General anatomy of skeletal muscle - its innervation and blood supply, dvelopment and regeneration

General anatomy of spinal nerve, angiology - general characteristics

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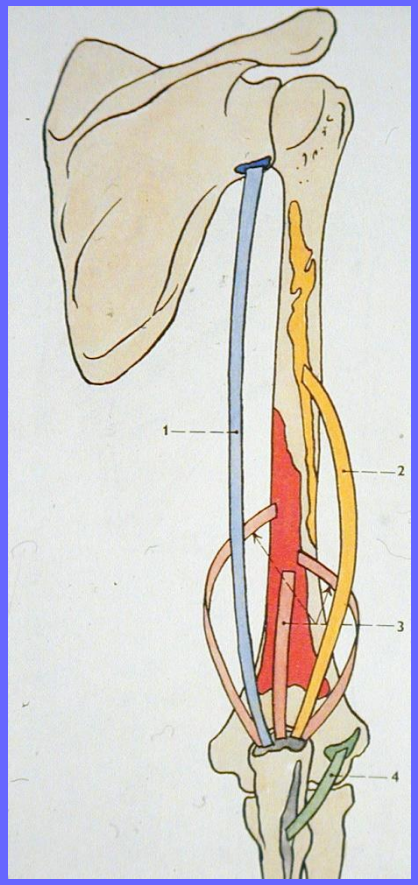
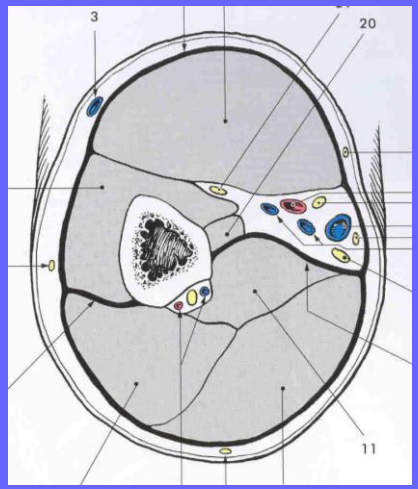
How to study skeletal muscles:

identification, origo, insertio, position (scheme, tables), muscle groups, innervation, function, osteofascial spaces (compartments), transverse sections of limb segments, dissection





General Anatomy of Skeletal Muscle

General features of striated muscle, attachments of skeletal muscles – origin, insertion, tendons, aponeuroses, myo-tendinous juncion

Structure of muscle: muscle fibers, myofibrils, sarcomeres, myofibrilar proteins, sliding filament mechanism of muscle contraction

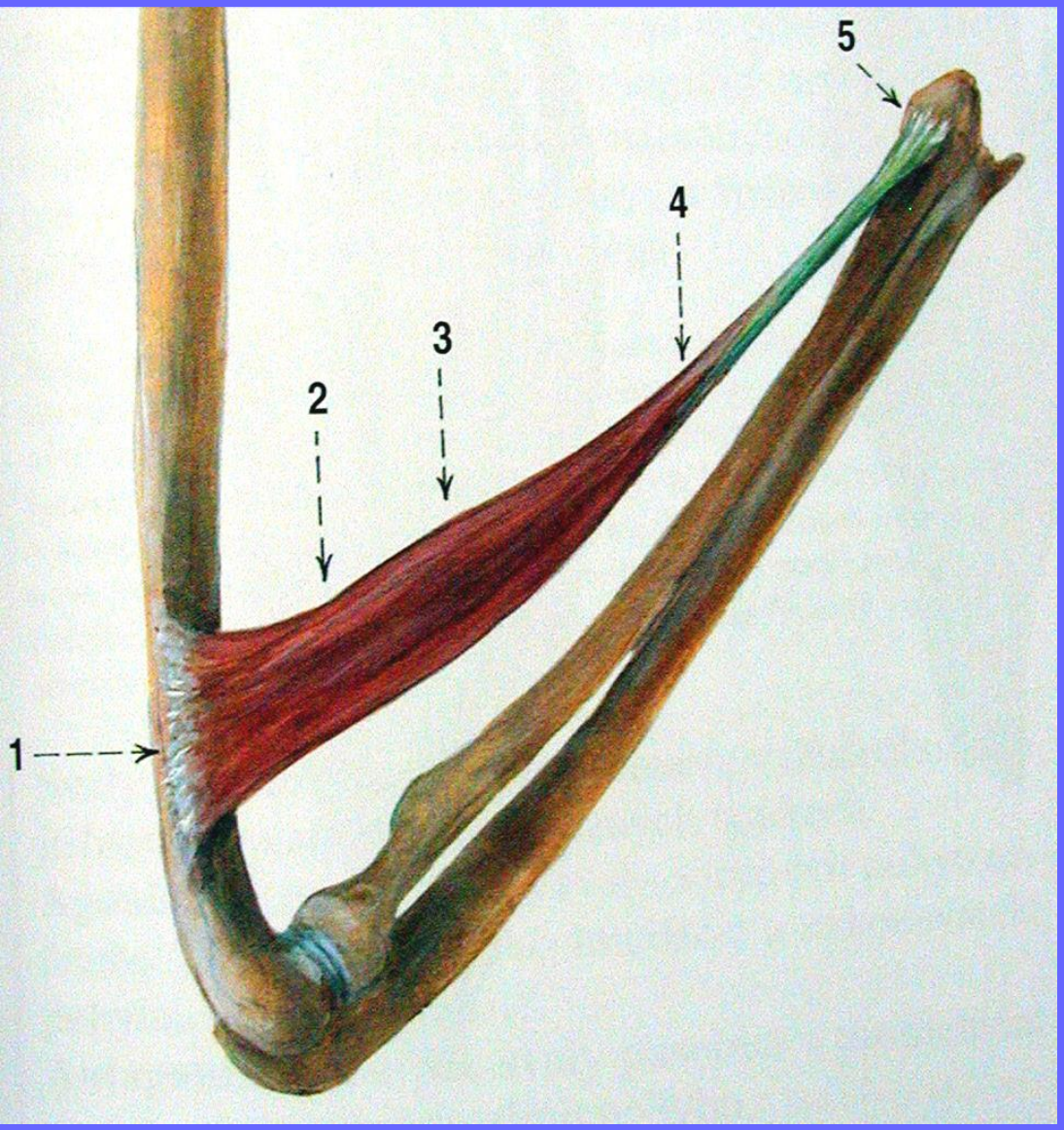
Naming of muscles, pennation

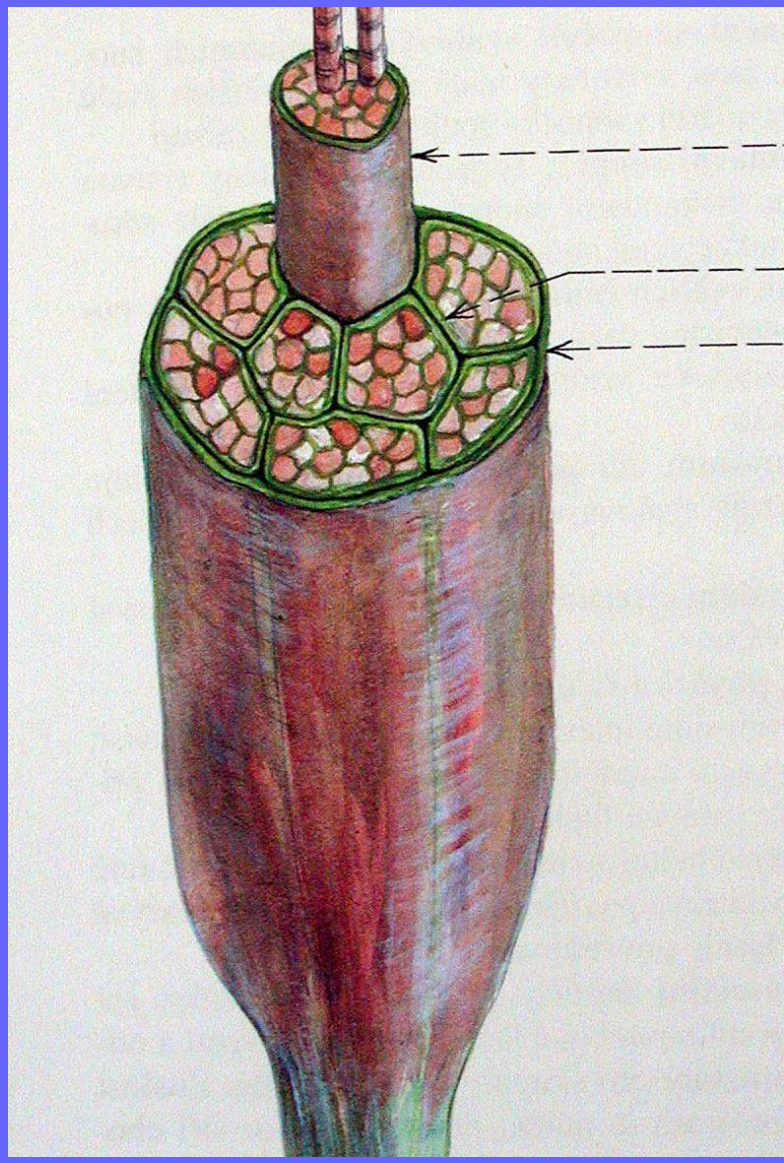
Accessory structures. fasciae, intermuscular septa, osteofibrous spaces, the endomysial and perimysial sheaths synovial sheaths and bursae,

Origin and diferentiation of mucle, molecular mechanisms

Muscle morphogenesis

Motor and proprioceptive innervation, motor end plate, motor unit, muscle spindle, Golgi tendon organ,

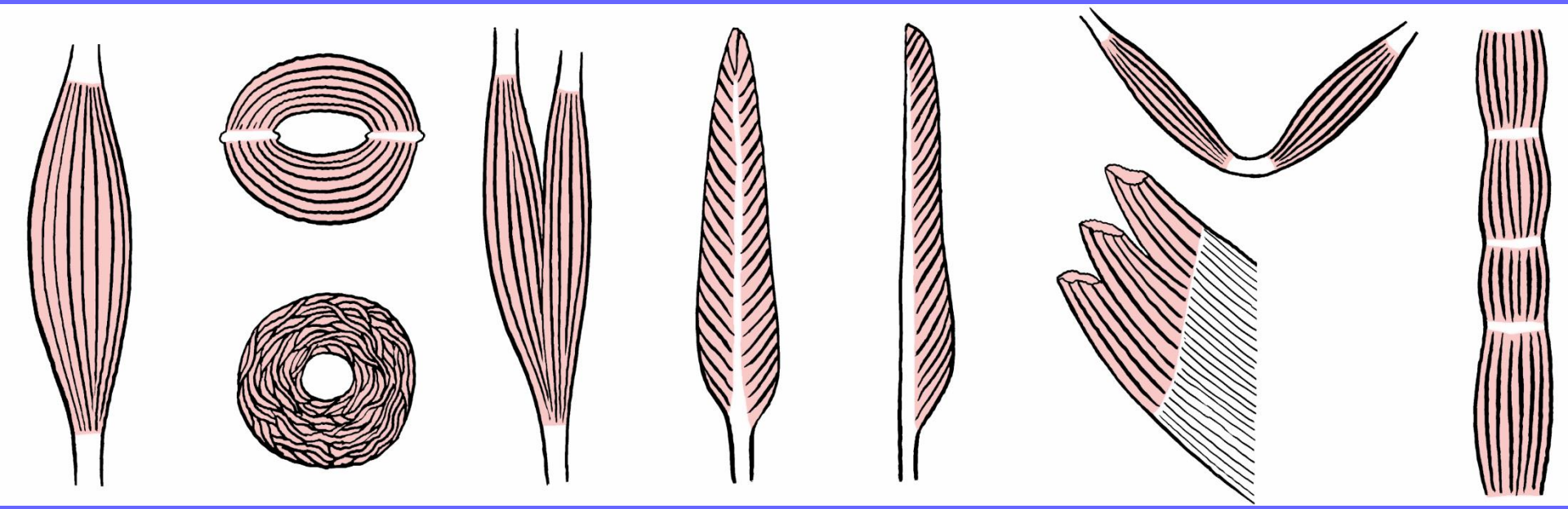


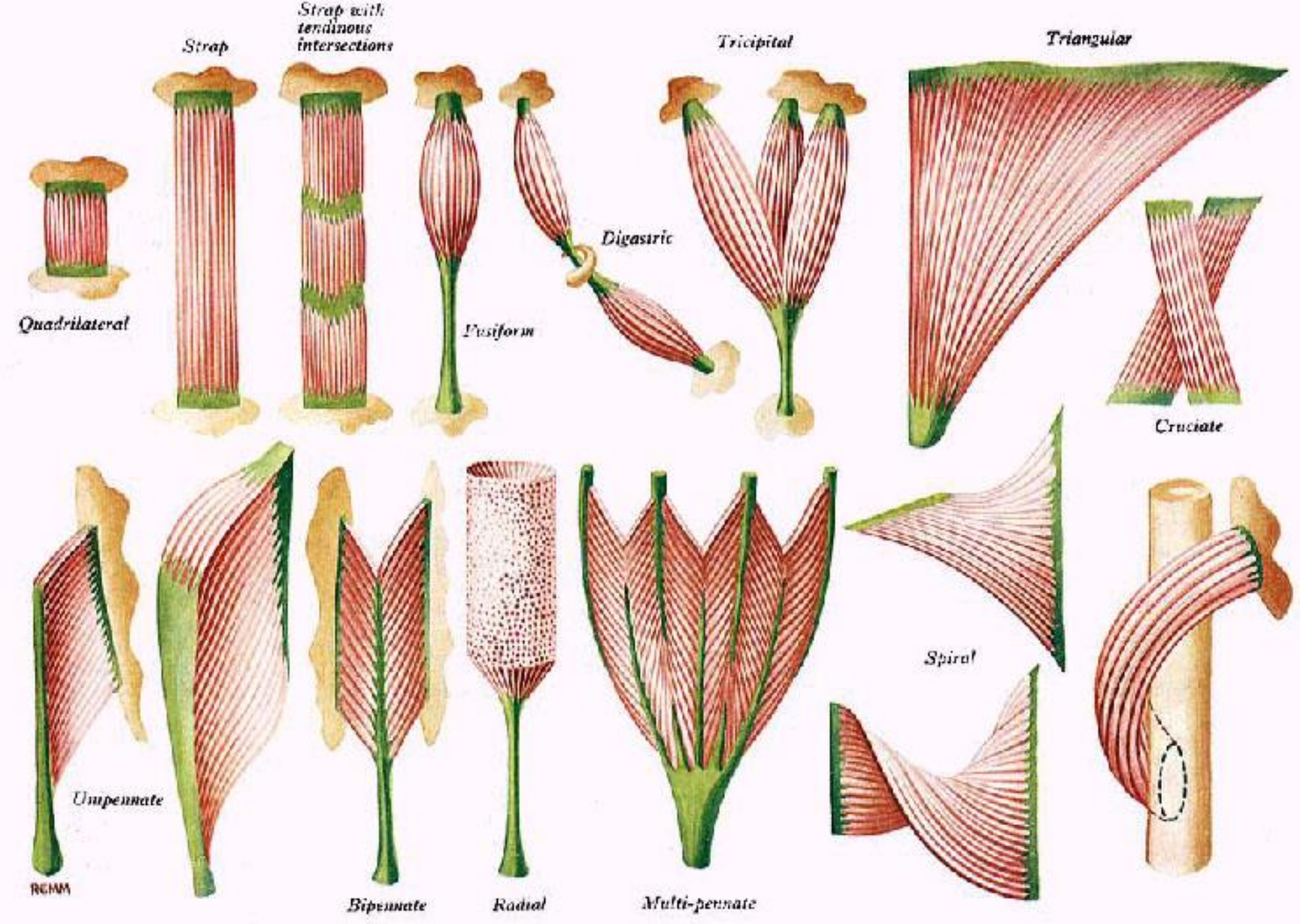


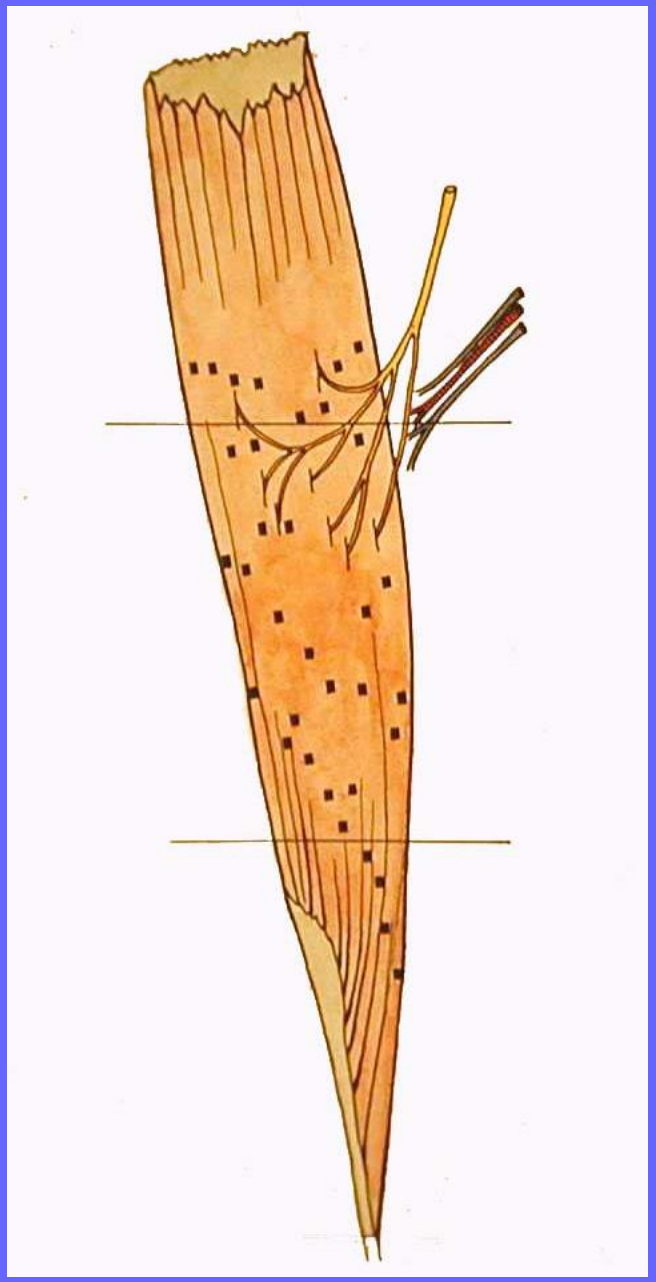
Attachments of skeletal muscles – origin, insertion, endomysial and perimysial sheaths, fascia

Myotendinous junction (MTJ)

