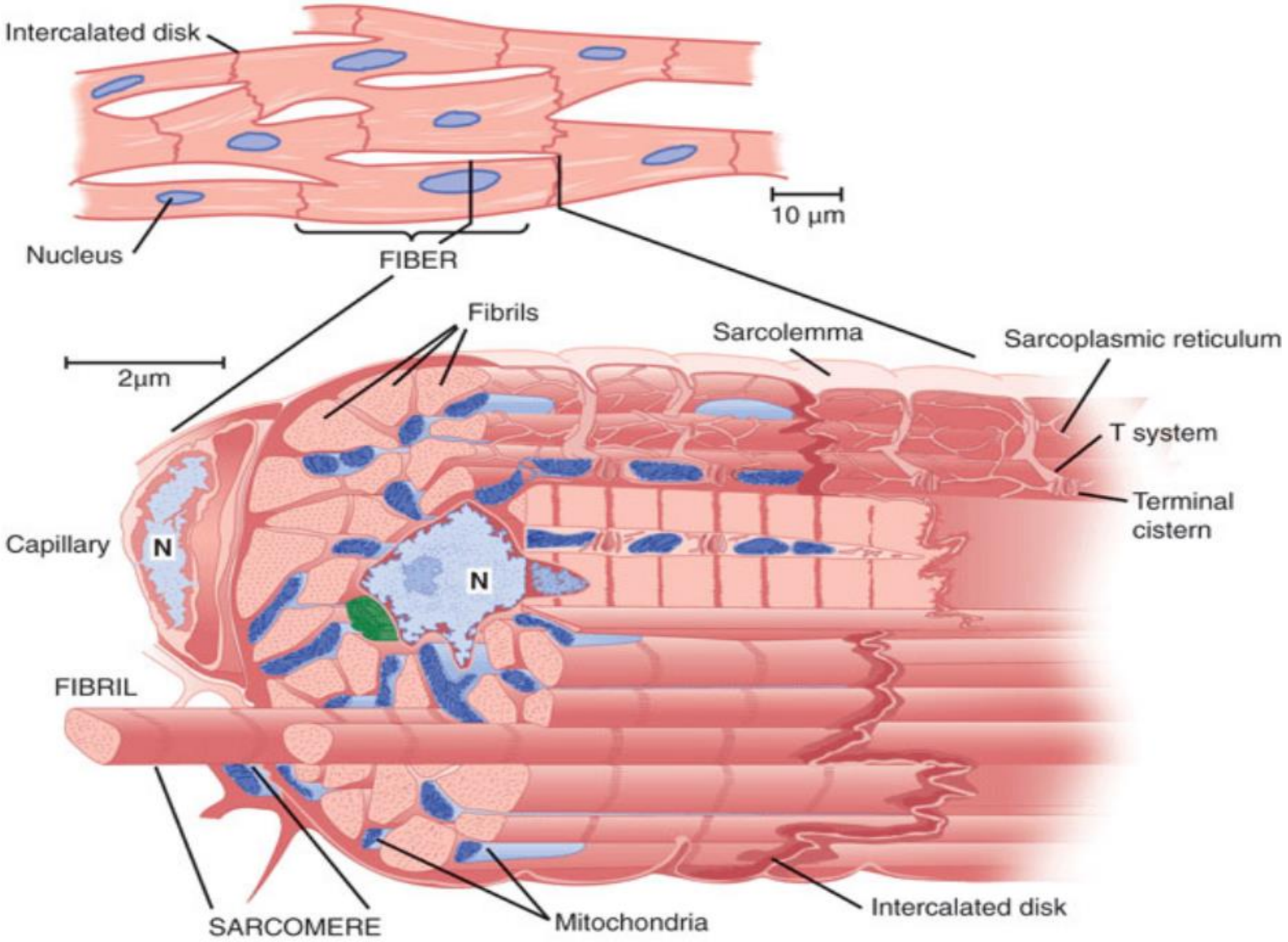
Cardiac Muscle (심장근)

- 미세구조

  섬유에 횡문을 갖는 골격근과 비슷한 구조

  개재판(intercalated disks): 하나의 근섬유 끝이 다른 근섬유 끝과 인접되는 곳에 양쪽 근섬유의 막이 중첩, Z선에 해당
- 불수의근으로 줄무늬가 있다
- 심장의 부피를 형성한다
- 세포들은 서로 연결되어 같은 방향으로 망상조직을 형성한다
- 근섬유는 단핵세포이며, 섬유의 중앙에 위치
- 엉성한 myofibril(근원섬유)이 골격근과 비슷하게 줄무늬를 형성한다
- 생리 식염수에서 자동적으로 수축해 자율신경계가 심장박동을 수행한다
- 수축과 이완이 동시에 이루어진다


capillary
nucleus
sarcolemma
cardiac muscle cell
Intercalated discs
a) diagram
cardiac muscle
Intercalated discs
nuclei
heart muscle fiber
b) photomicrograph

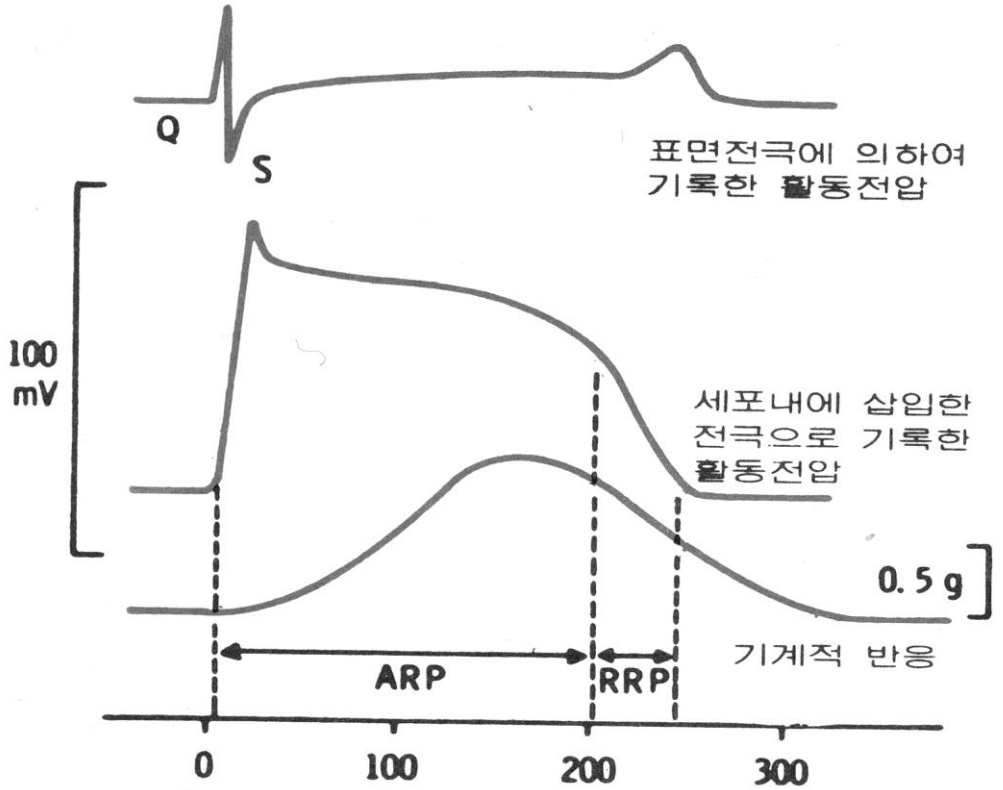

Intercalated disk
Nucleus
FIBER
10 µm
2µm
Fibrils
Sarcolemma
Sarcoplasmic reticulum
T system
Terminal cistern
Capillary
N
N
FIBRIL
SARCOMERE
Mitochondria
Intercalated disk