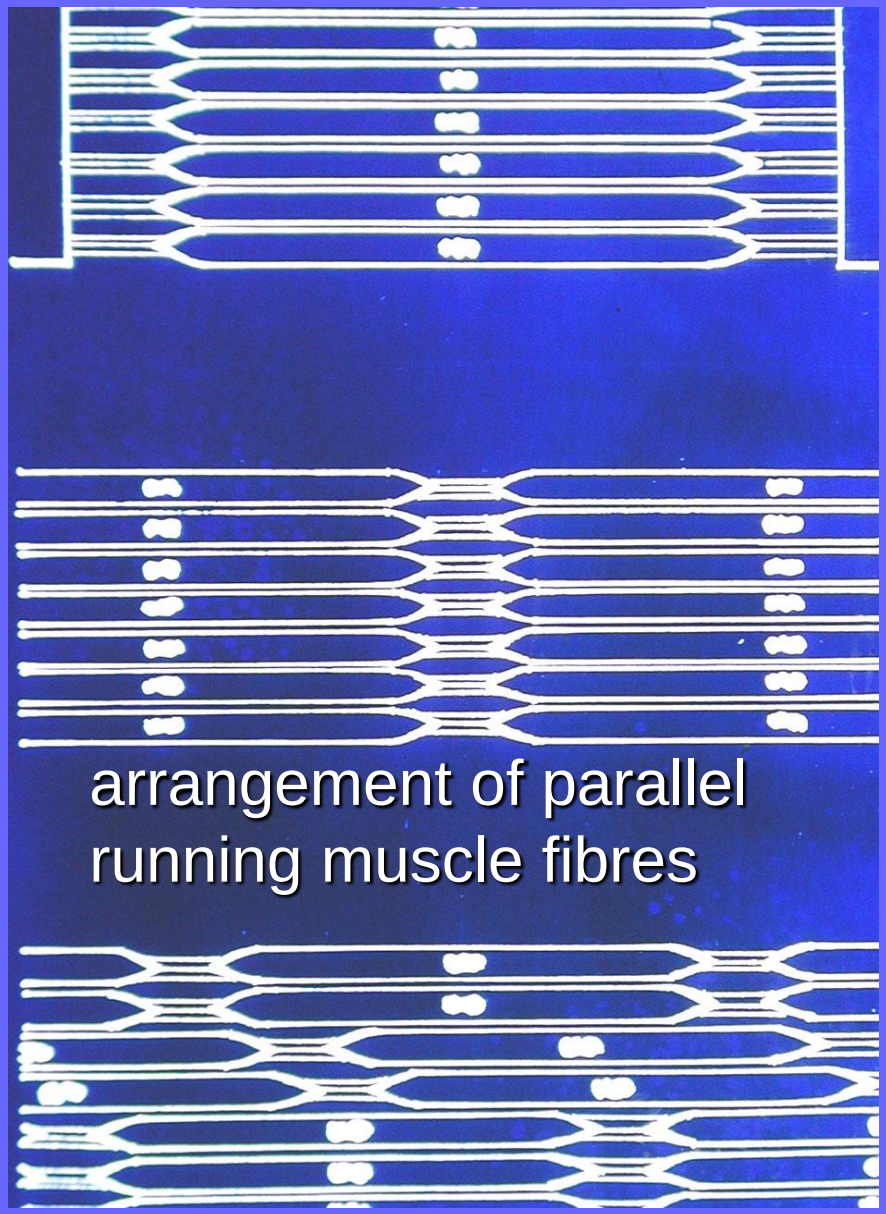
Muscle shape

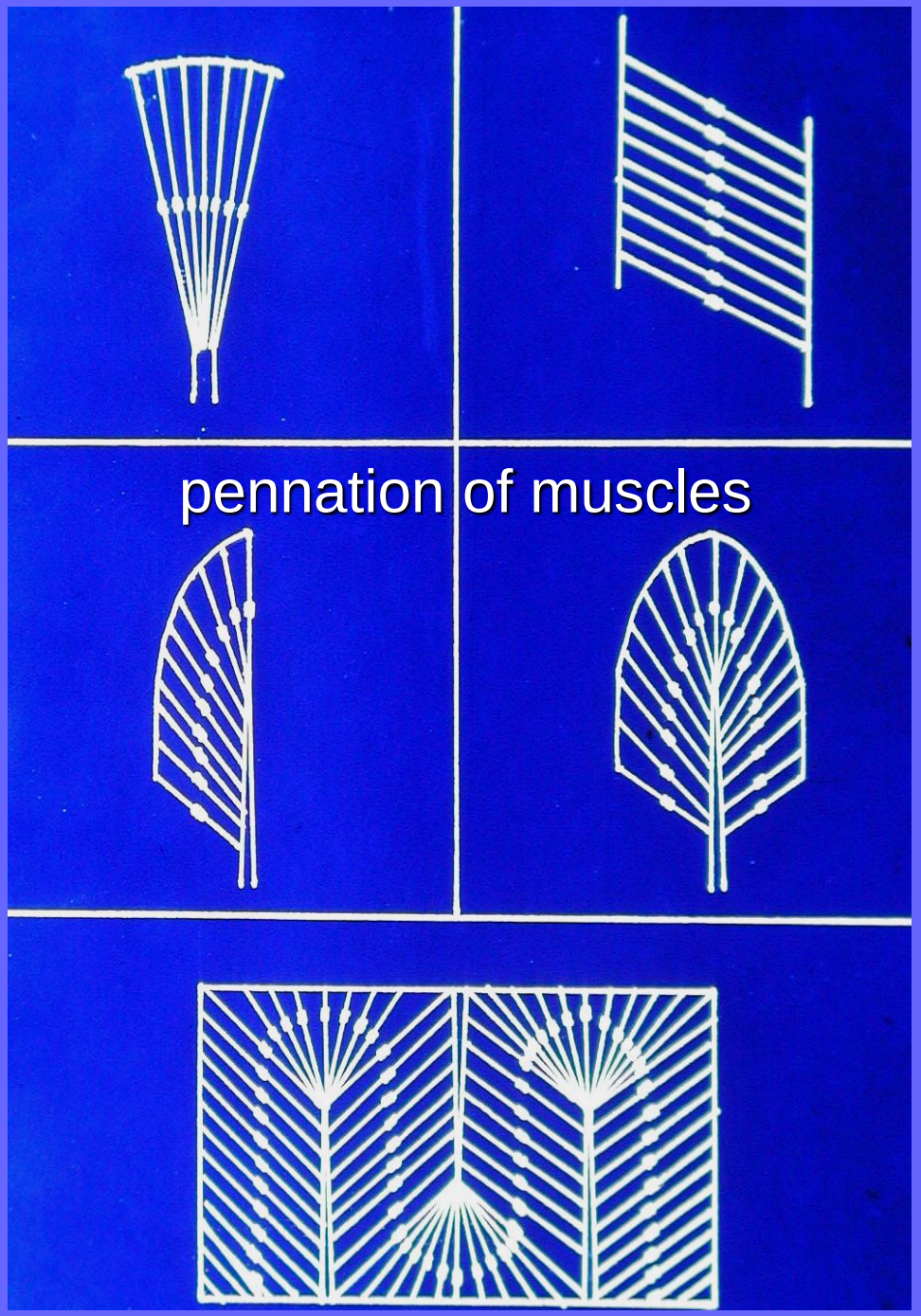



Strap
Strap with tendinous intersections
Tricipital
Triangular
Quadrilateral
Fusiform
Digastric
Cruciate
Unipennate
Bipennate
Radial
Multi-pennate
Spiral



tendons, aponeuroses, neuro-vascular hilum (motor point)


arrangement of parallel
running muscle fibres


pennation of muscles

Motoneurones terminate on muscle fibers in motor end plates (mediator = acetylcholin - ACh)

visualization of motor end plates and axons (Ag) by detection of acetylcholinesterase (AChE) in the subneural apparatus (SNA)

Naming of Muscles

Shape:

deltoid (= triangular), quadratus (= square), rhomboid (= diamond-shaped), teres (= round), gracilis (= slender), rectus (= straight), lumbrical (= worm-like)

Size : major, minor, longus (= long), brevis (= short), latissimus (= broadest), longissimus (= longest)

Number of Heads or Bellies:

biceps (= 2 heads), triceps (= 3 heads), quadriceps (= 4 heads)
digastric (= 2 bellies), biventer (= 2 bellies),

Position: anterior, posterior, interosseus (= between bones) supraspinatus (= above spine of scapula), infraspinatus (= below spine), dorsi (= of the back), abdominis (= of the abdomen), pectoralis (= of the chest), brachii (= of the arm) femoris (= of the thigh), oris (= of the mouth),

Naming of Muscles II

Depth:

superficialis (= superficial), profundus (= deep), externus (or externi), internus (or interni)

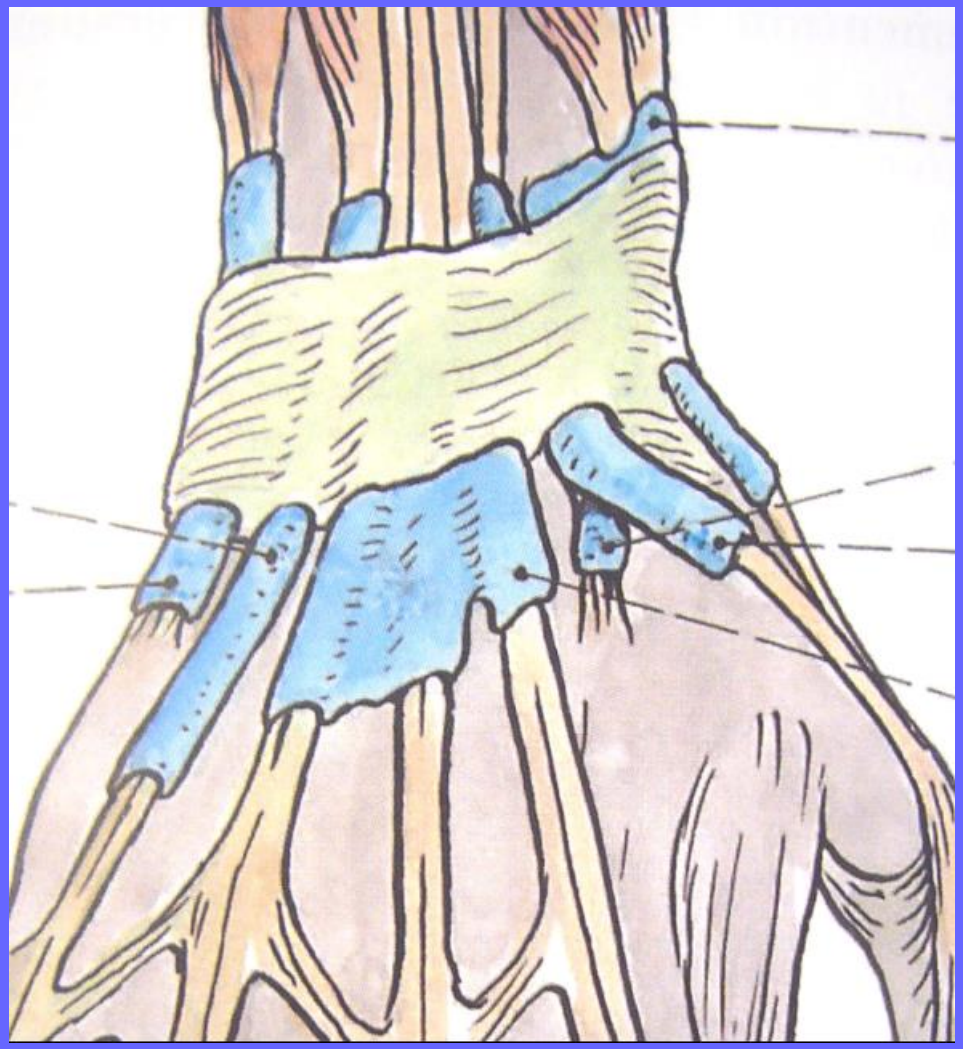
Attachment:

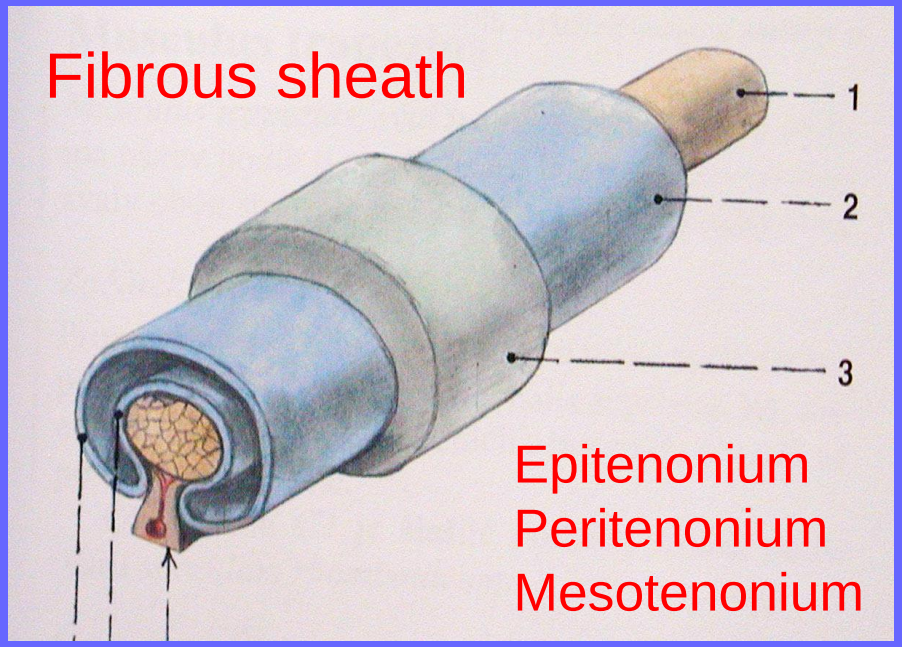
sternocleidomastoid

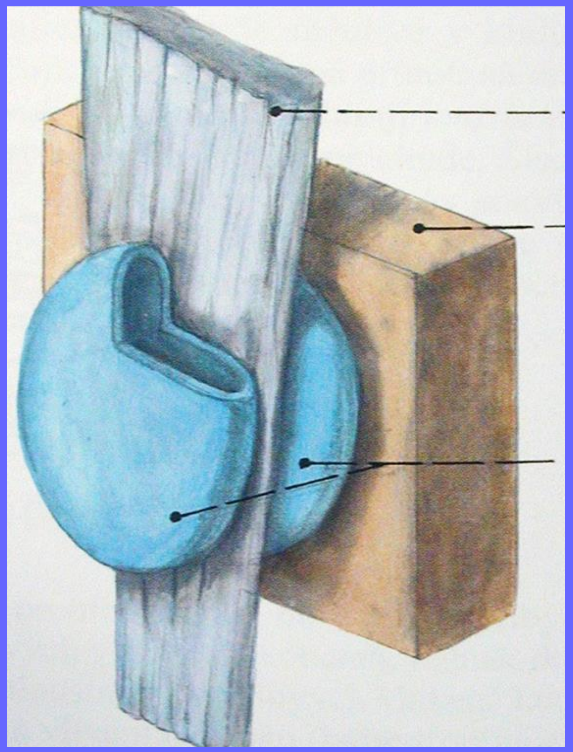
(from sternum and clavicle to mastoid process)

coracobrachialis (from the coracoid process to the arm)

Function: extensor, flexor, abduktor, adductor, pronator, supinator, levator, depressor, spincter, dilator