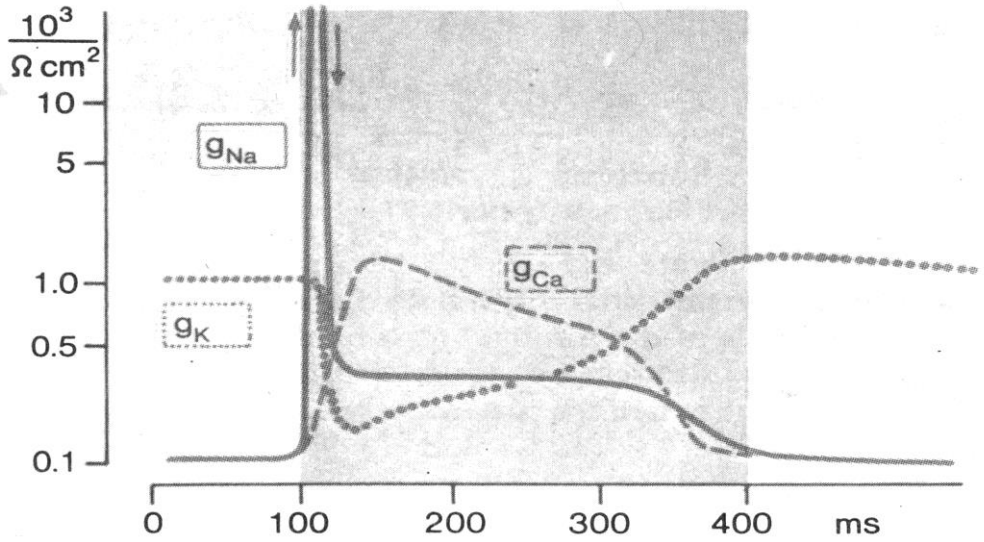
❖막전압과 활동전압

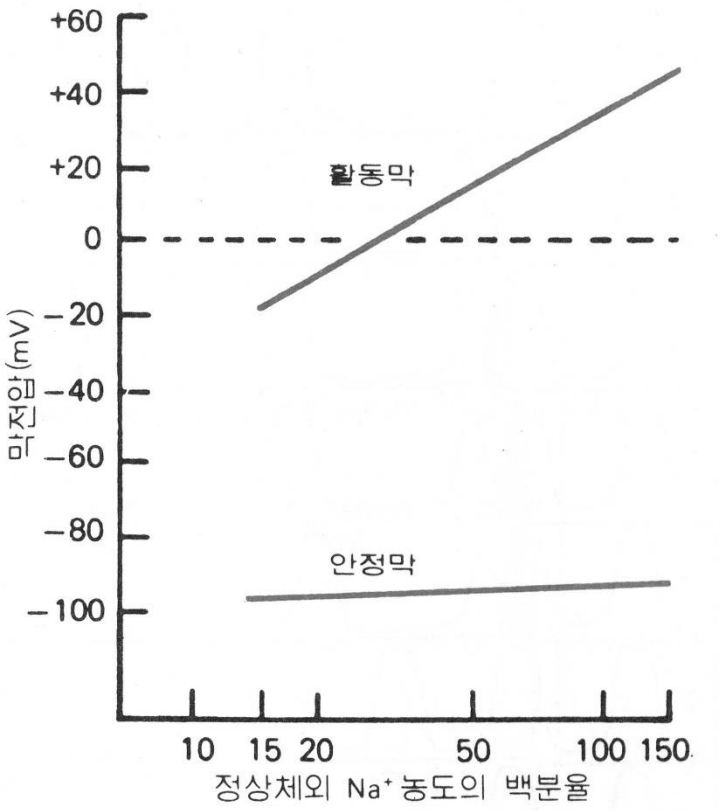
[심장근의 활동전압과 Na^+, Ca^{++}, K^+의 콘덕탄스 변동.