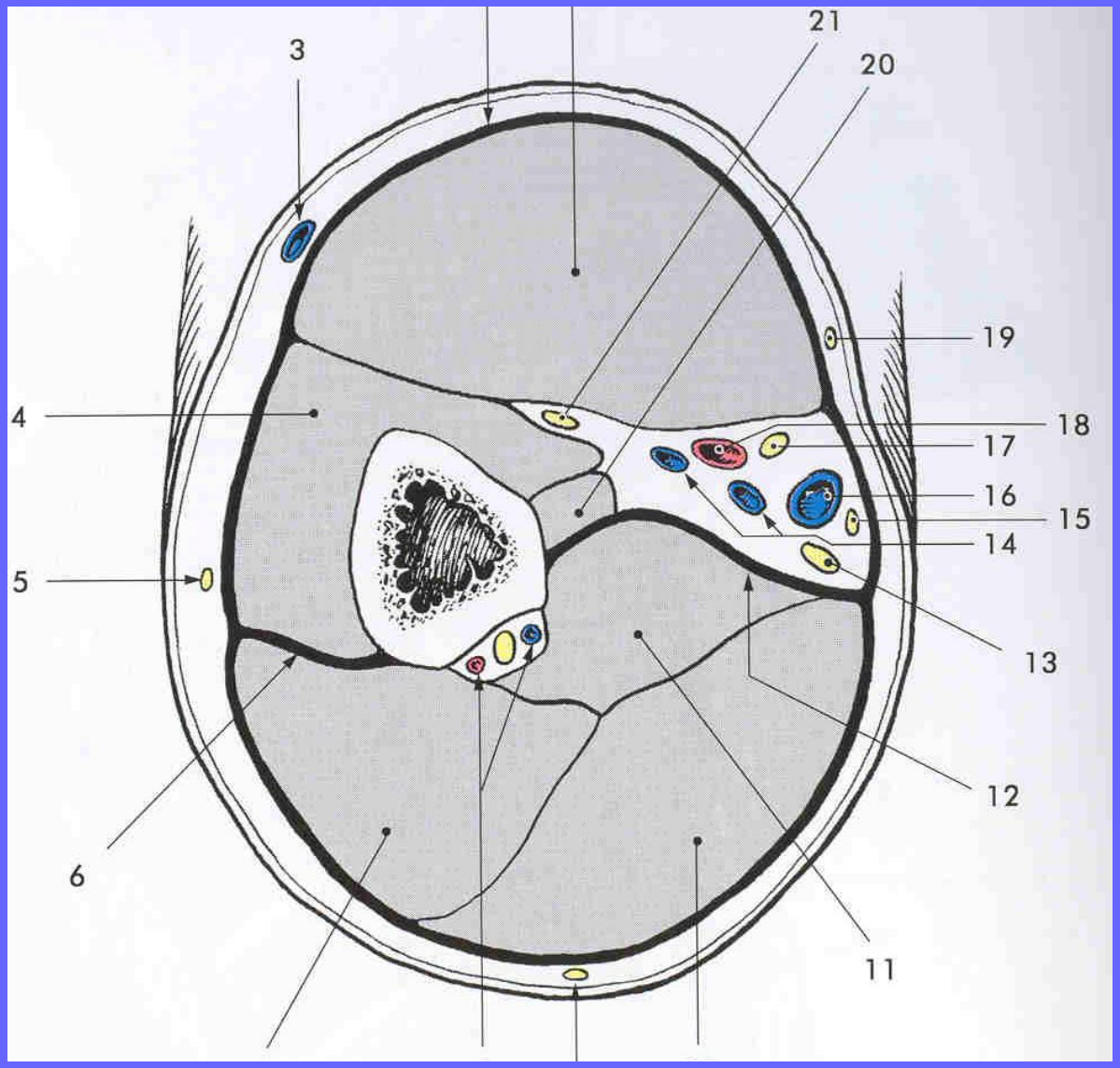


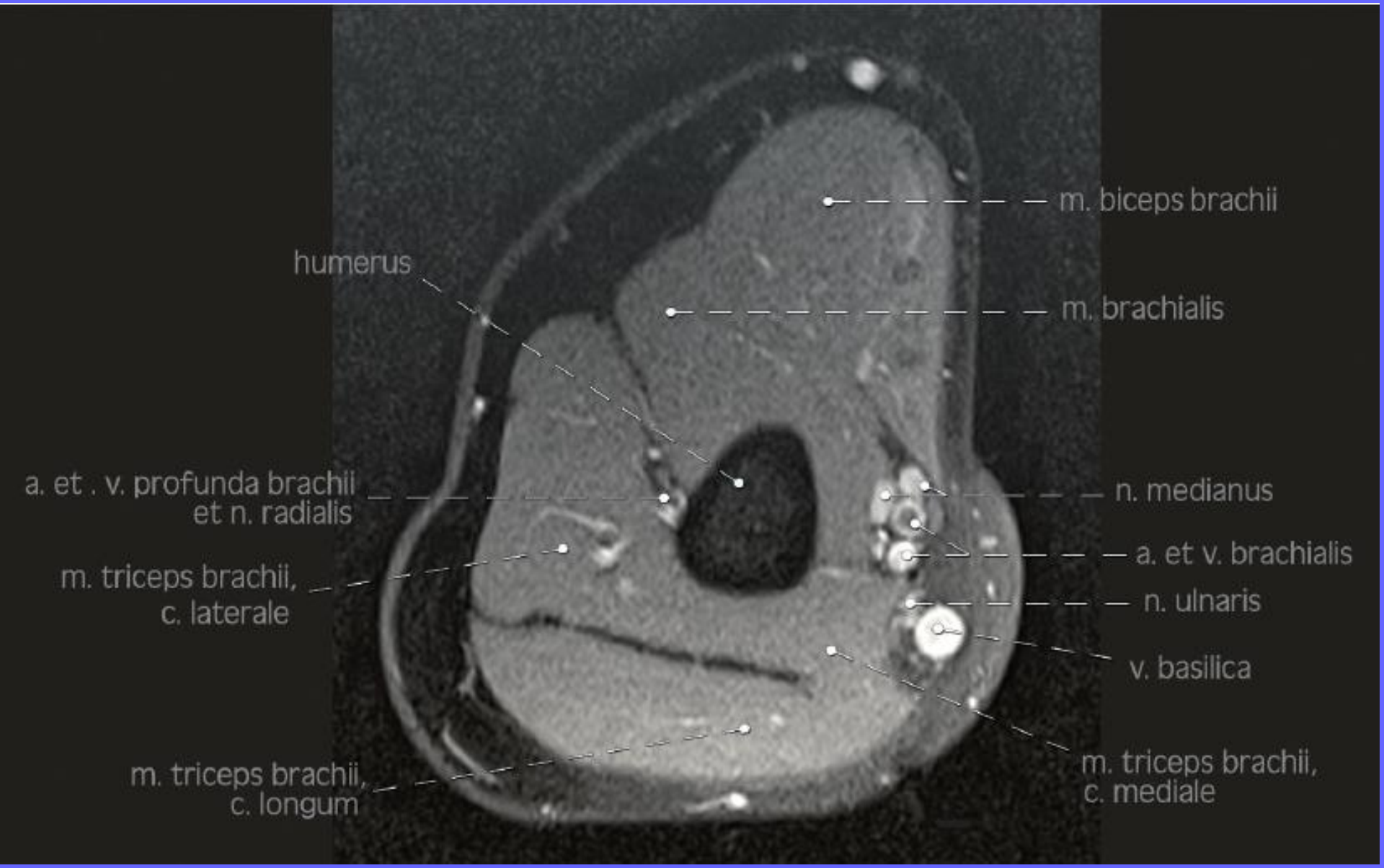


retinaculum musculorum extensorum
synovial sheath, synovial bursae

Accessory muscle structures

Fascia, intermuscular septum, osteofibrous spaces

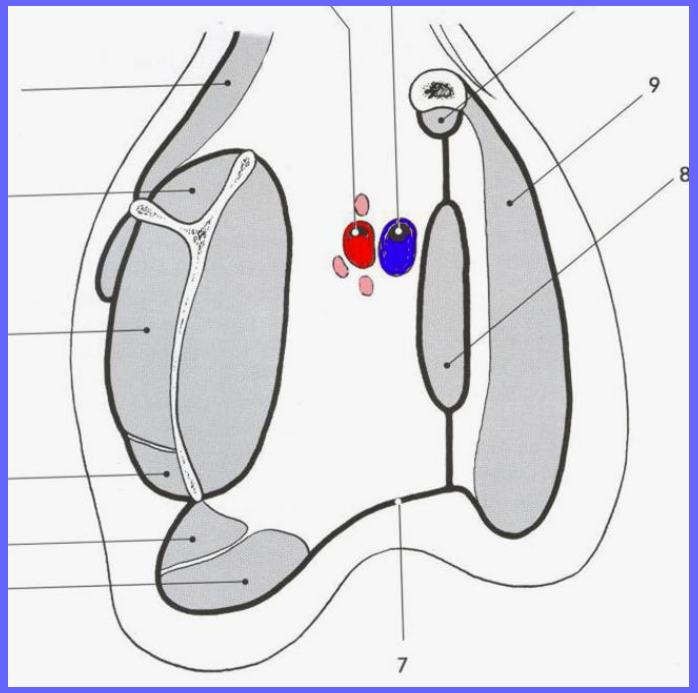


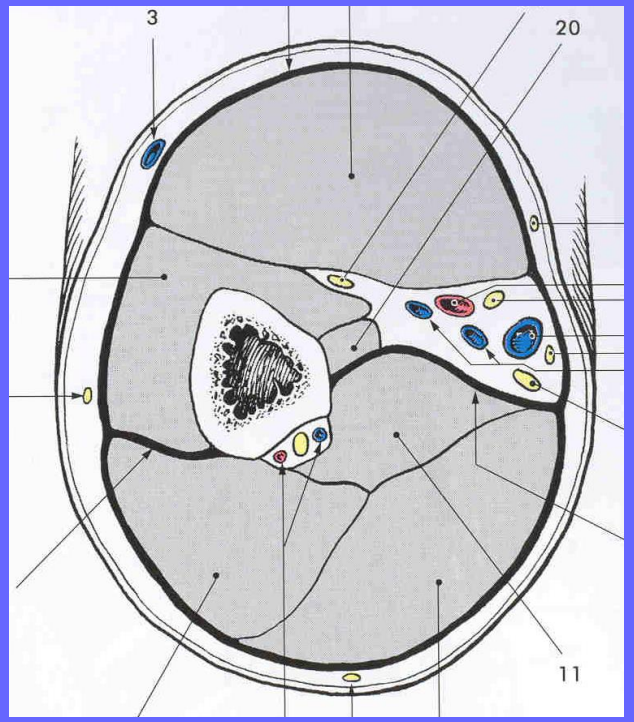


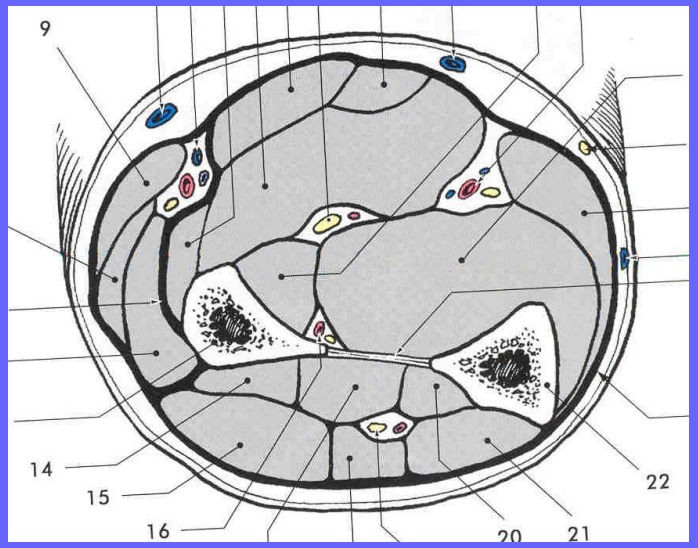
Cross section of the arm, MRI

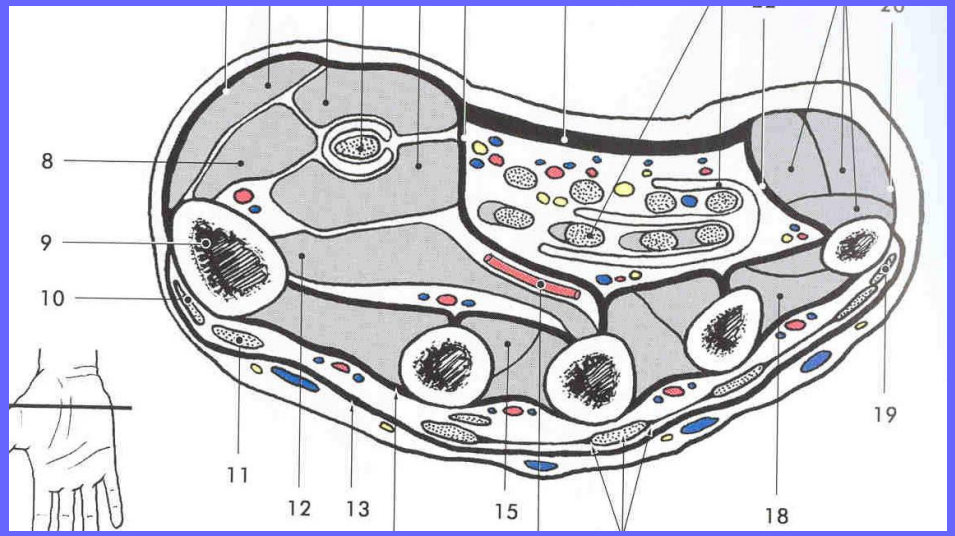
Osteofascial spaces of the upper limb

axilla, arm, forearm, hand

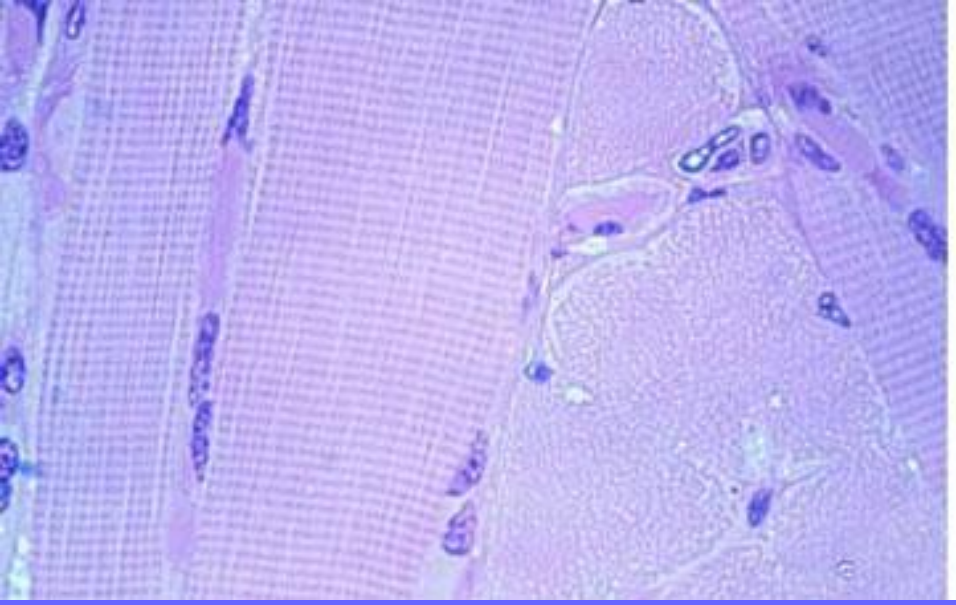


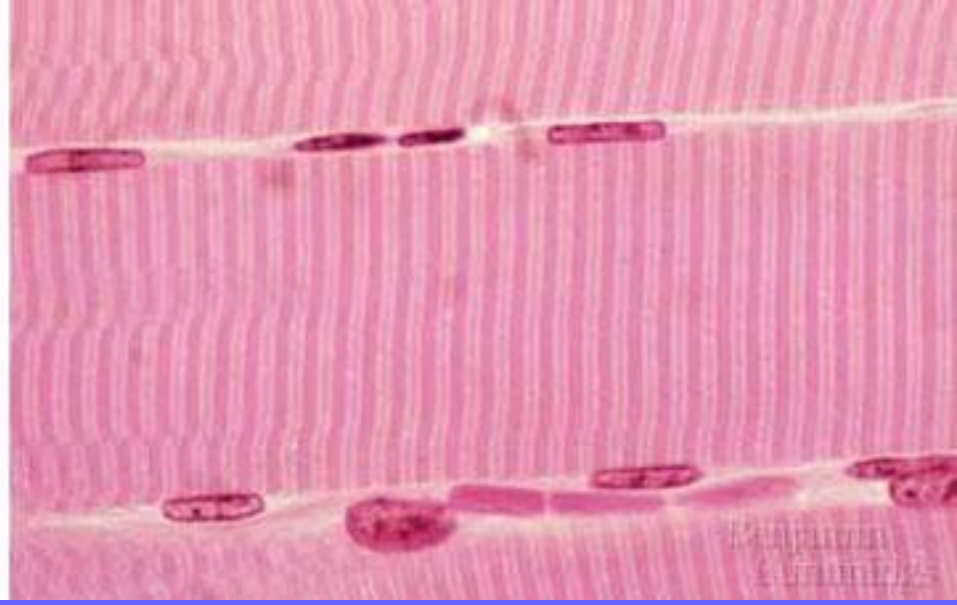




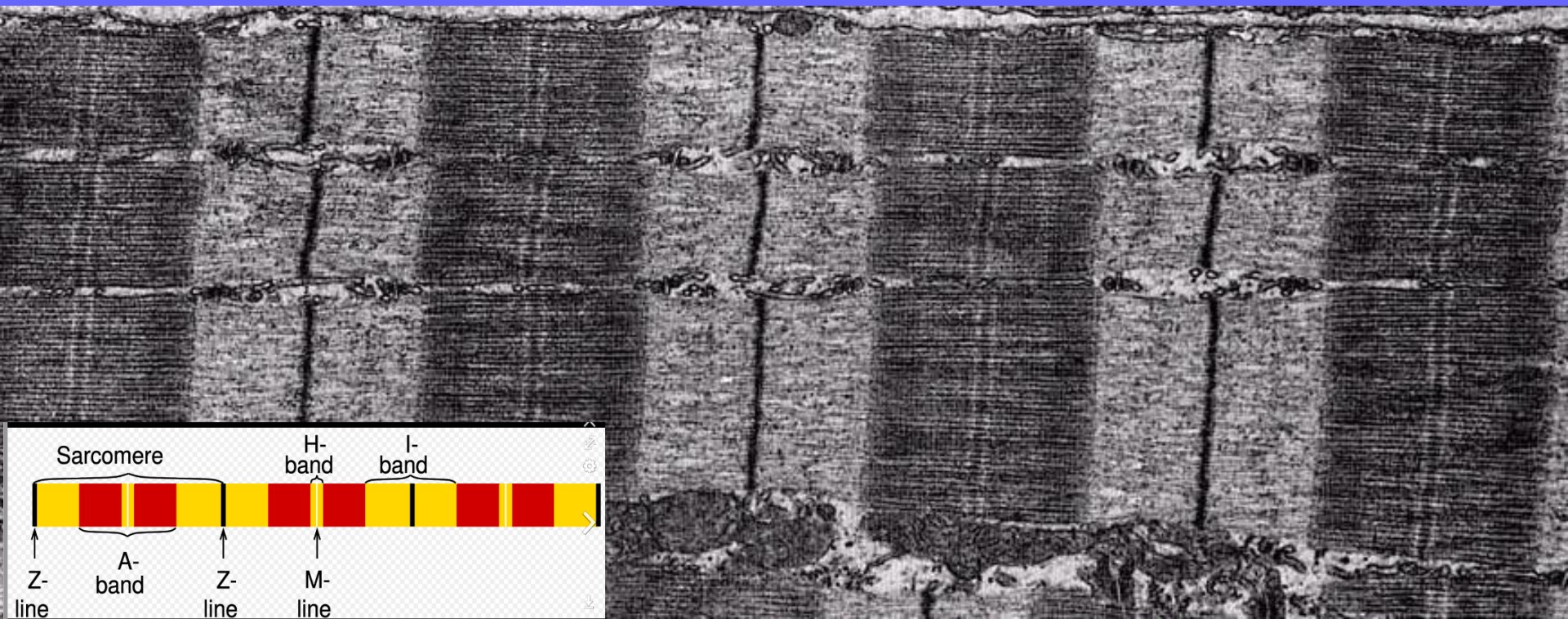


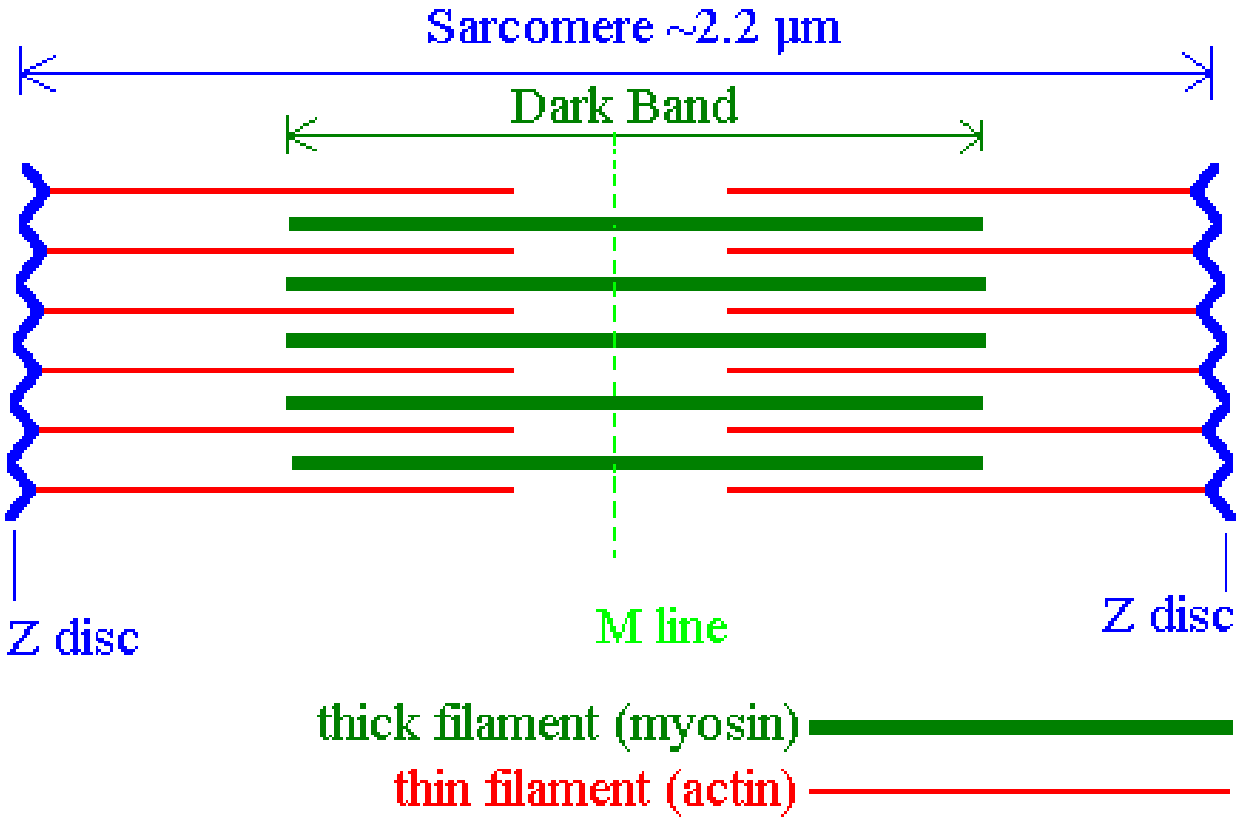
Stingl,Grim, Druga: 5.Anatomie krajin těla, Galén 2008

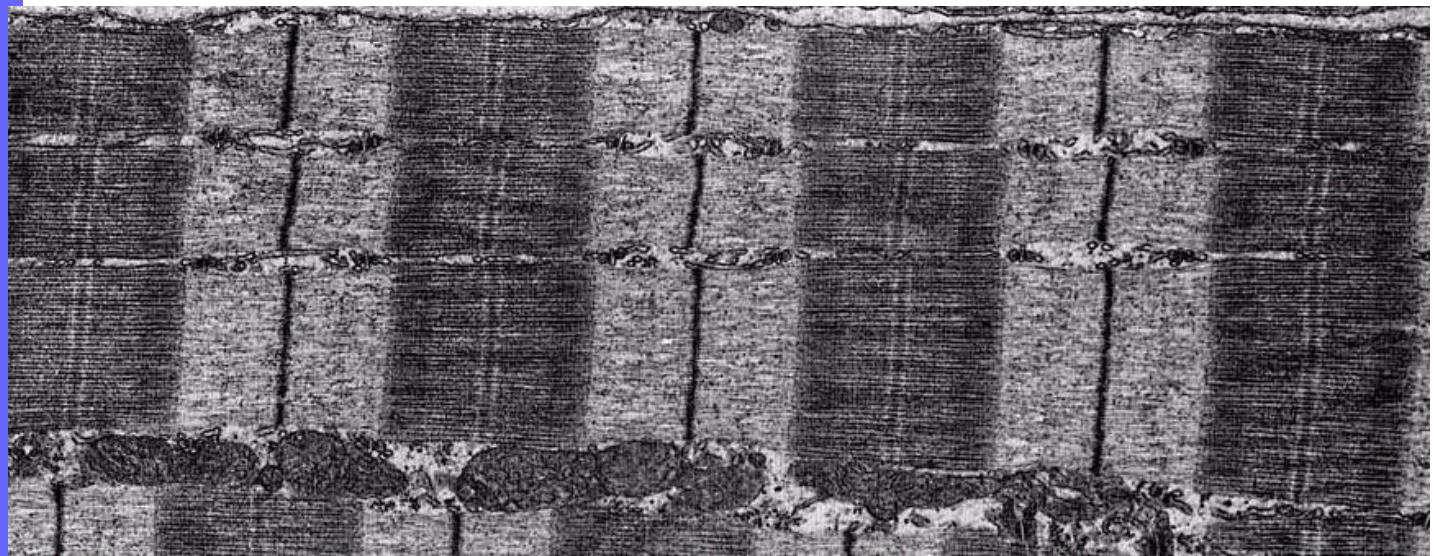




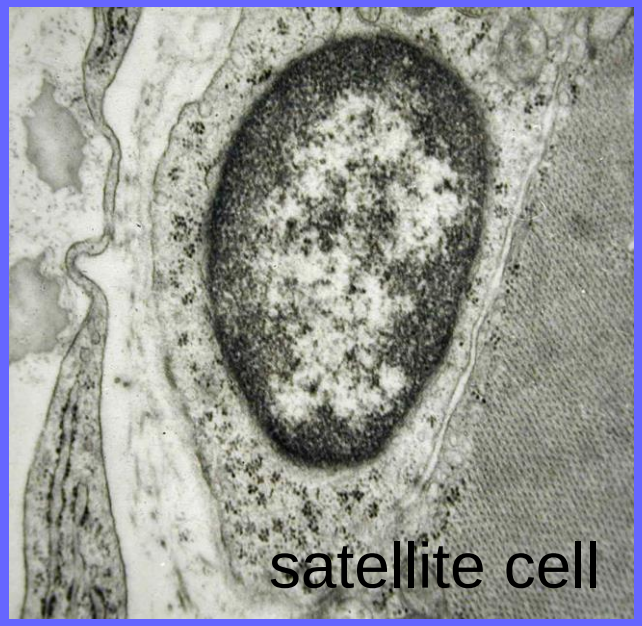
striated muscle fibres

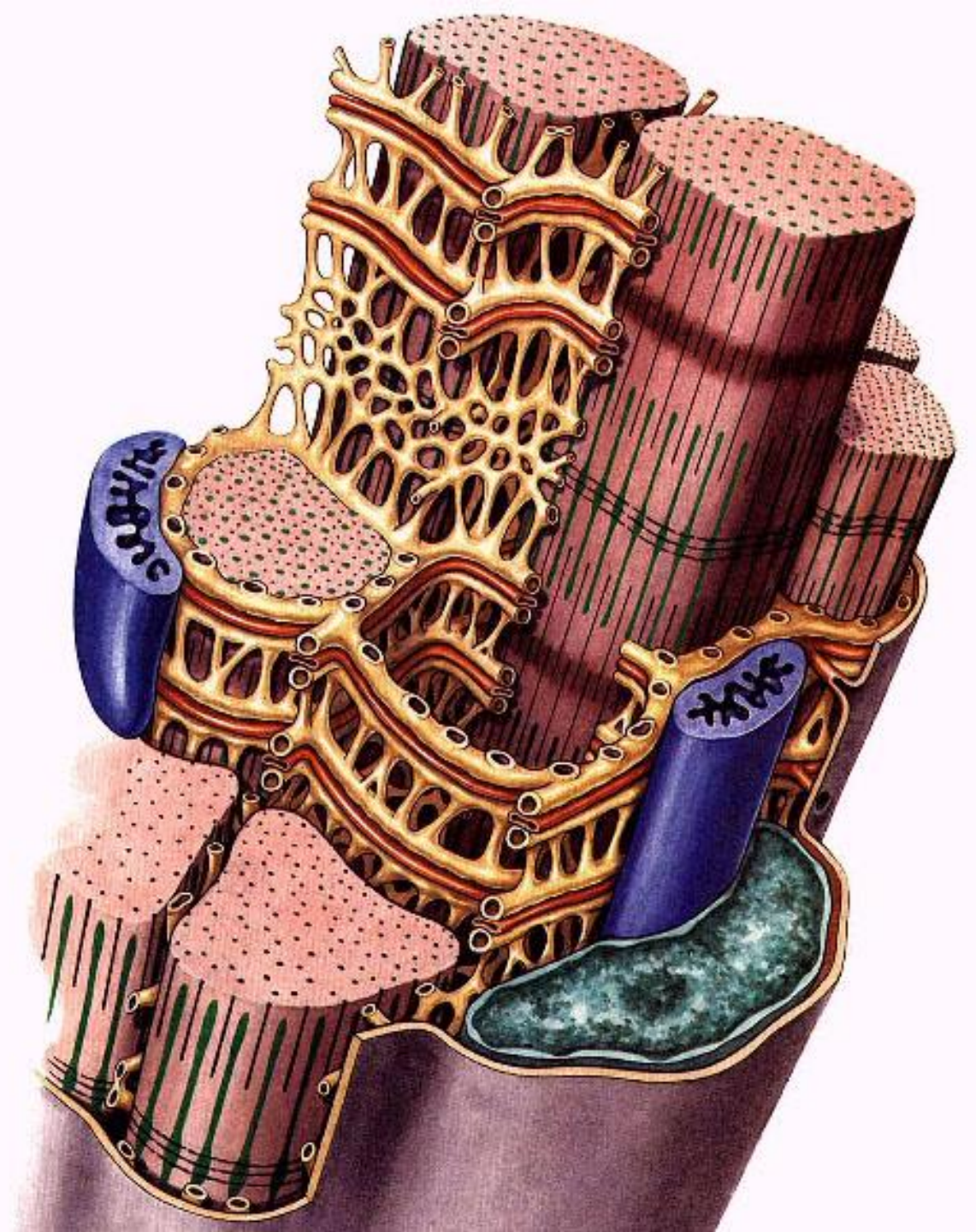



Sarcomere ~2.2 µm
Dark Band
Z disc
M line
Z disc
thick filament (myosin)
thin filament (actin)

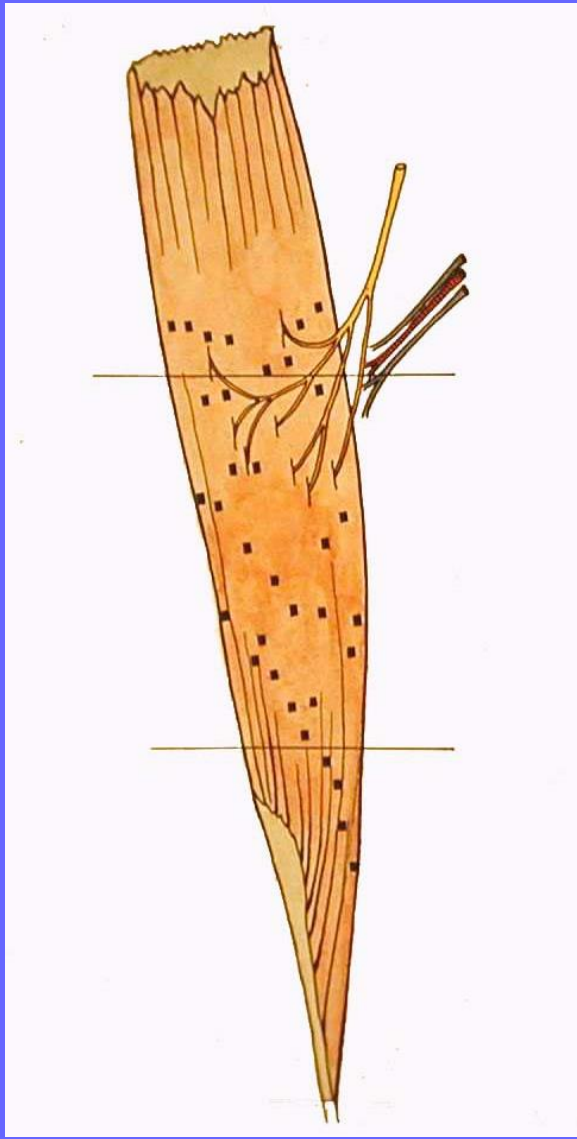


muscle fiber,
myofibril,
sarcomere
sarcoplasmic reticulum,
T-tubules,
triads
mitochondria,
sarcolemma,
basal lamina



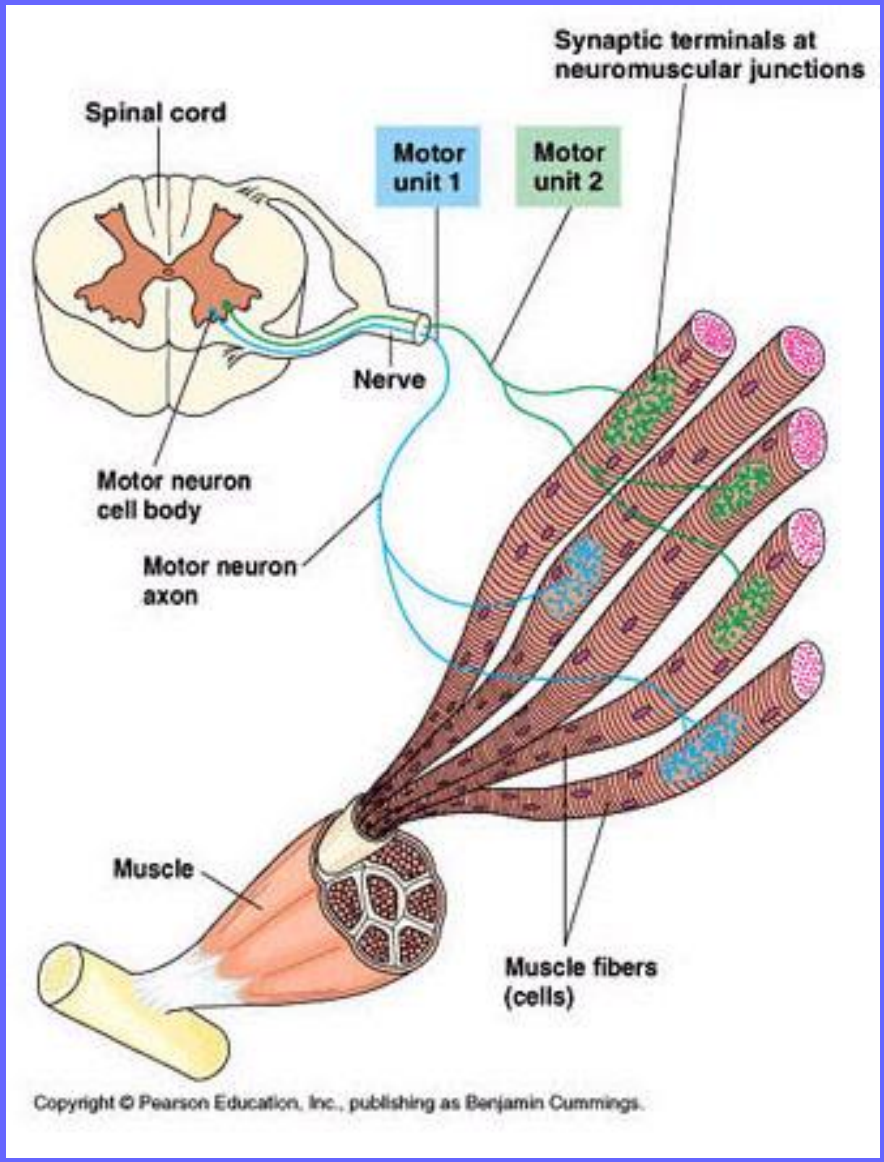


Innervation of skeletal muscle



Neurovascular hilum

motor units, zones of motor end-plates

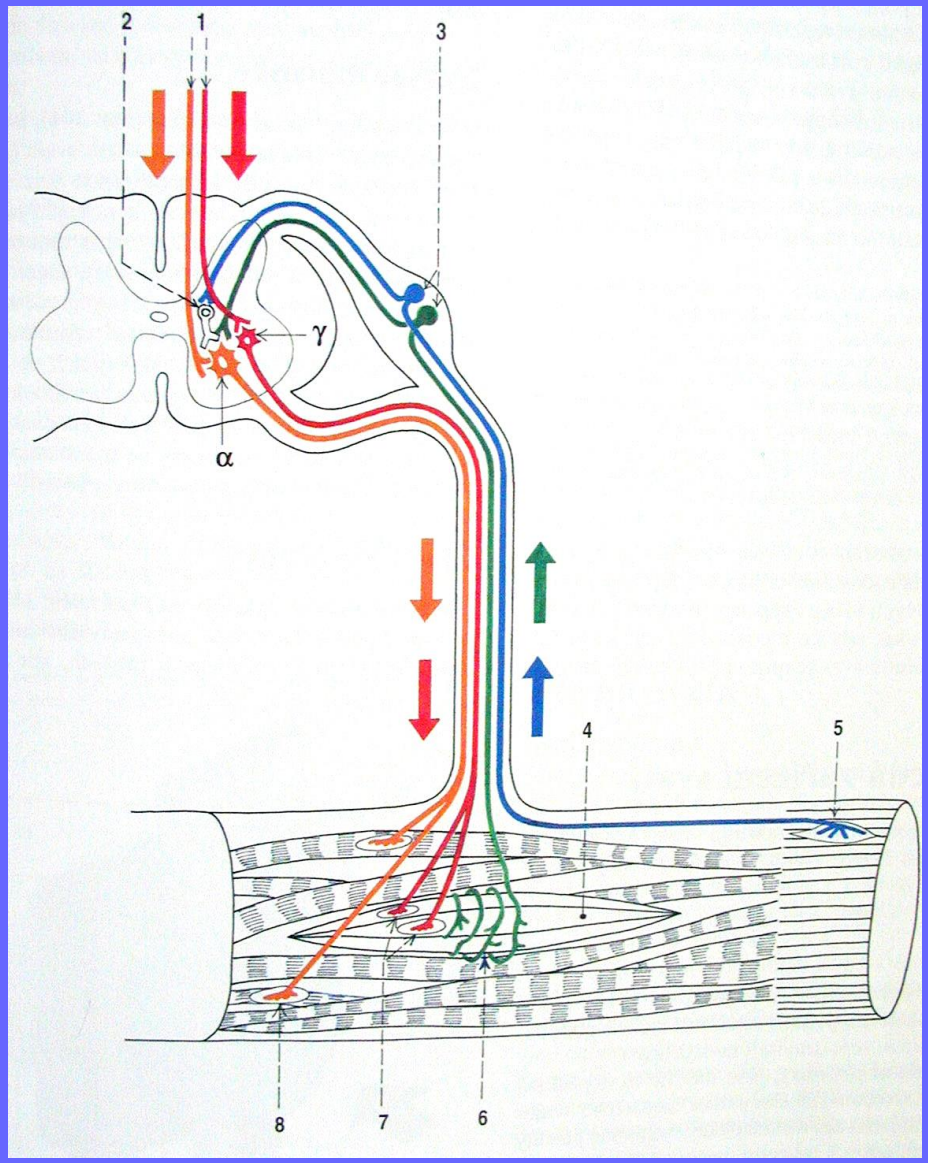


visualization of motor end plates

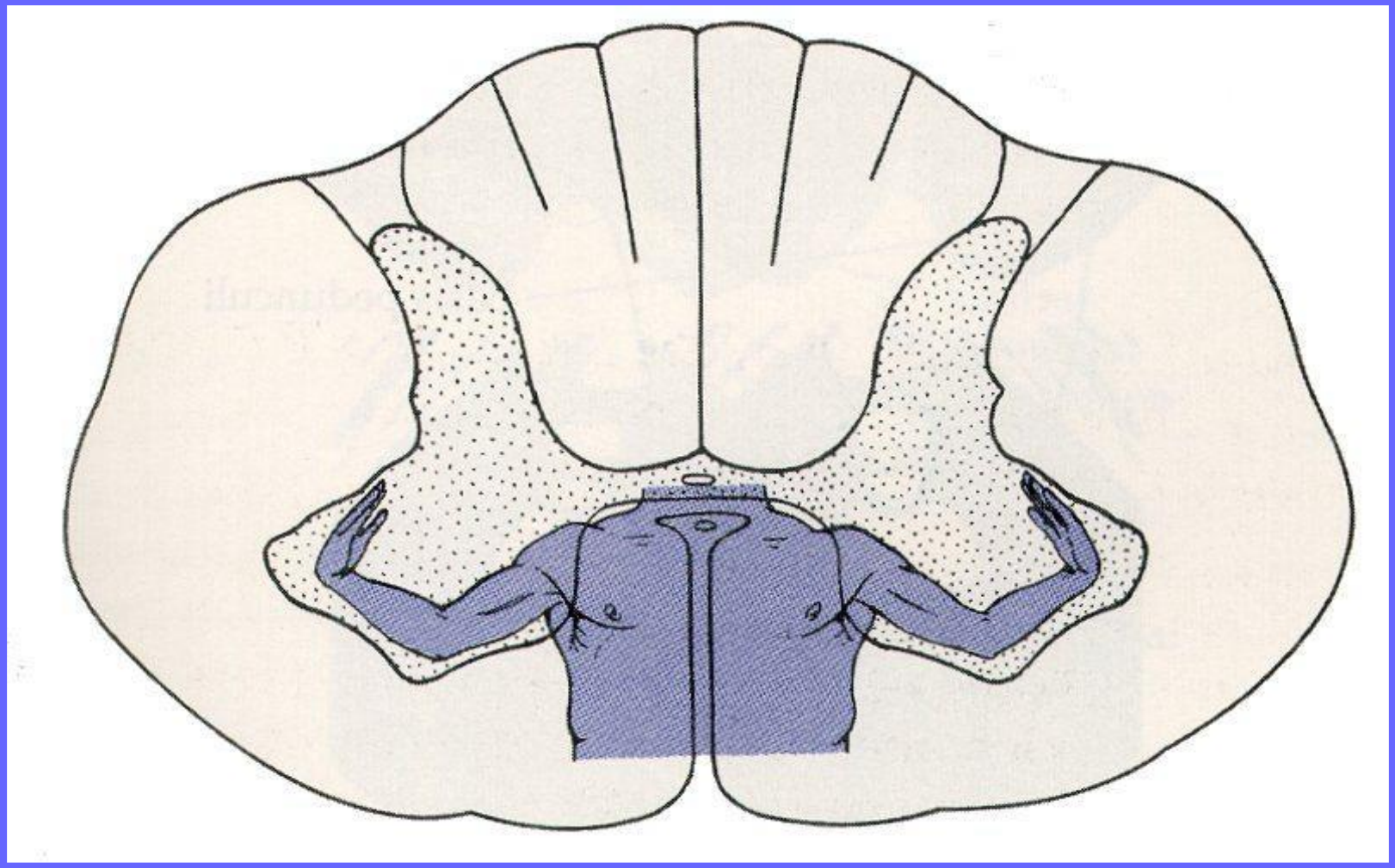
A muscle that is not innervated undergoes atrophy (degeneration)

Motoneurons:
alfa motoneurons, (slow and fast) innervate extrafusal fibers
gamma motoneurons innervate intrafusal fbers of muscle spindles

Sensory neurons (proprioceptive neurons) innervate muscle receptors: muscle spindles, Golgi tendon organs



Innervation of skeletal muscle: motoneurons, motor units, motor end- plates, acetylcholine, proprioceptive neurons, muscle spindles, Golgi tendon organs



Somatotopic distribution of motoneurons
innervating groups of muscles of the upper limb and trunk
on the transversal section of the cervical spinal cord

Types of muscle contraction

Posture, isometric contraction

Postural muscles

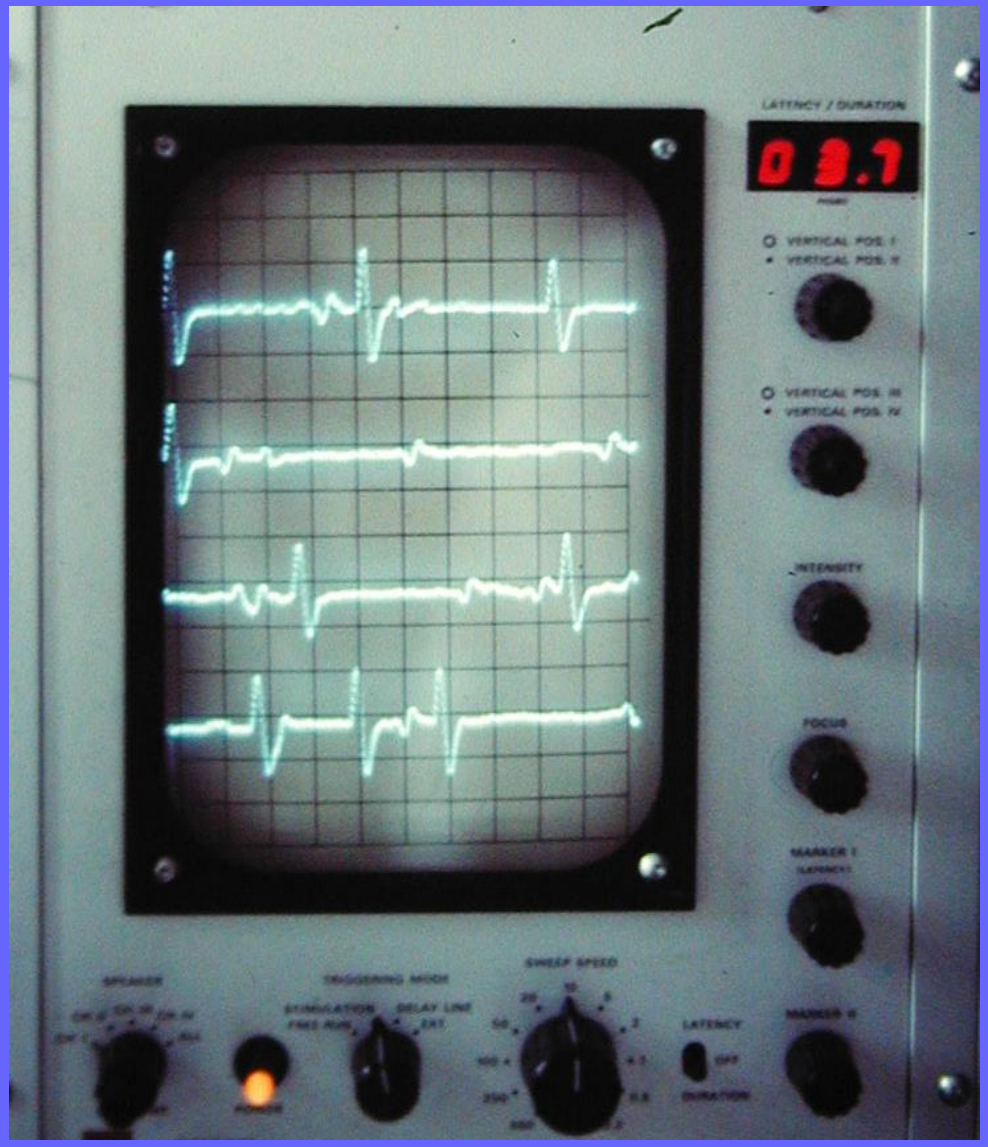
postural muscles (antigravity) are muscles that secure an upright posture
(they are stretched due to the gravity of the earth – eg. back mscles, extensors of lower limbs)

Postural stability is the ability to maintain upright posture - a position of a person's body when standing or sitting

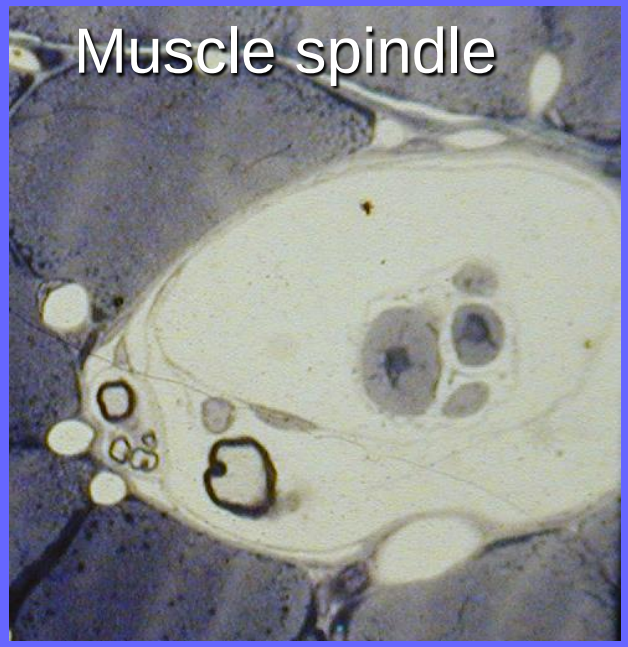
Types of muscle contraction

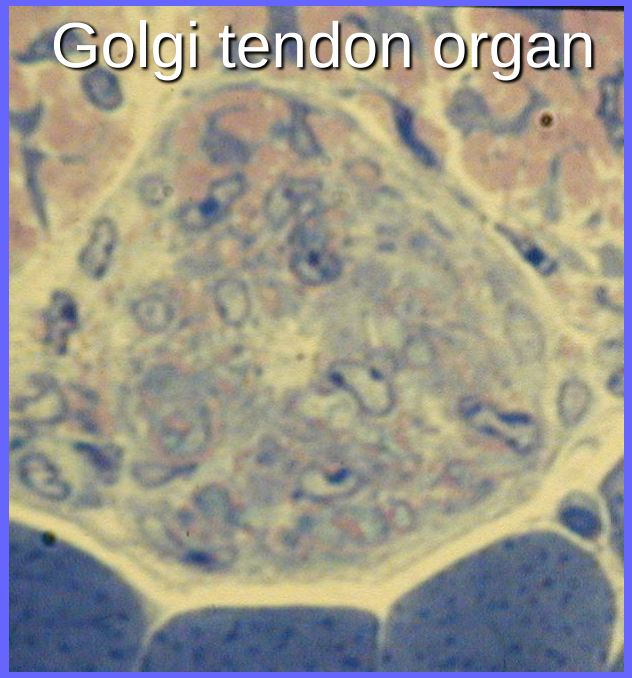
Motion, isotonic contraction

synaptic vesicles containing acetylcholine (neurotransmitter) in axon terminal of motor end-plate; curare blocks the transmission



Elektromyography **(EMG)**





A young women with sensory neuropathy of unknown origin who completely lost proprioceptive sensation:
She could not stand without watching her feet,
she could not held anything in her hands, and they wandered around without her awareness…

„Something awful´s happened, I can´t feel my body.
I feel weird-disembodied“, she said, and „I may lose my arms. I think they´re one place and I find they´re another“.
After having proprioception explained, she said:
„This proprioception is like the eyes of the body, the way the body sees itself. And if it goes, as it´s gone with me, it´s like the body is blind…so I have to watch it - be its eyes. Right?“