위: 상단곡선-기록 전극을 심장근 표면에 접촉하고 기록한 곡선. 중단 곡선-세포내에 미소전극을 삽입하고 기록한 곡선. 하단 곡선-기계적 반응 즉, 수축 곡선. APR-절대 불응기. PRP-상대성 불응기.

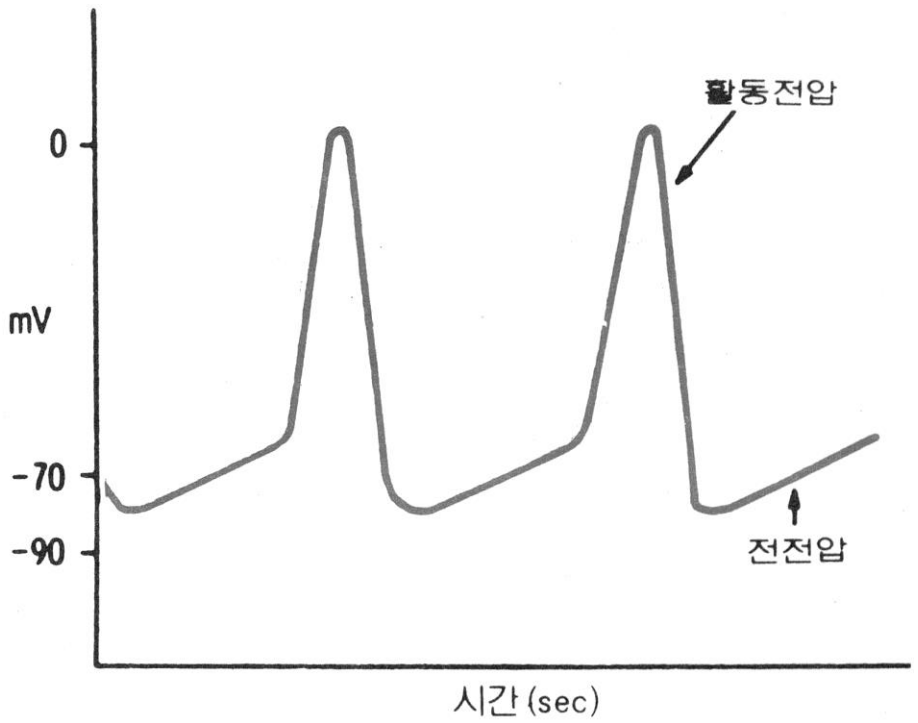
아래: 심장근의 활동전압 경과 중에 gNa, gCa 및 gK의 변동을 시간과 크기로 표현]







[심장근의 활동전압과 안정막전압에 미치는 세포외액의 Na+ 농도의 효과]