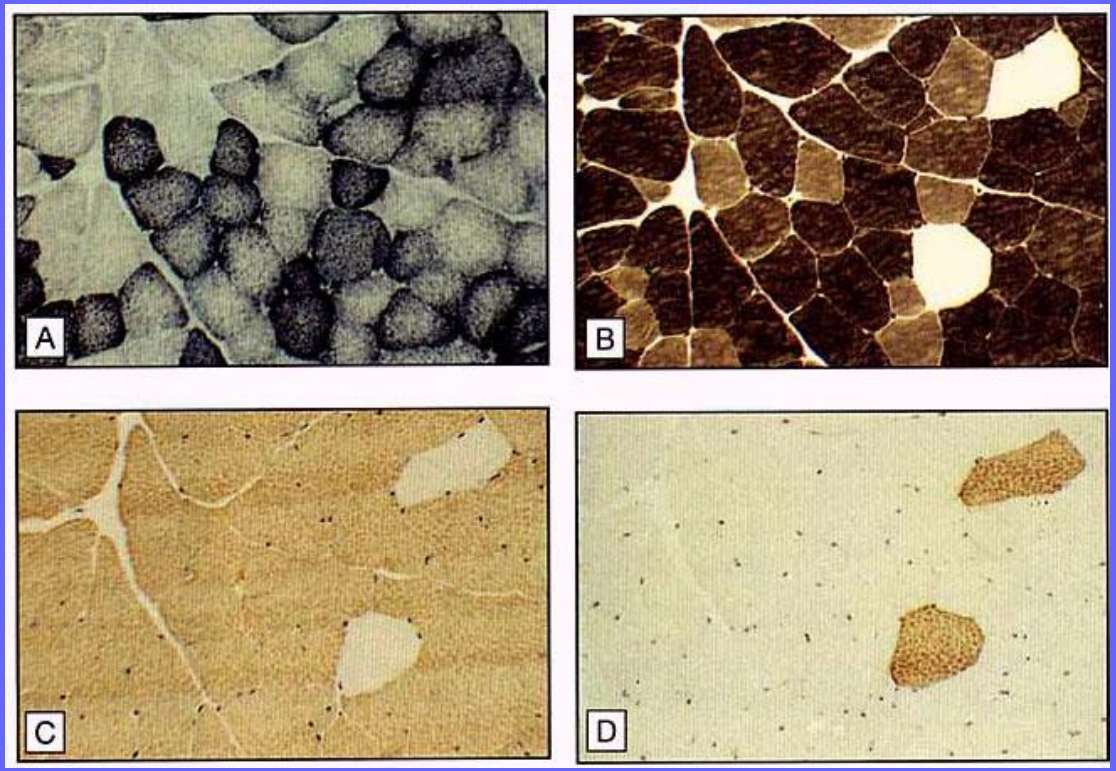
Take home message

Muscle without proprioception is not under control and the body doesn't know about it

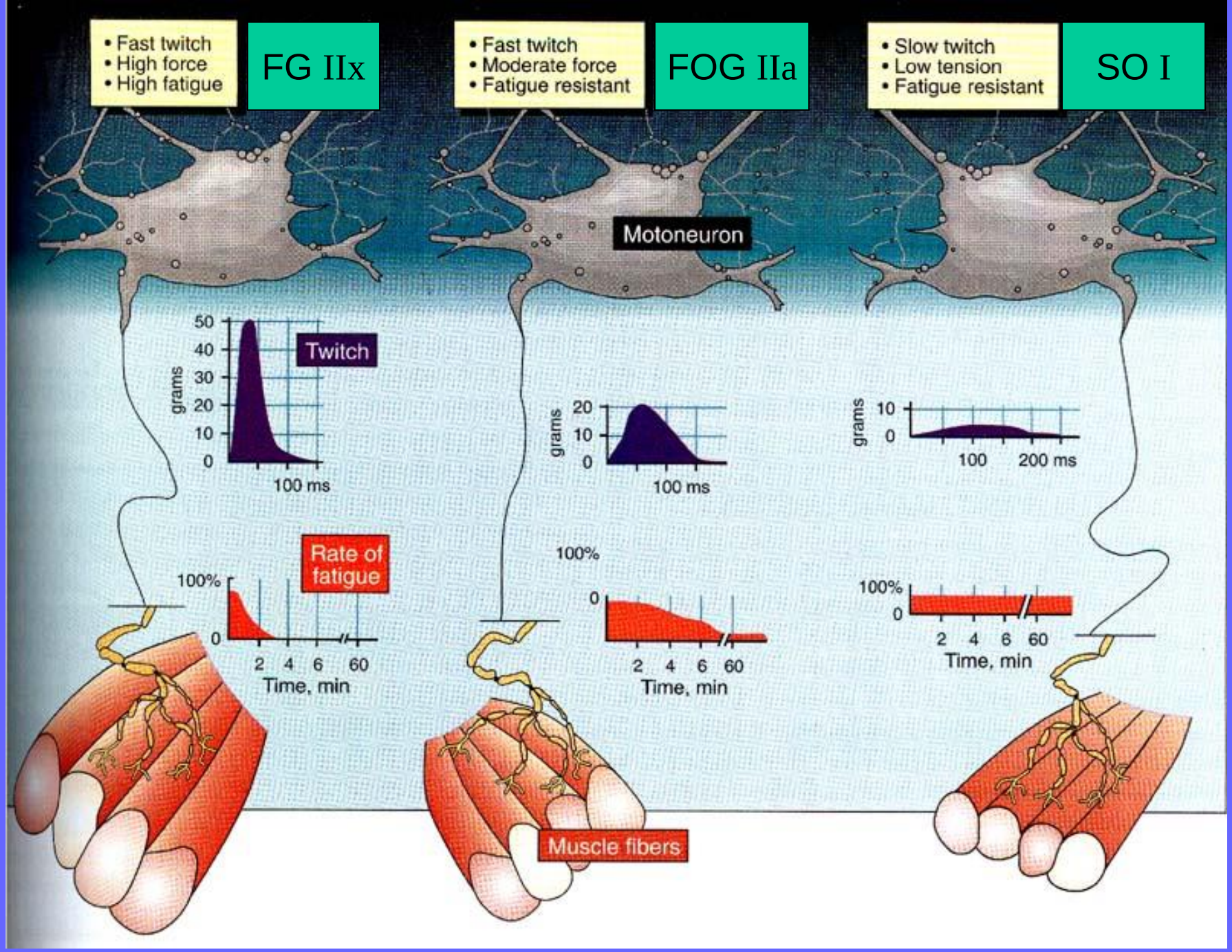
Firre Types of Skeletal Muscle

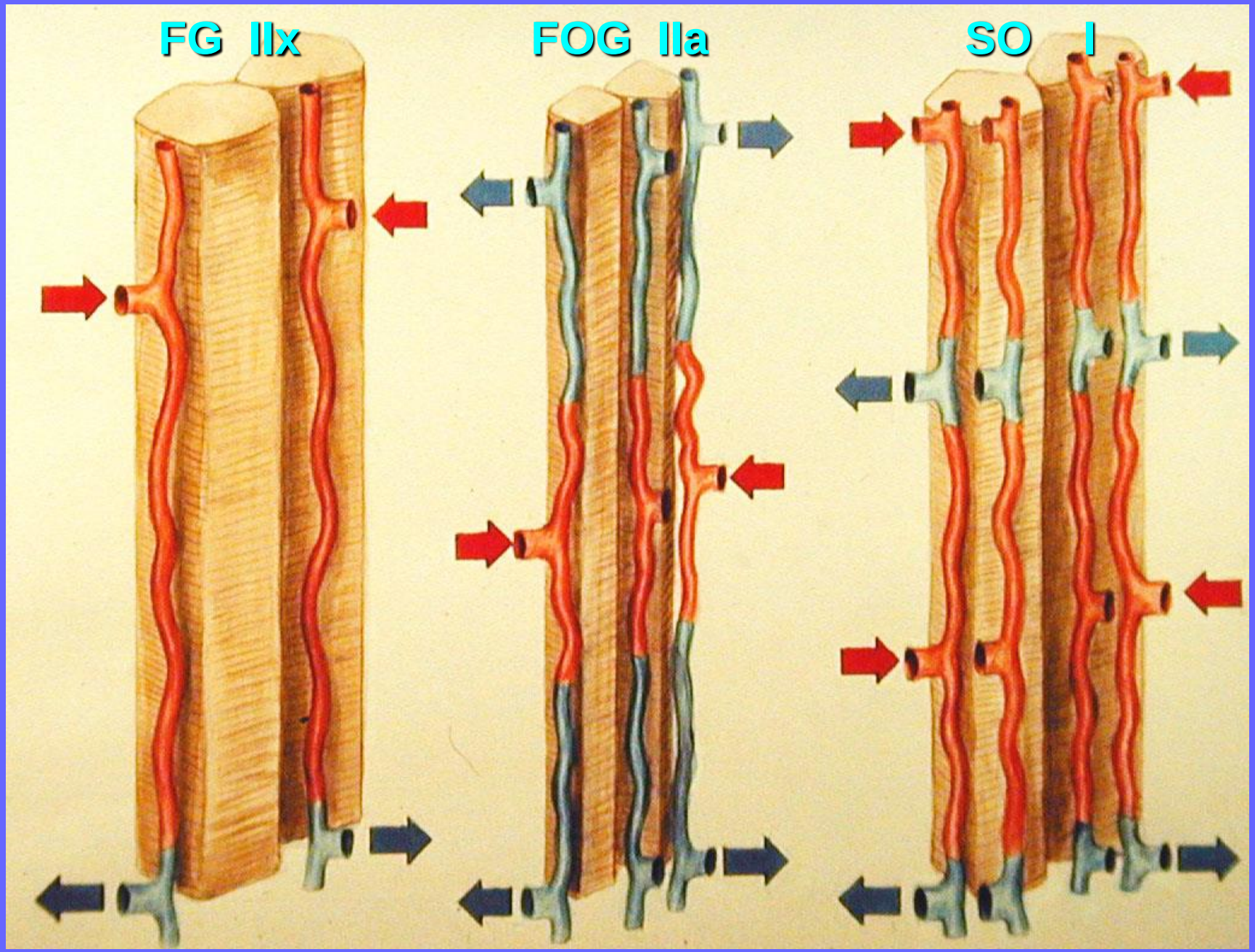
- Type 1 fibres are slow-contracting and fatigue-resistant
- Type 2A fibres are fast-contracting and fatigue-resistant
- Type 2X (B) fibres are fast-contracting and susceptible to fatigue

Type I SO Type IIa FOG Type IIx FG

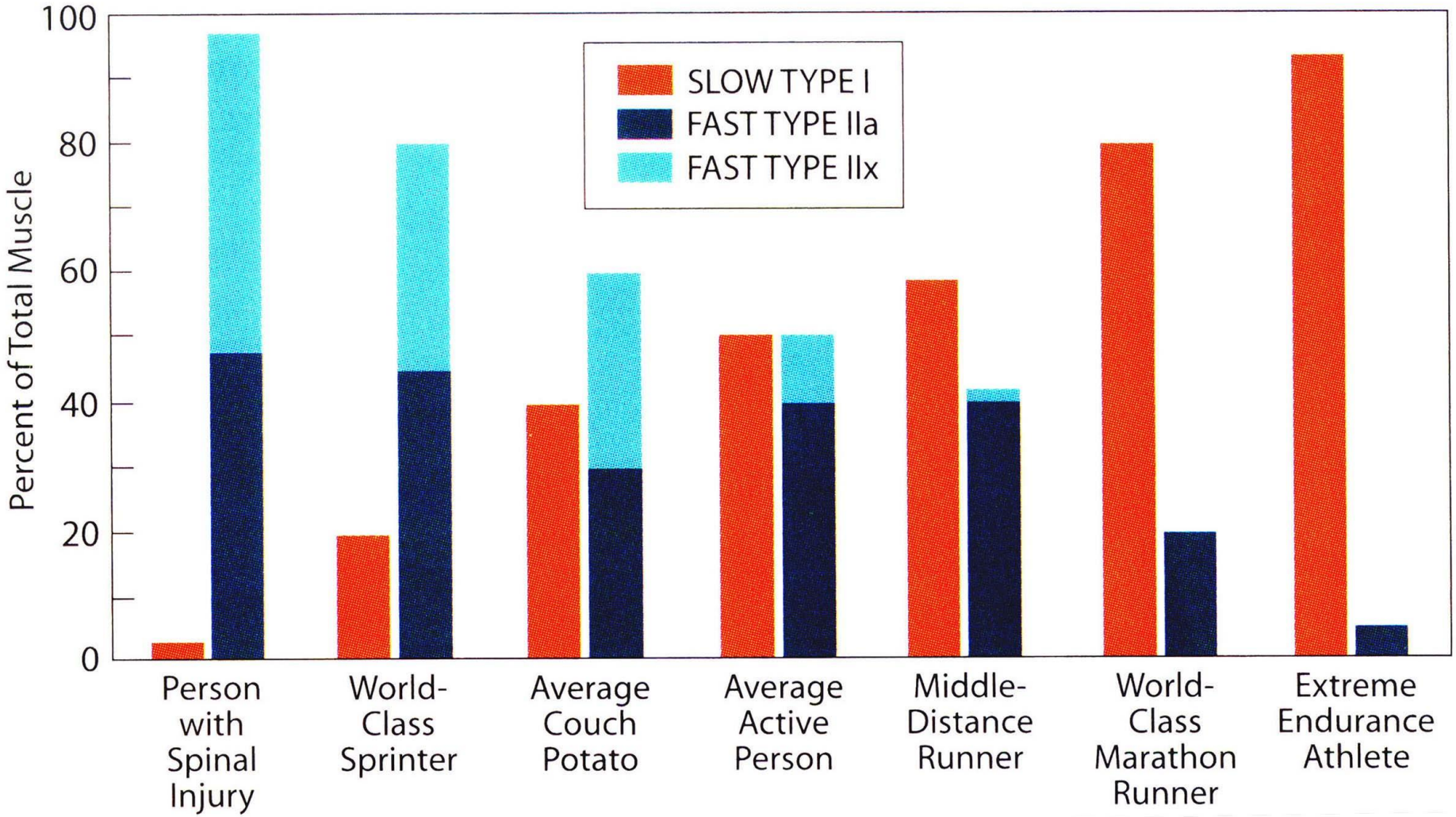


myosin ATPase, dehydrogenase, glycogen phosphorylase


• Fast twitch
• High force
• High fatigue
FG IIx
• Fast twitch
• Moderate force
• Fatigue resistant
FOG IIa
• Slow twitch
• Low tension
• Fatigue resistant
SO I
Motoneuron
Twitch
grams
50
40
30
20
10
0
100 ms
20
10
0
100 ms
10
0
100
200 ms
Rate of fatigue
100%
0
2 4 6 60
Time, min
100%
0
2 4 6 60
Time, min
100%
0
2 4 6 60
Time, min
Muscle fibers



Blood supply capillaries of skeletal muscle


100
80
60
40
20
0
Percent of Total Muscle
SLOW TYPE I
FAST TYPE IIa
FAST TYPE IIx
Person with Spinal Injury
World-Class Sprinter
Average Couch Potato
Average Active Person
Middle-Distance Runner
World-Class Marathon Runner
Extreme Endurance Athlete

Muscle fiber types distribution

Three basic muscle fibers types occur in a certain ratio in each muscle.

Usually, fast muscle fibers (FG) are localised closer to the muscle surface and slow muscle fibers (SO) in the deeper parts of the muscle.

Gen for speed

ACTN3 gene encodes alpha-actinin-3 and has two alleles (R, X). Only the R allele allows the synthesis of alpha actinin 3, a protein that is predominantly contained in the FG (IIx) muscle fibers responsible for rapid and profound muscle contraction.

At least one R allele is carried by 95% of elite sprinters and 50% of them even have both R alleles - each from one parent.

In Kenya, 99% of the population carries at least one R allele, in Jamaica it is 98% of the population, but in the European population it is only 82% of individuals.

Non-alpha-actinin-3 homozygotes X / X are believed to be 15-25% of the population worldwide.

Differentiation of Skeletal Muscle -myogenesis

Progenitor cells

Myogenic Determination Factors

Myf-5, myogenin, MyoD and Myf-6 (herculin)

Proliferating myoblasts

Myostatin blocks proliferation

Postmitotic myoblasts - myocytes

Muscle protein gene expression

Myoblasts fusion

Myotubes

Muscle fibers

Growth of Skeletal Muscle,
(hypertrophy, not hyperplasia)

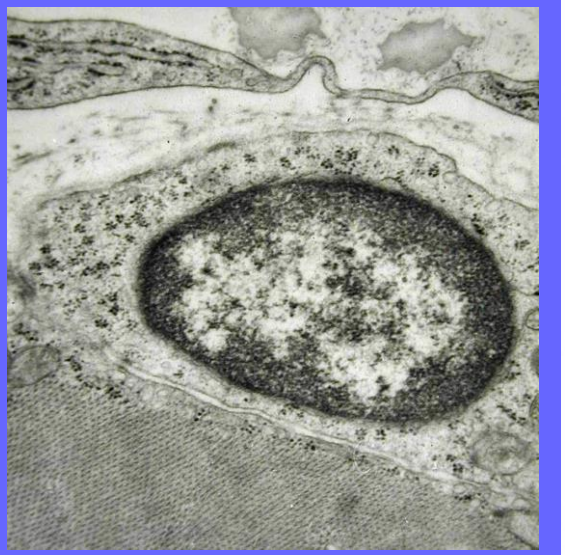
Regeneration of Skeletal Muscle

(activation of satellite cell- stem cells of muscle fibers

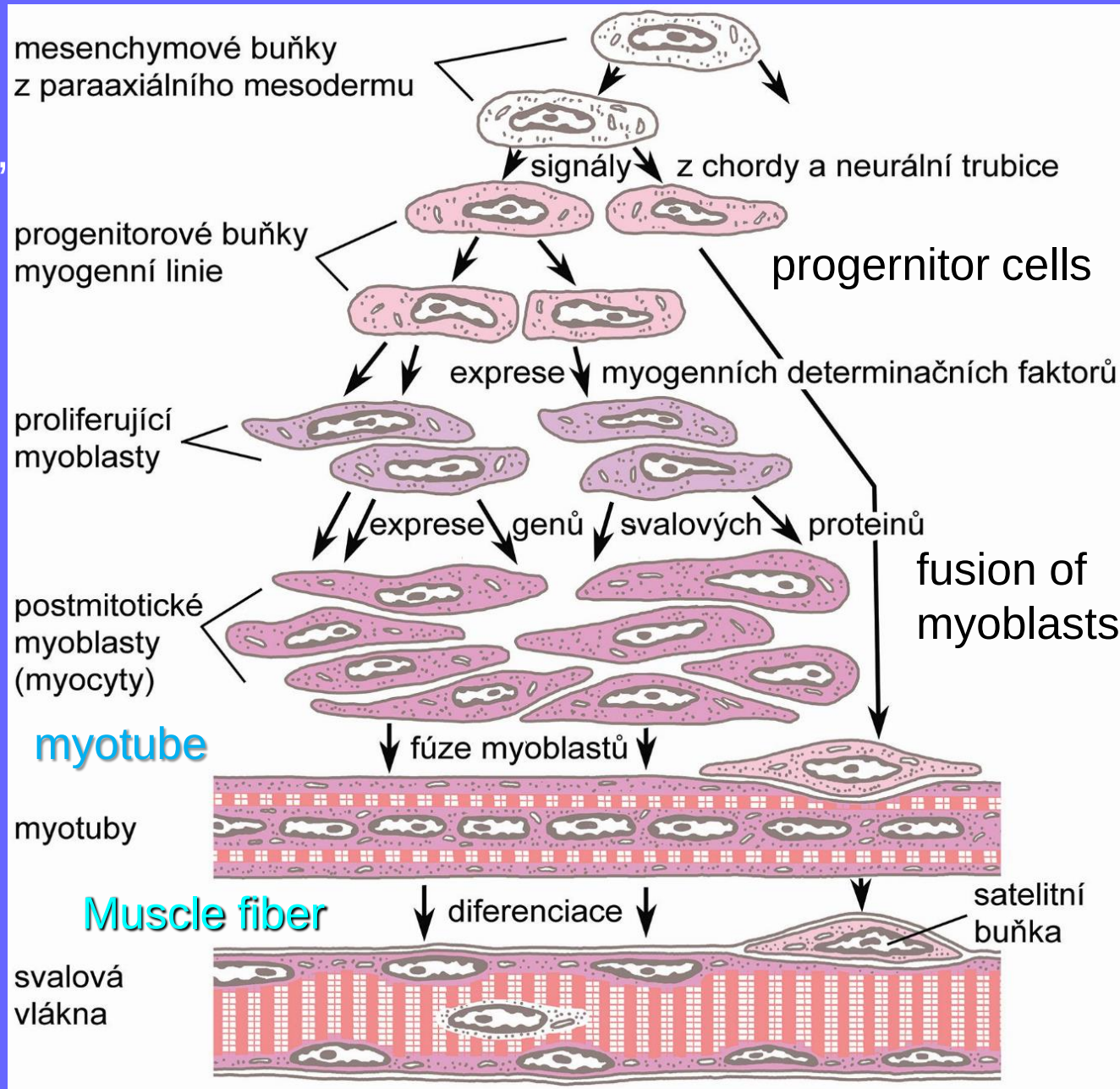
Schema of myogenesis

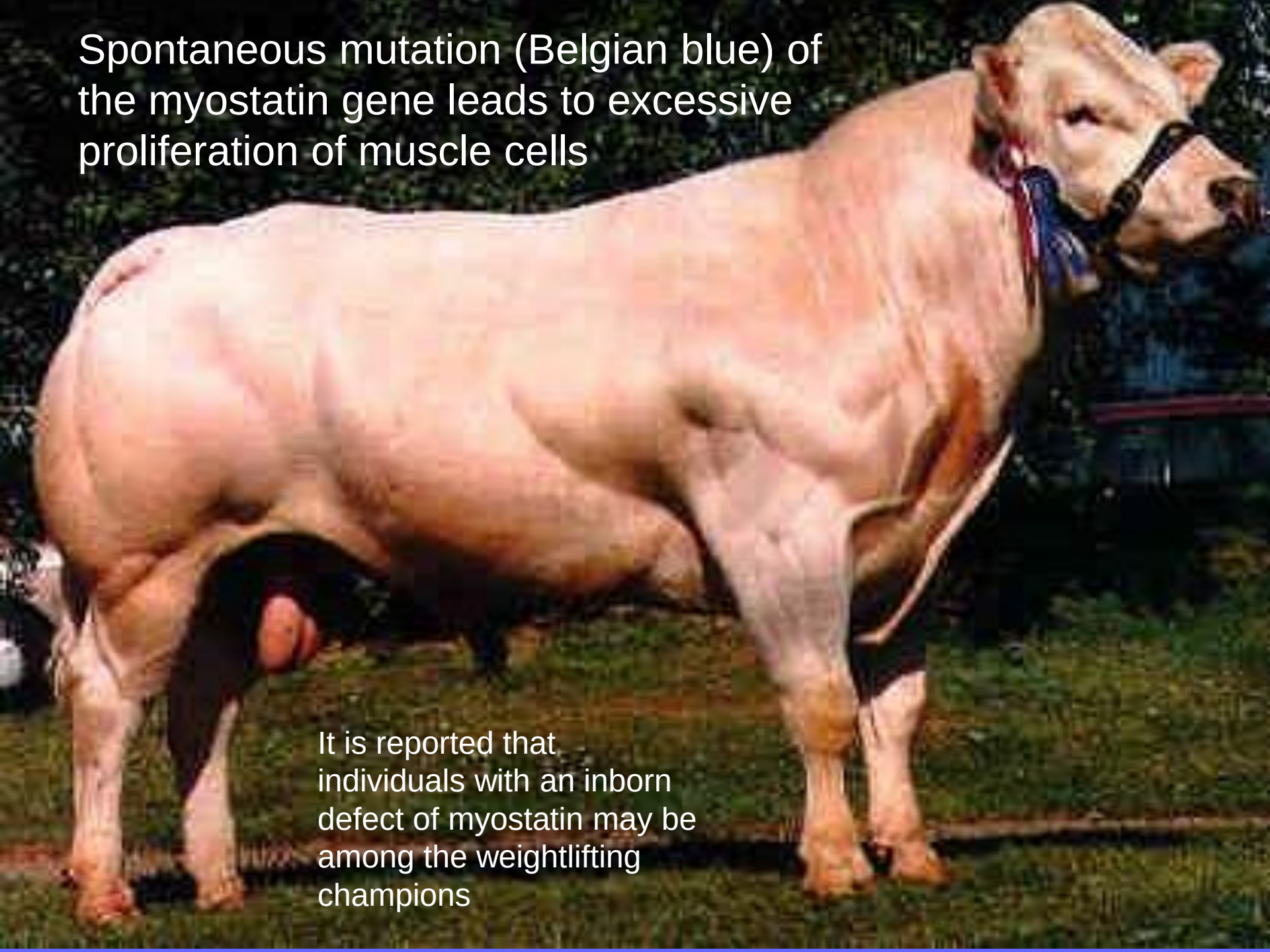
myogenic determination factors (MyoD, Myf5, myogenin)

myostatin blocks proliferation of myoblasts



Satellite cell




Spontaneous mutation (Belgian blue) of the myostatin gene leads to excessive proliferation of muscle cells
It is reported that individuals with an inborn defect of myostatin may be among the weightlifting champions

Development of skeletal muscles

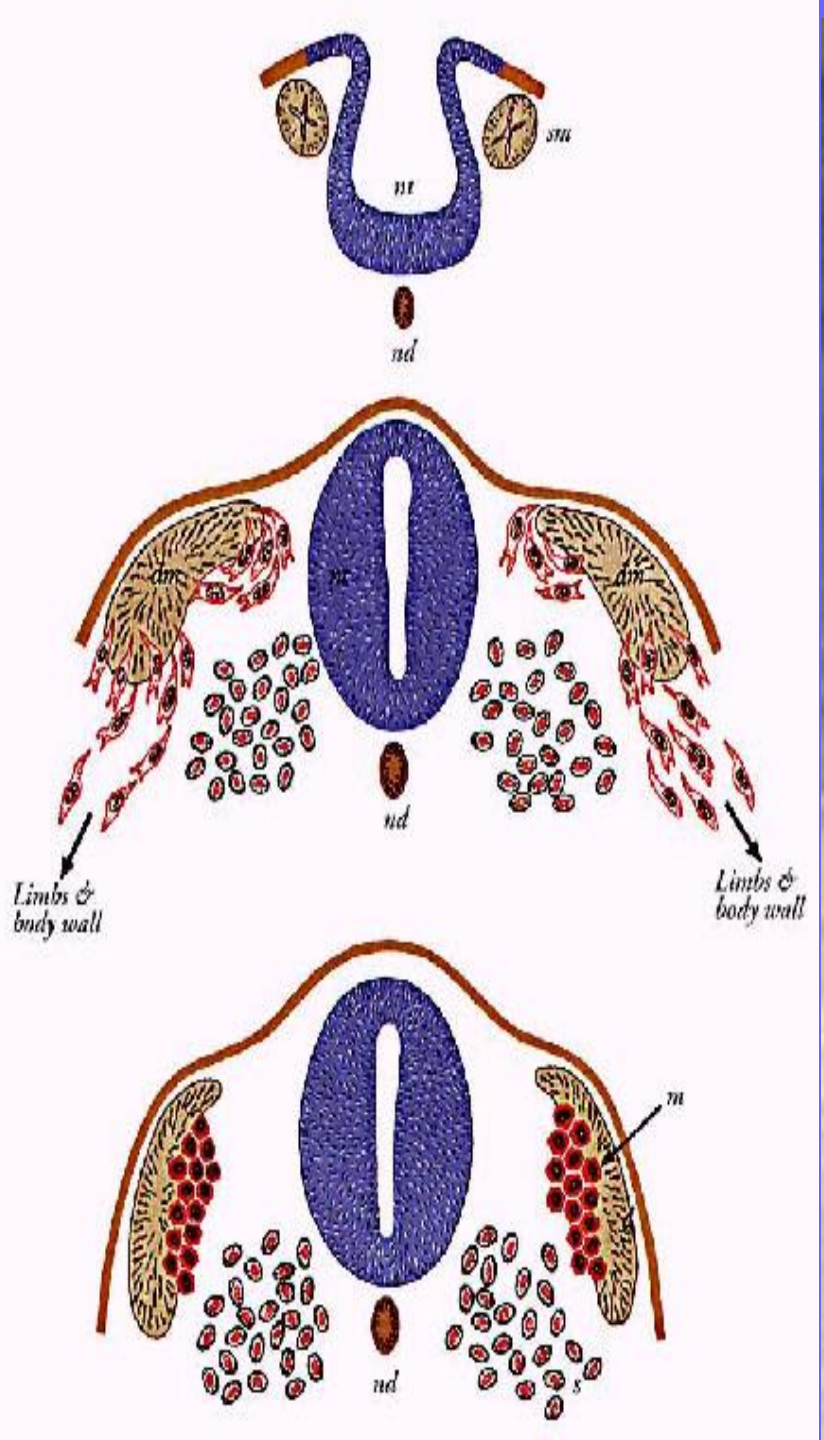
Formation of muscle blastema
Splitting of muscle blastema into muscle primordia
Migration of myogenic cells into the periphery
Local diferentaiation of muscle within myotomes

Myogenic cells from mesoderm

Nonsegmented mesoderm in the head

Somites in the trunk

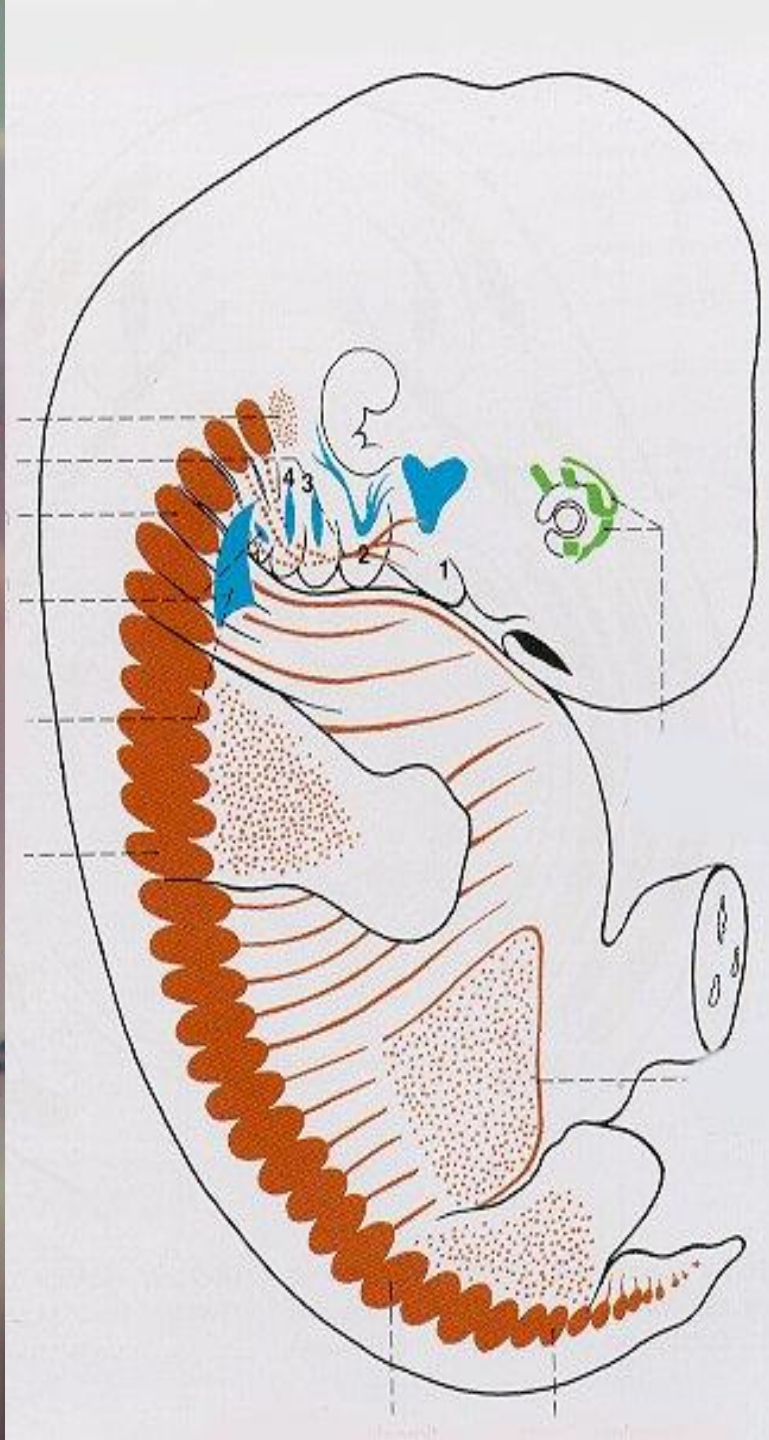
Migration of myogenic cells from somites into the body wall and limb primordia

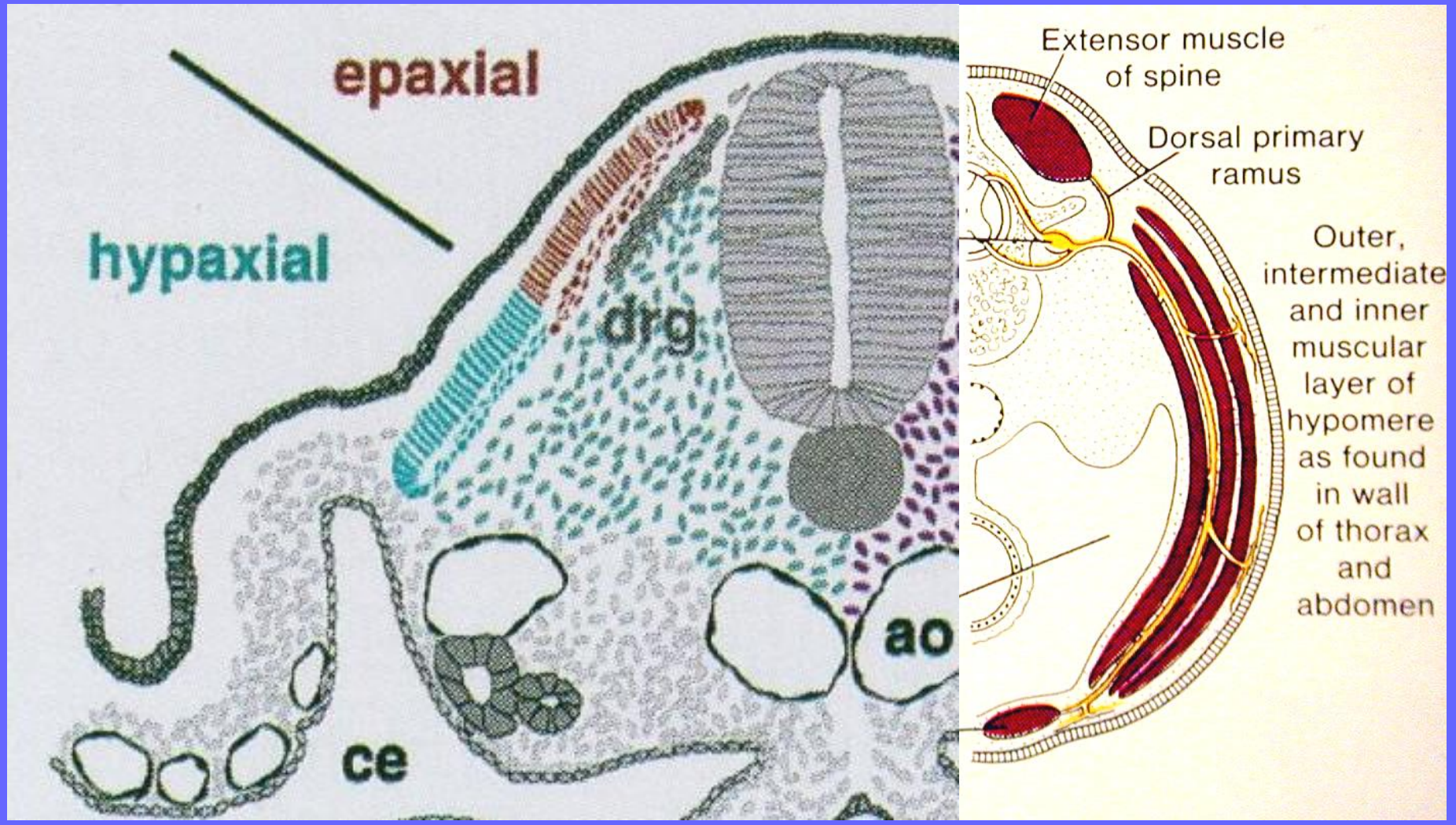


MyoD

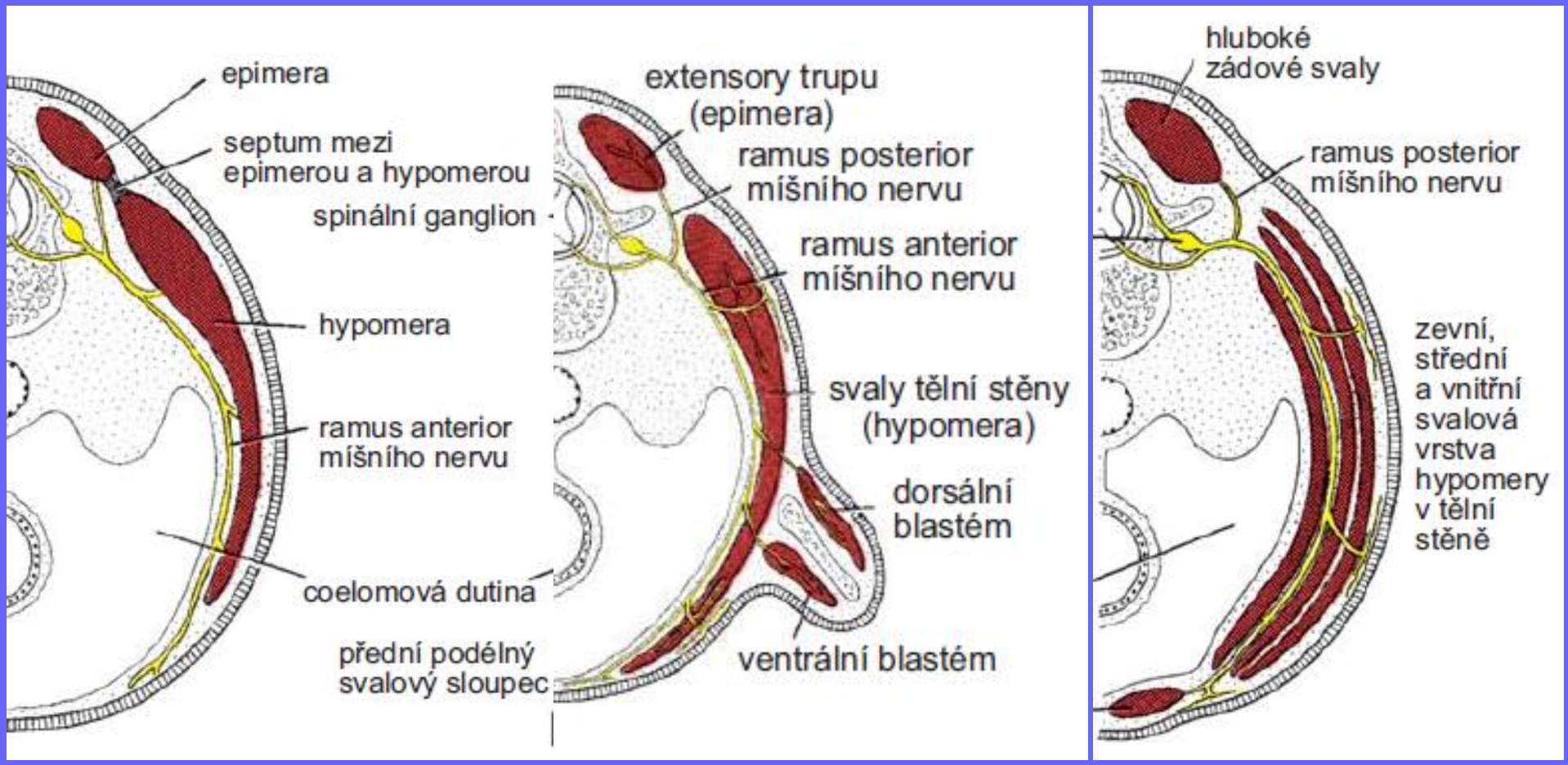
HH 25

Myogenic cells expressing MyoD



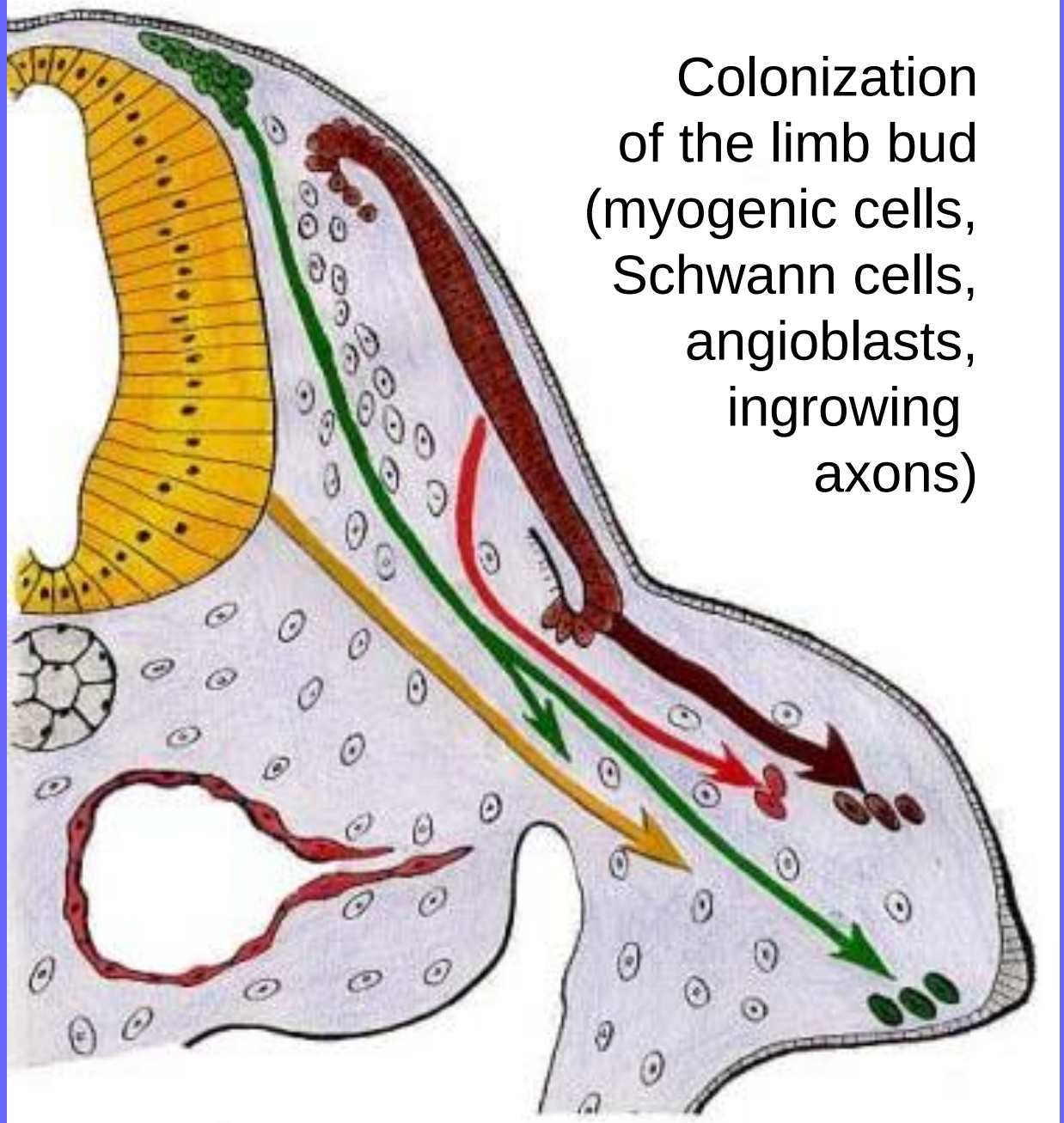


Epaxial and hypaxial musculature and its innervation from dorsal and ventral branches of spinal nerves