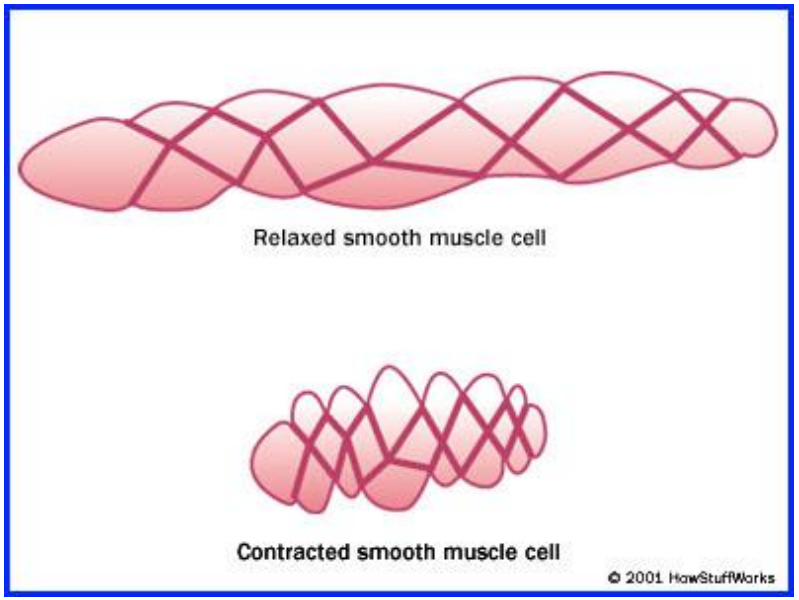


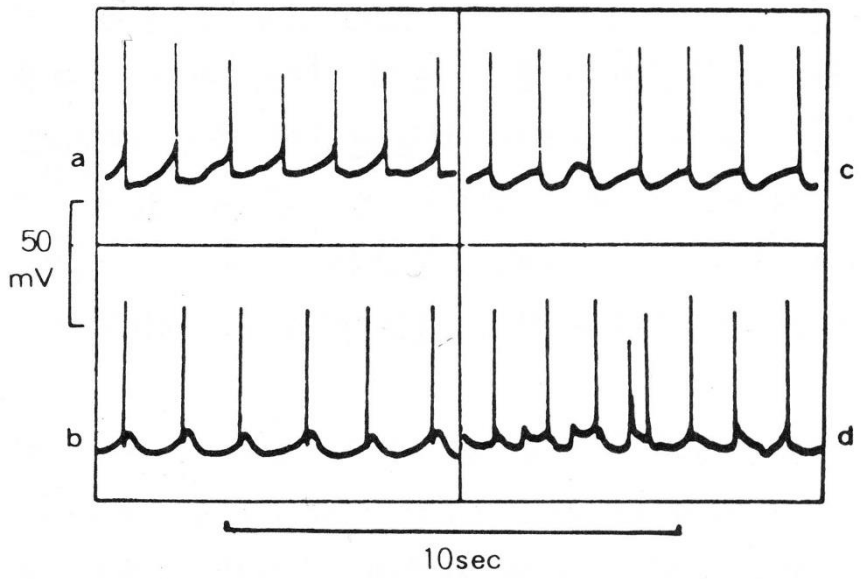
[심장의 향도잡이 막전압]

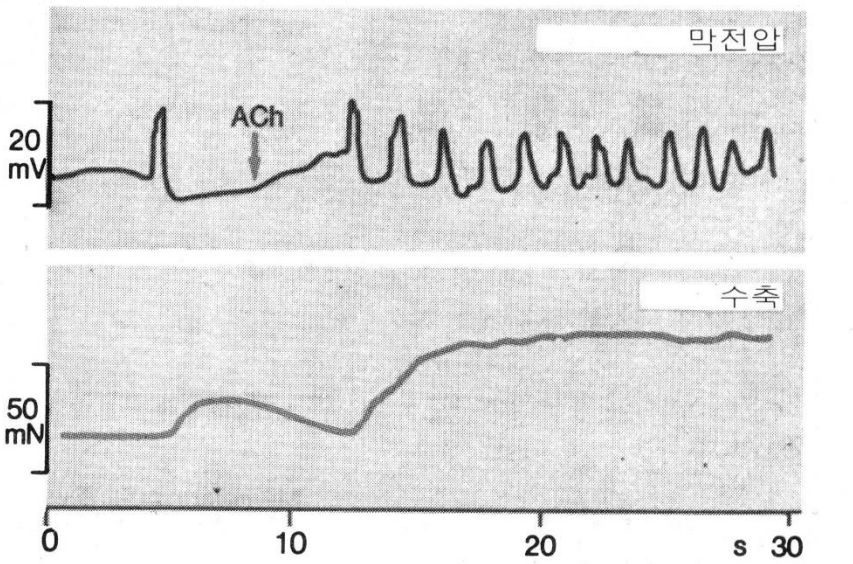
평활근 (Smooth Muscle)

- 내장근 (visceral muscle), 불수의근 이다
- 방추형의 근섬유에 의해 형성, 1개의 핵
- 근섬유→ 단핵세포, 줄무늬형태가 아님
- 장관벽, 혈관벽, 자궁의 벽을 형성한다
- 자율 신경계에 의해 움직인다
- 횡무늬근에 비해 서서히 수축하고,
  지속적인 수축이 가능
- Calmodulin: Ca^{2+} 결합 단백질
- 치밀체(dens body)가 있다

- **smooth-muscle cells** are small.
- They are spindle-shaped, about 50 to 200 microns long and only 2 to 10 microns in diameter.
- They have no striations or sarcomeres. Instead, they have bundles of thin and thick filaments (as opposed to well-developed bands) that correspond to myofibrils.
- In smooth-muscle cells, **intermediate filaments** are interlaced through the cell much like the threads in a pair of "fish-net" stockings. The intermediate filaments anchor the thin filaments and correspond to the Z-disks of skeletal muscle. Unlike skeletal-muscle cells, smooth-muscle cells have no troponin, tropomyosin or organized sarcoplasmic reticulum.







평활근의 막전압

a: 향도잡이 양식.

b: 사인 커브형 곡선의 상행각에서의 활동전압.

c: 사인 커브형 곡선의 하행각에서의 활동전압.

d: 향도잡이 방식

평활근의 활동전압과 수축곡선

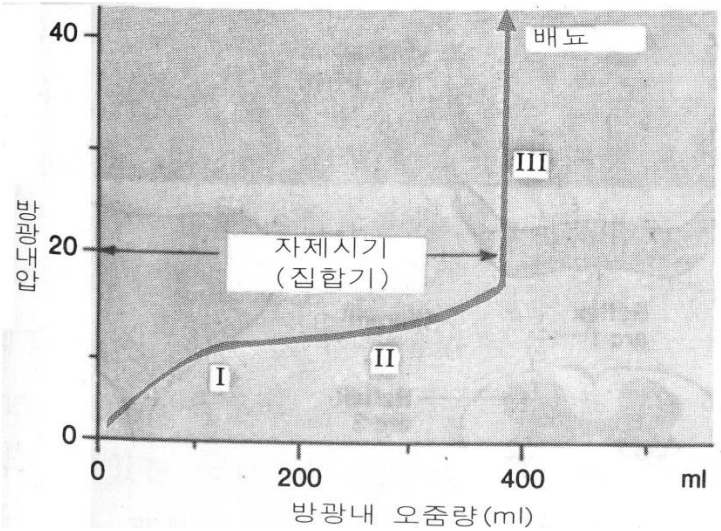
위: 연축을 일으키는 활동전압과 아세틸콜린 투여후의 활동전압.

아래: 활동전압이 일어날 경우 수축곡선.

❖ 흥분전파→수축

- 낮은 저항의 세포와 세포 사이 결합 부위에서 활동전압을 일으키게 막전압을 감소
  → 5~10cm/sec 속도로 기능적 세포결체(syncytium) 형성
  → Ca^{++}과 calmodin 결합
  → myosin light chain kinase 활성
  → 마이오신의 인산화 촉매
  → 액틴이 마이오신으로 이동, 수축
  → Ca^{++}농도가 10^{-8}mol/ℓ 이하, 이완

❖ 가소성



- 길이가 길어진 후에도 같은 장력을 유지

[방광 압력곡선.
방광 내 오줌량 증가함에 따라 압력 증가하는 부위 I, 오줌량의 증가에 관계없이 압력이 같은 부위 II, 급격하게 압력 증가 III(배뇨반사 시작)]

Calcium ions regulate contraction in smooth muscle, but they do it in a slightly different way than in skeletal muscle:

1. Calcium ions come from outside of the cell.
2. Calcium ions bind to an enzyme complex on myosin, called **calmodulin-myosin light chain kinase**.
3. The enzyme complex breaks up ATP into ADP and transfers the P_i directly to myosin.
4. This P_i transfer activates myosin.
5. Myosin forms crossbridges with actin (as occurs in skeletal muscle).
6. When calcium is pumped out of the cell, the P_i gets removed from myosin by another enzyme.
7. The myosin becomes inactive, and the muscle relaxes