Hypomeras splitting in three layers of muscles in the abdominal wall; ventral and dorsal muscle blastema in limb primordium

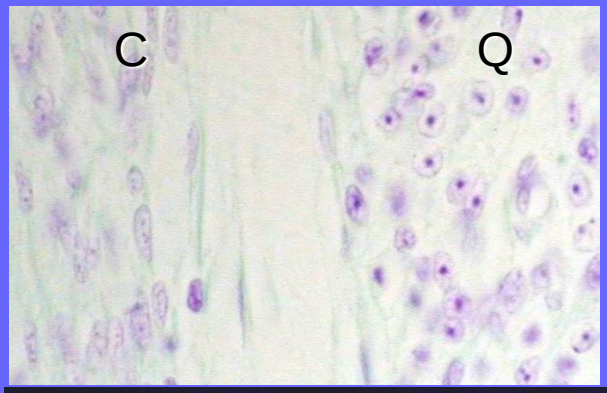
Limb bud formed by mesenchymal cells covered by the ectoderm (lower extremity of chick embryo in the stage HH22 (3.5 – 4 days)

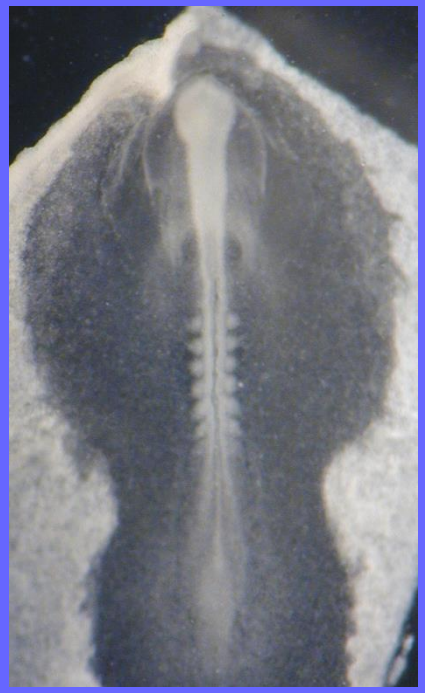


Colonization
of the limb bud
(myogenic cells,
Schwann cells,
angioblasts,
ingrowing
axons)

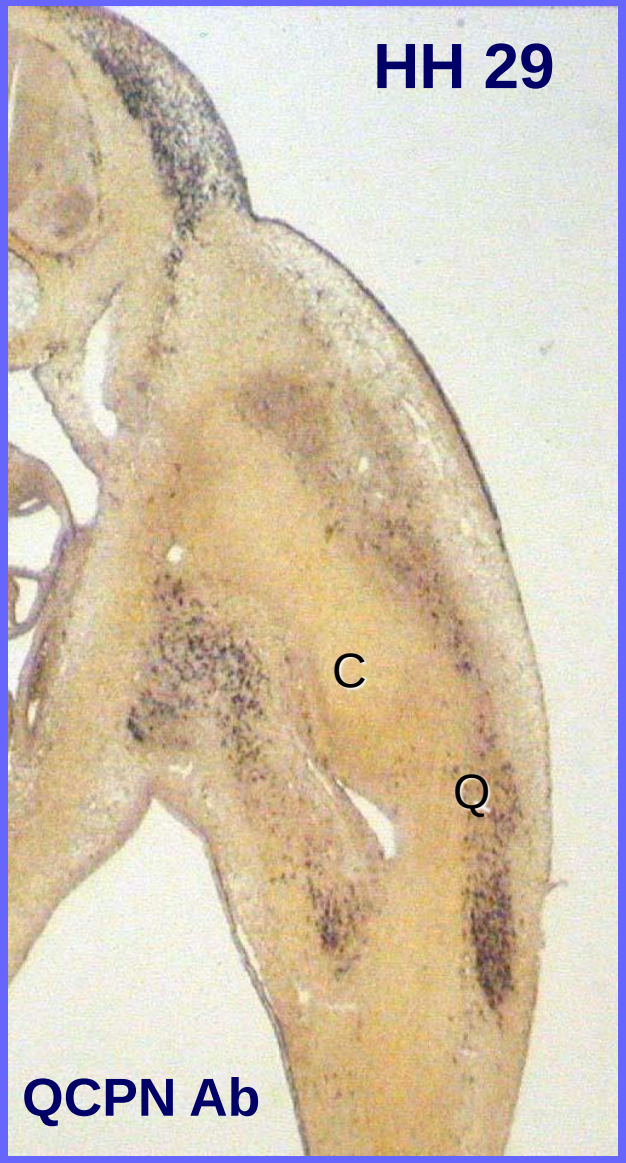
Chick(C) – quail (Q) embryonic chimera, somite grafting, migration of somitic cells into the limb primordium

Somite origin of myogenic cells

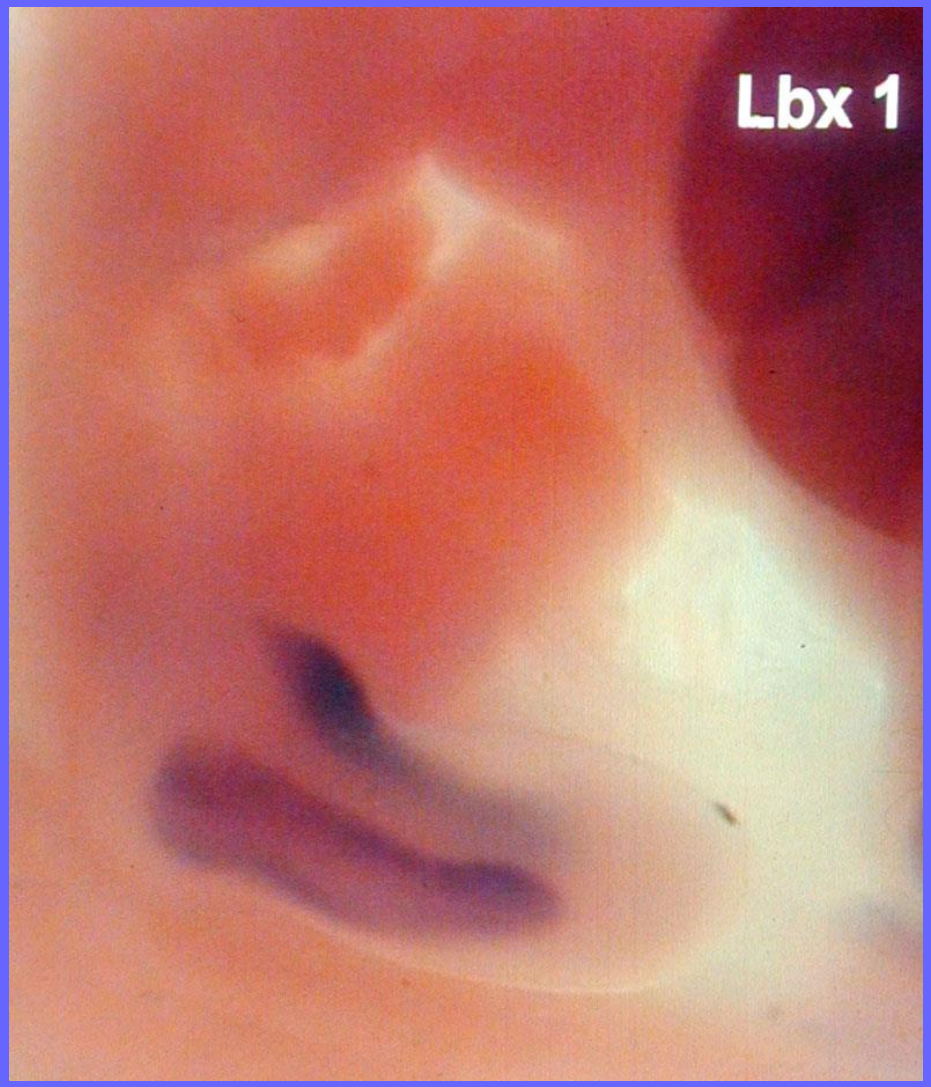


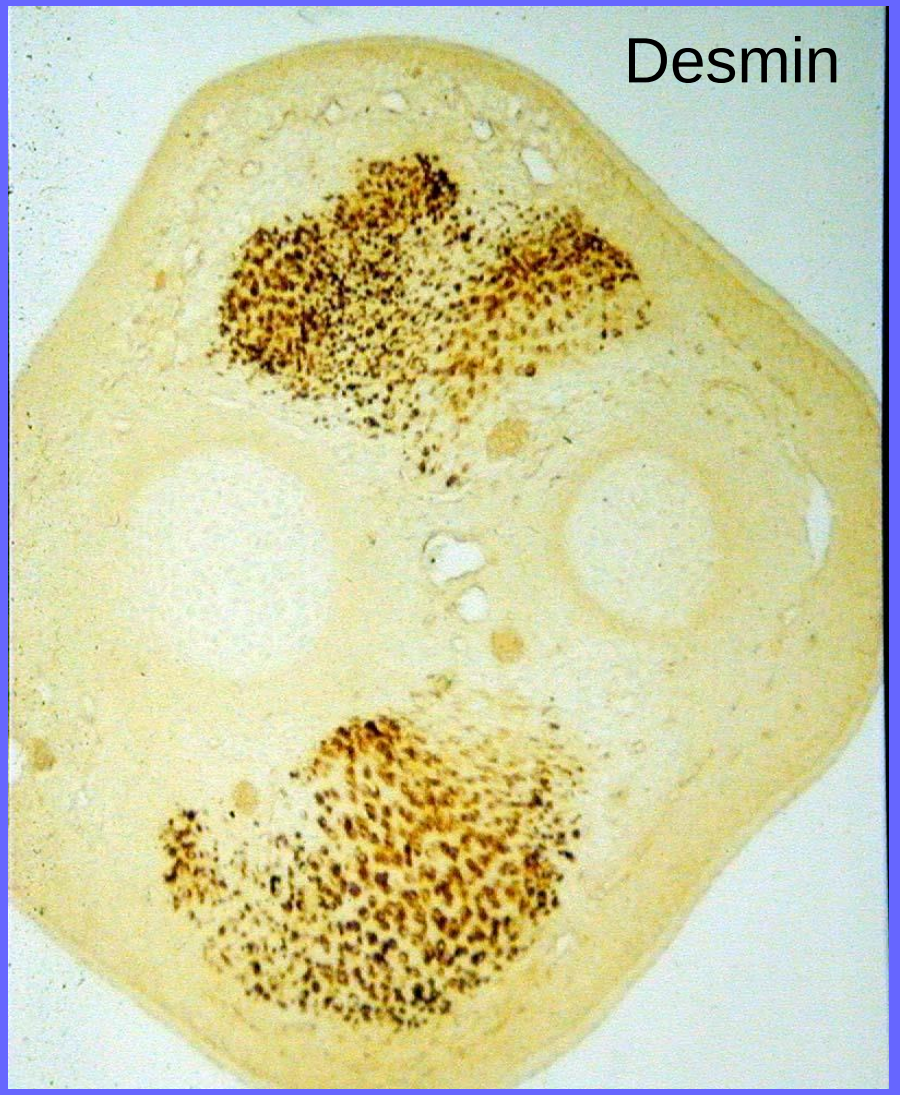


Pax3
cMet
SF
Lbx1
MyoD

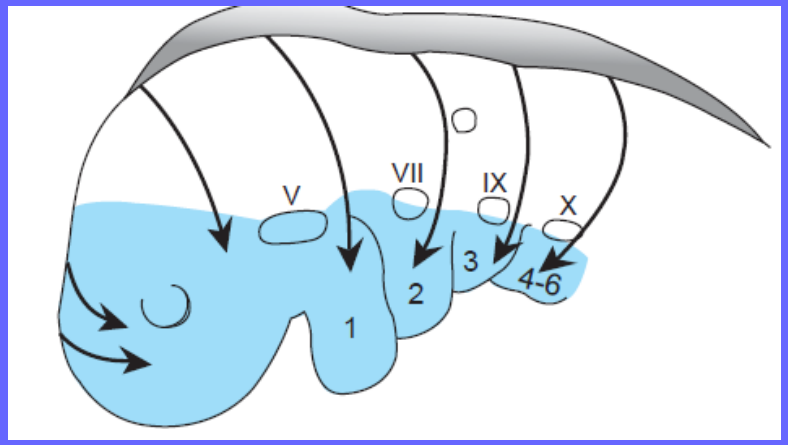


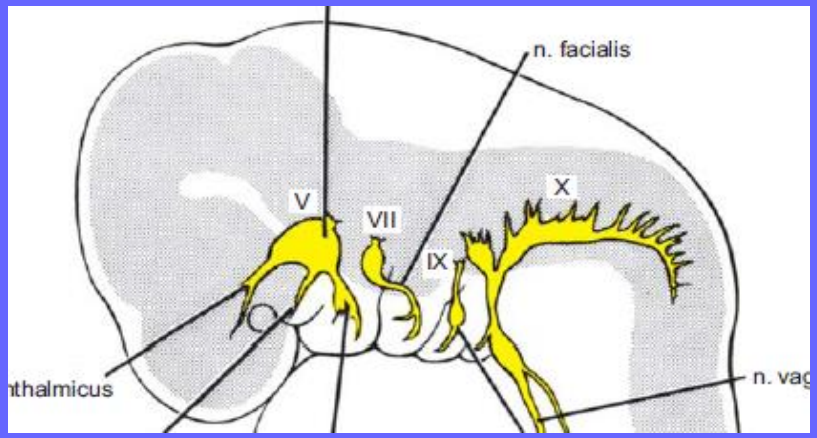
Development of limb muscles





Ventral and dorsal muscle blastema in limb primordium





Morphogenesis of head muscles

Extra-ocular muscles
(Innervation III.,IV. VI.)

Muscles of auditory ossicles (BA 1,2.- V., VII.)

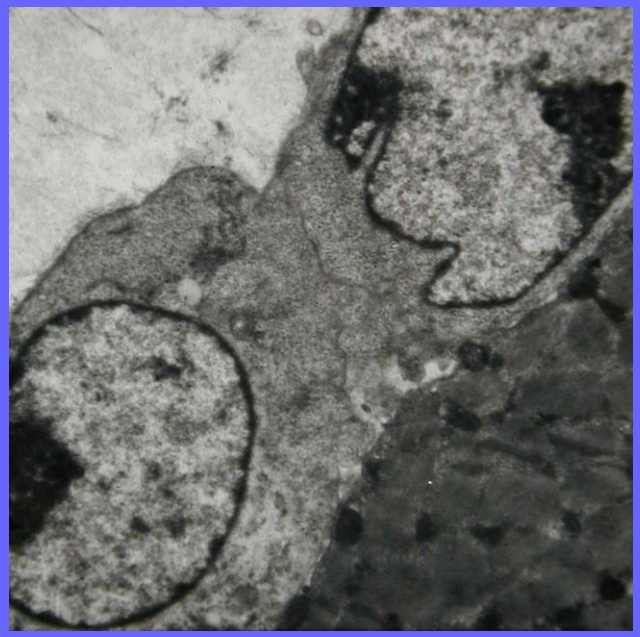
Masticatory muscles (BA 1 -V.)

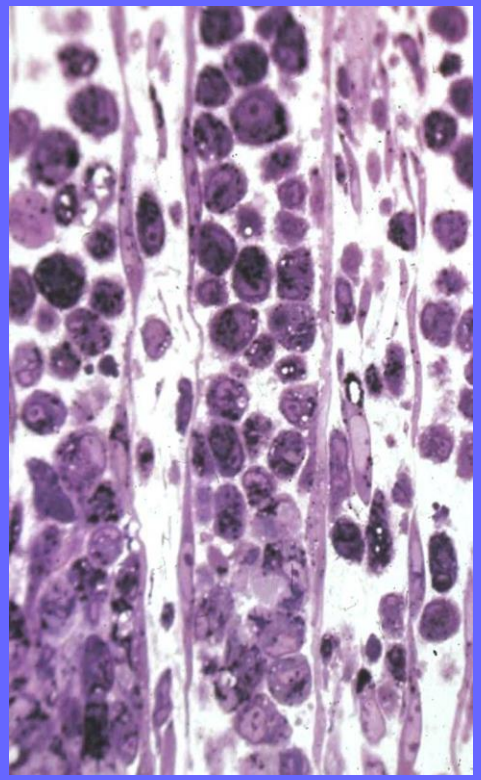
Facial muscles (BA 2 -VII.)
Musculi palati mollis et at faucium (IX., X.)

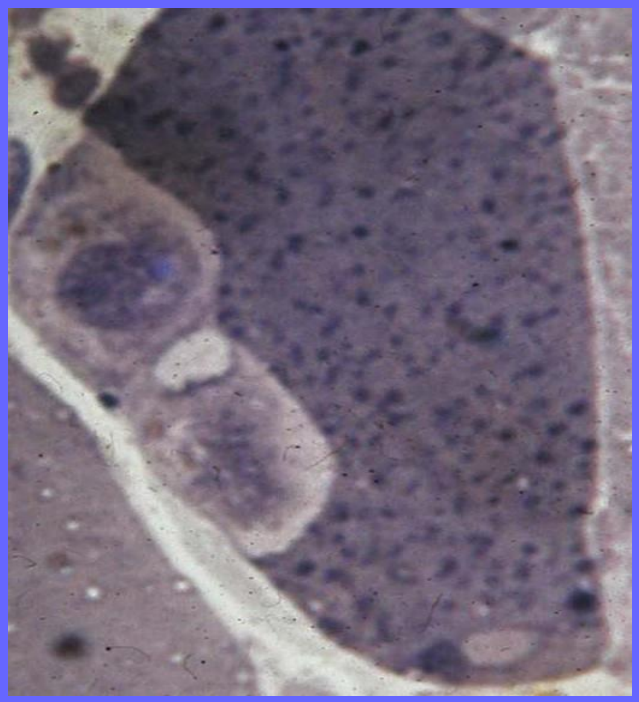
Muscles from occipital somites
Musculi linguae (XII.),
Musculi laryngis (X.)
M. trapezius,
M. sternocleidomastoideus (XI.)

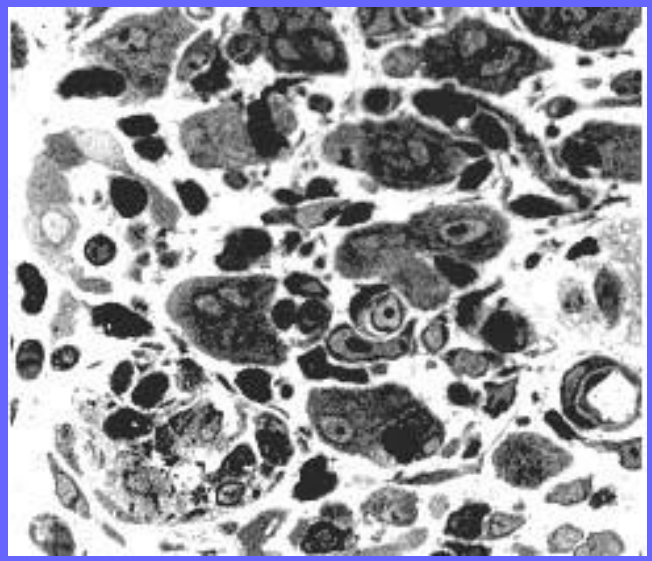
Regeneration of skeletal muscle

Activation of satellite cells during muscle regeneration

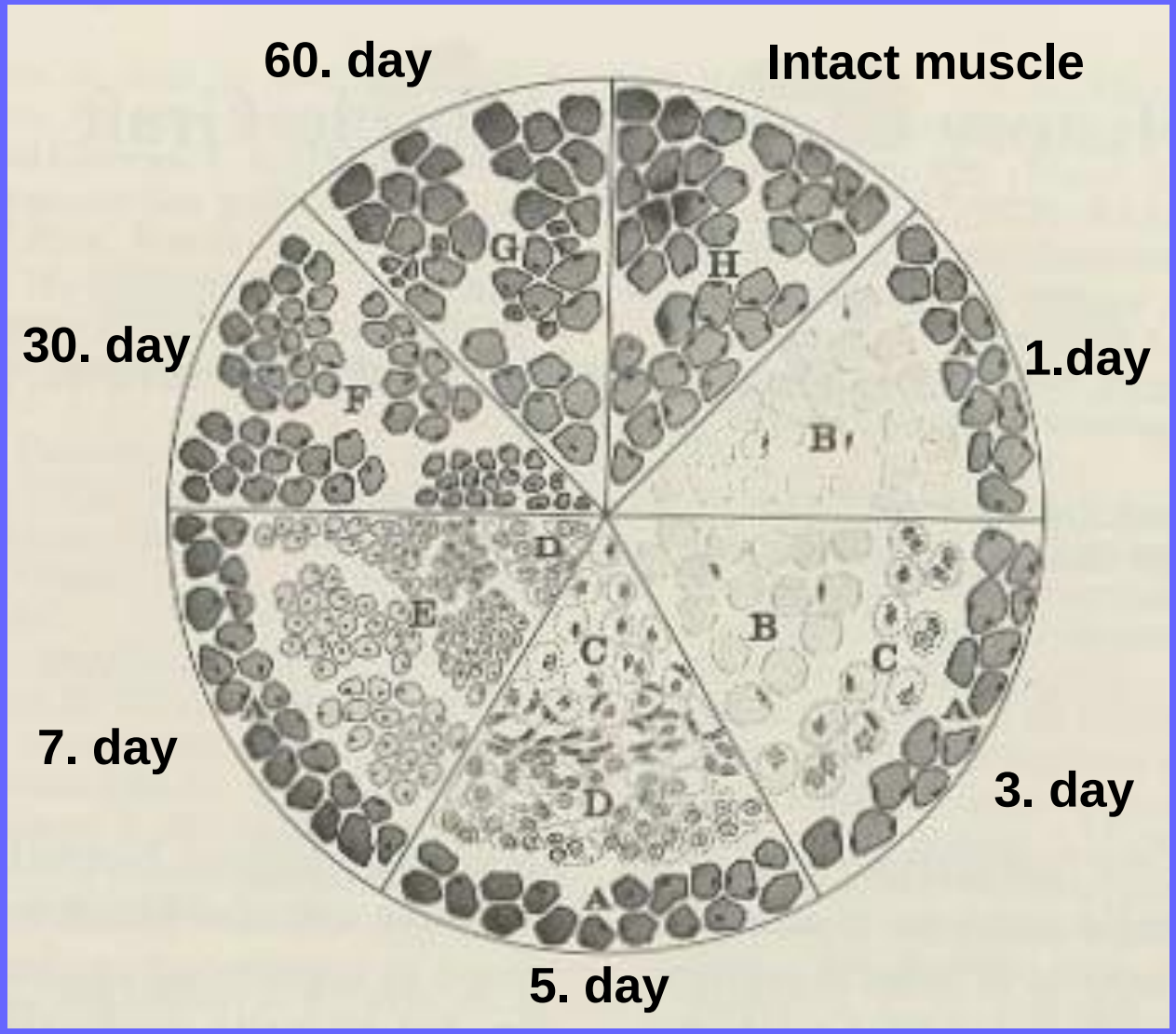








Ttime course of skeletal muscle regeneration in laboratory rat



(muscle was grafted and its vascular supply interrupted)

General anatomy of peripheral nervous system (PNS)

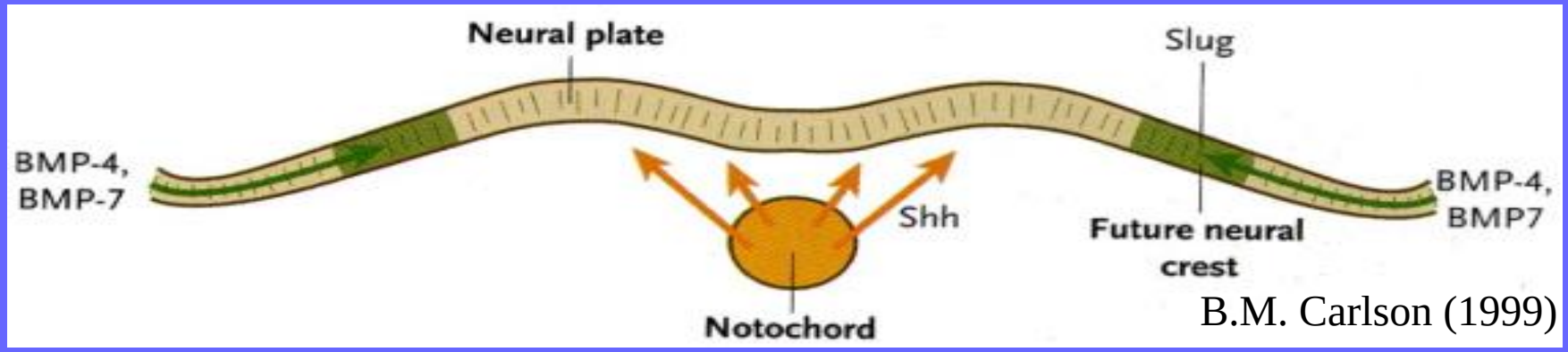
Cranial nerves, Spinal nerves, Autonomic nervous system- sympathetic and parasympathetis part

General structure of the spinal nerve and its branches, spinal nerve plexuses, autonomic plexuses, perivascular plexuses neuron, neuroglia (Schwann cells) nerve fibres, endoneurium, perineurium, epineurium, synapse, ganglion

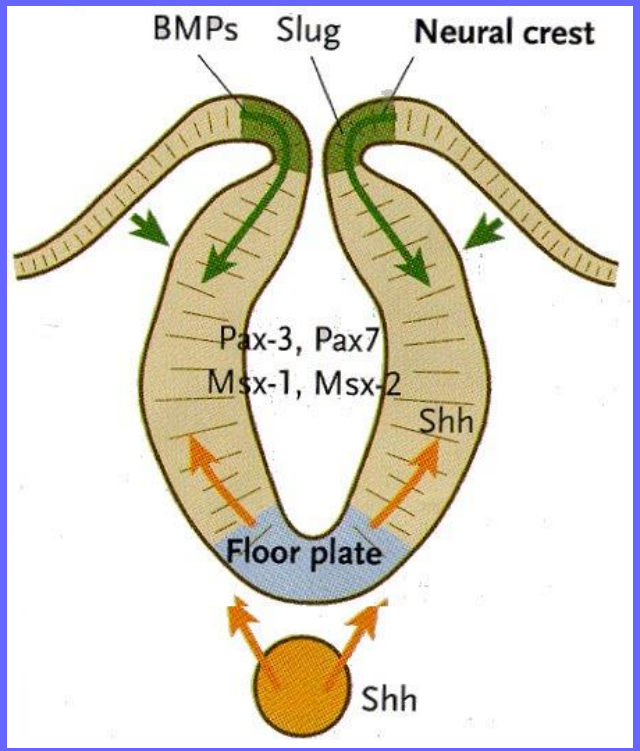
Neural crest cells and its derivatives

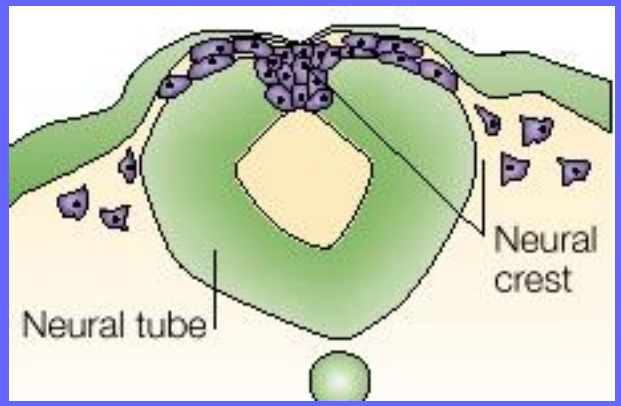
Segmental innervation, radicular areas, dermatomes, Head´s zones (zones of reffered visceral pain), sensory receptors, peripheral nerve regeneration

Development of nervous system - neurulation

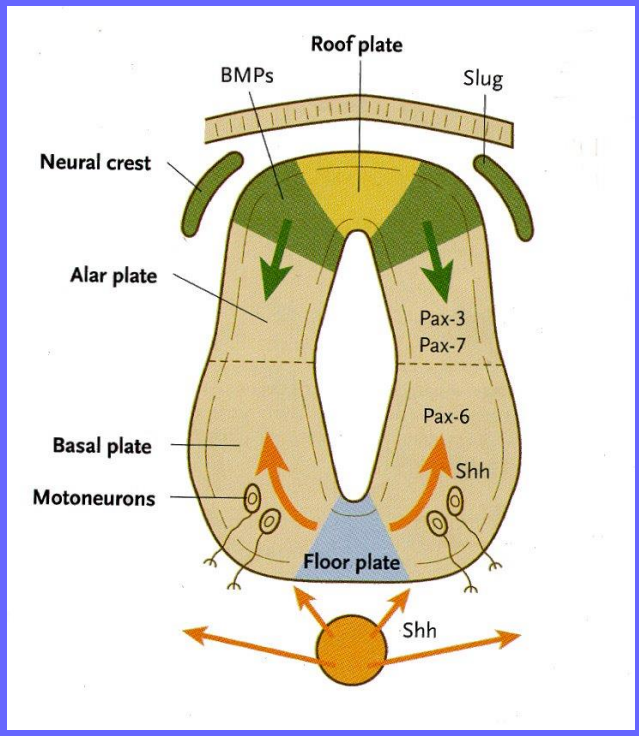


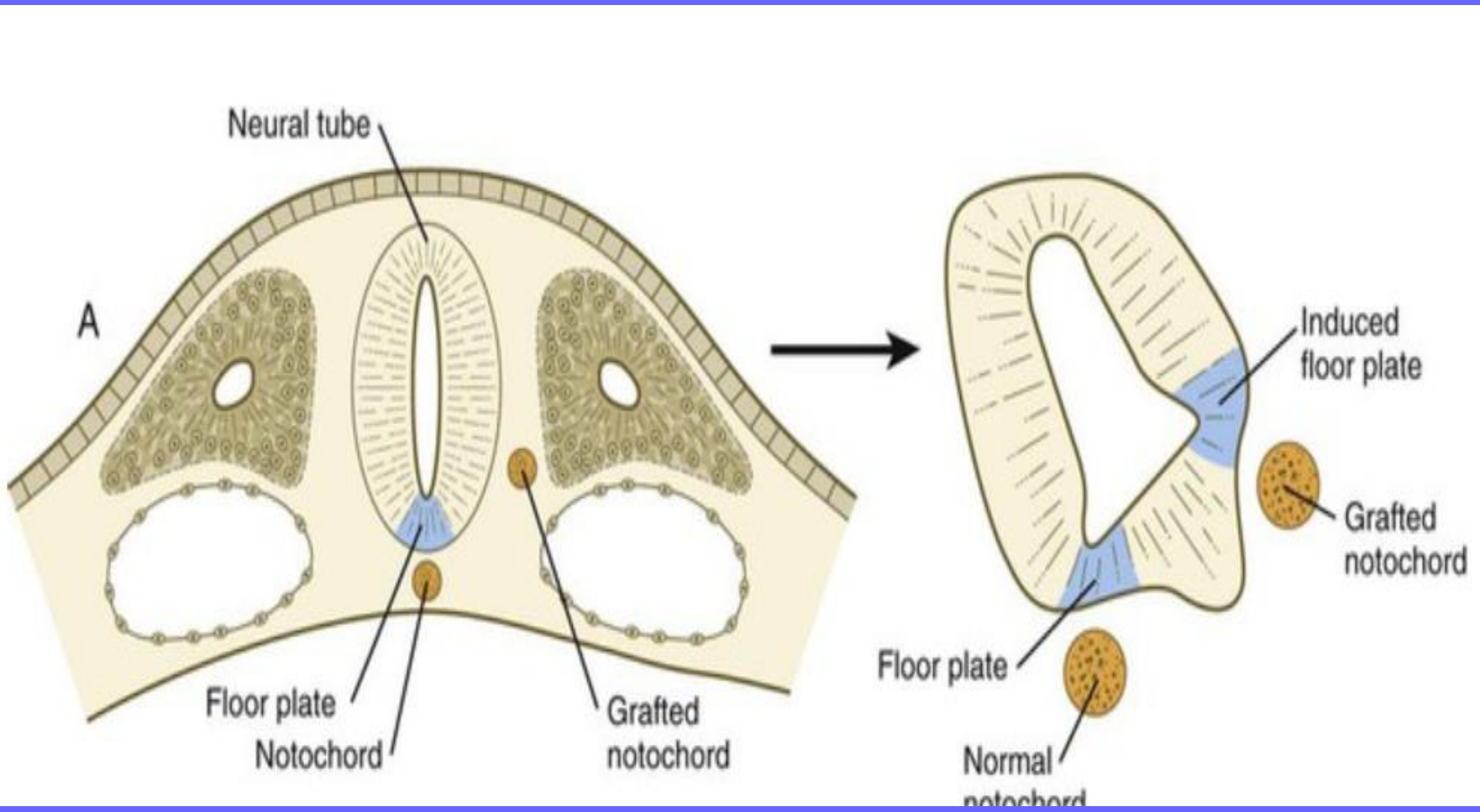
B.M. Carlson (1999)





Neural tube
Brain vesicles
Neural crest
Neural placodes

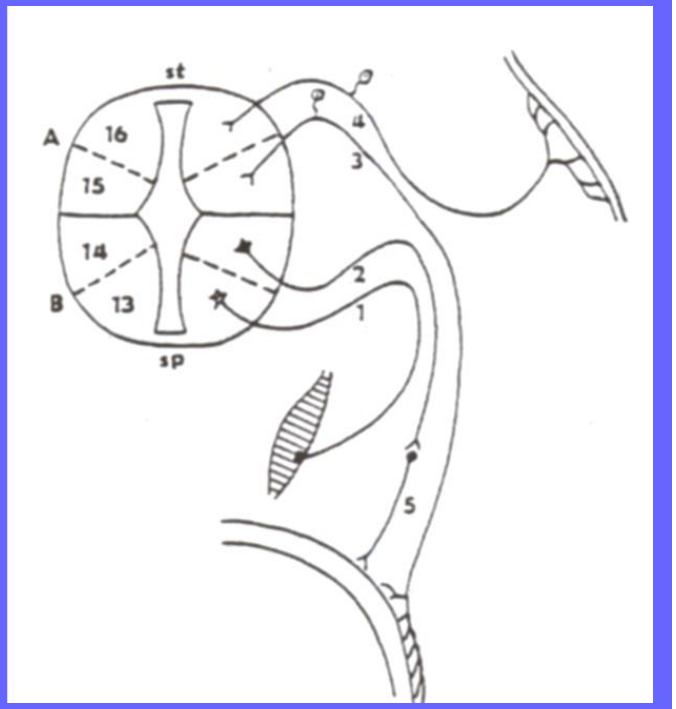


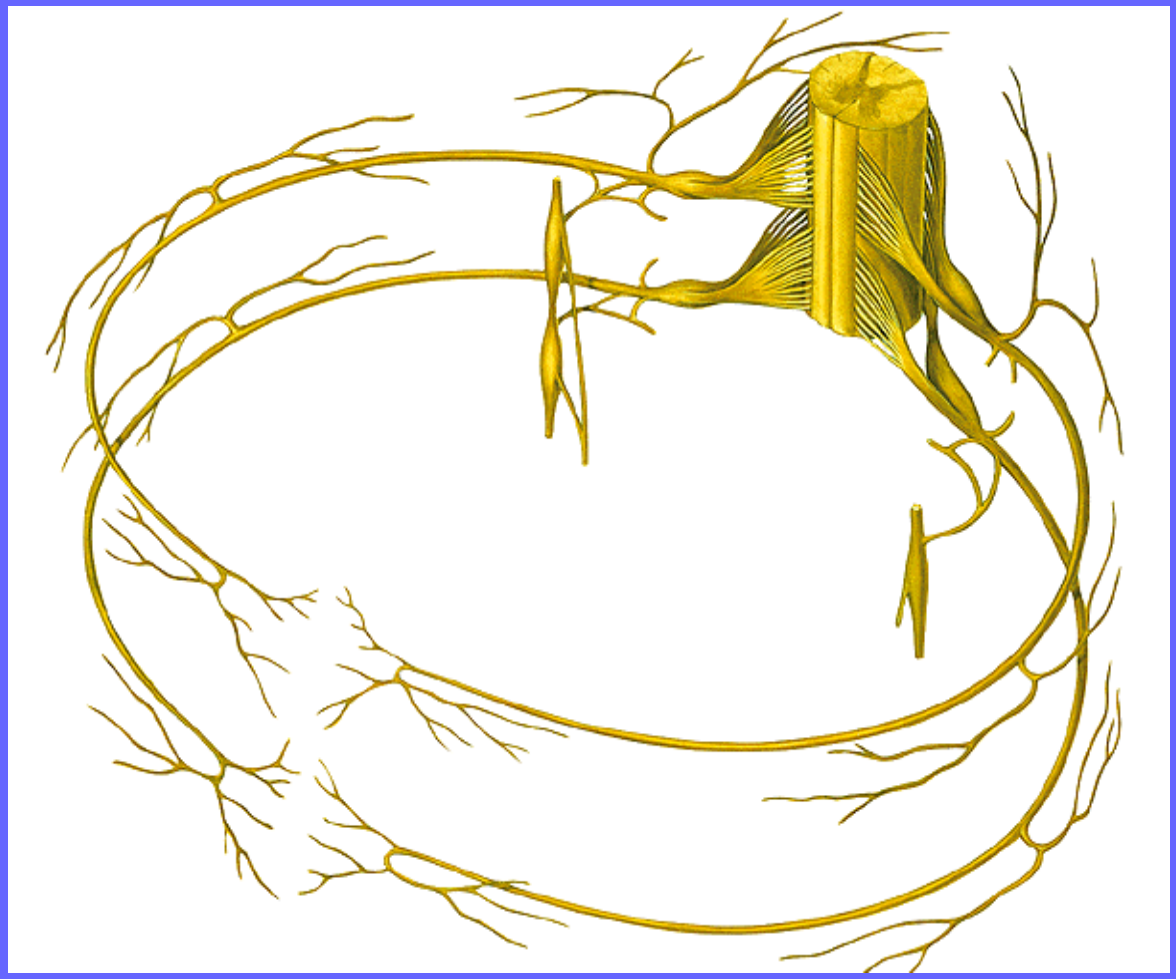


Notochord induces floor plate

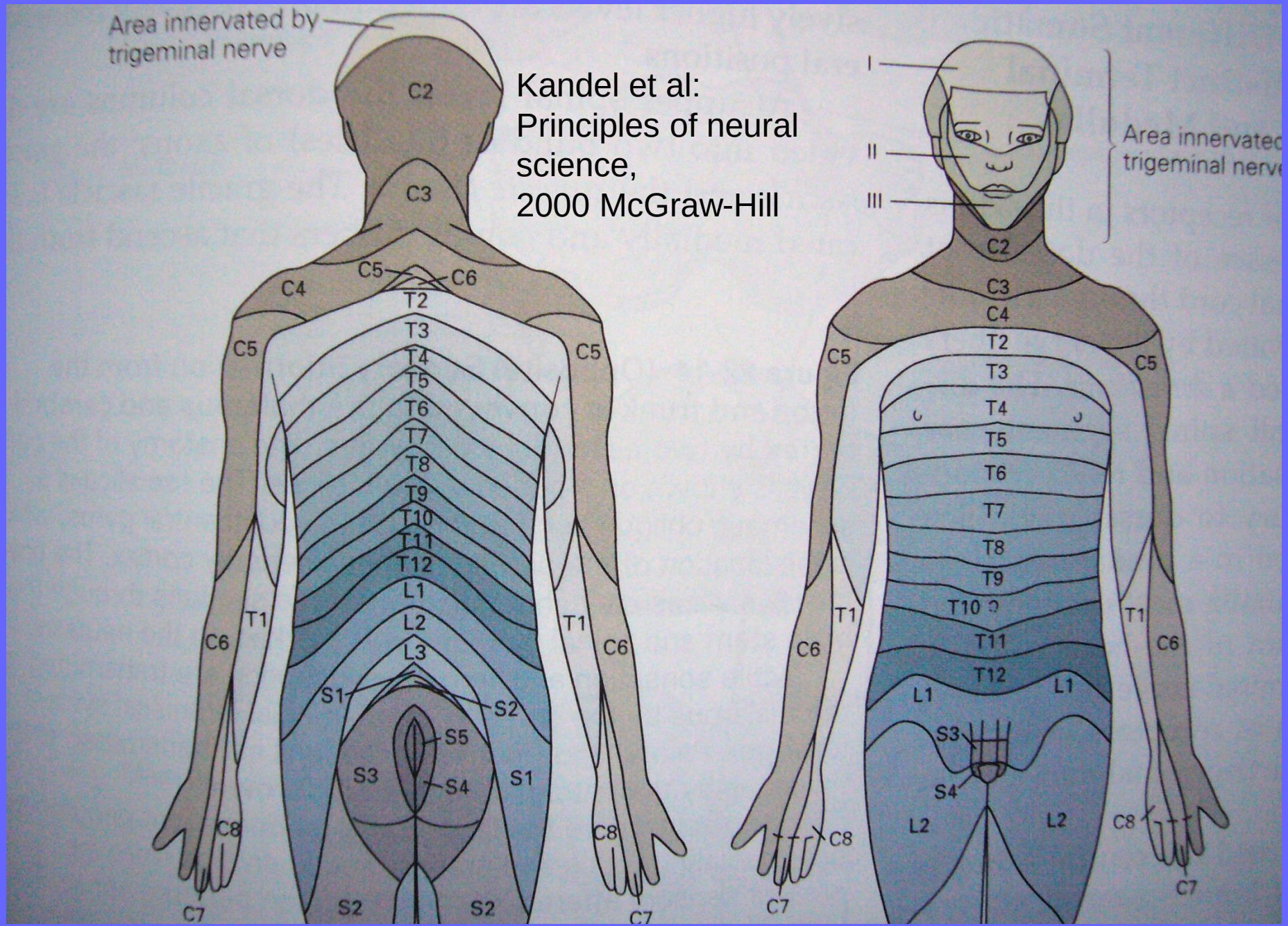
Spinal nerve

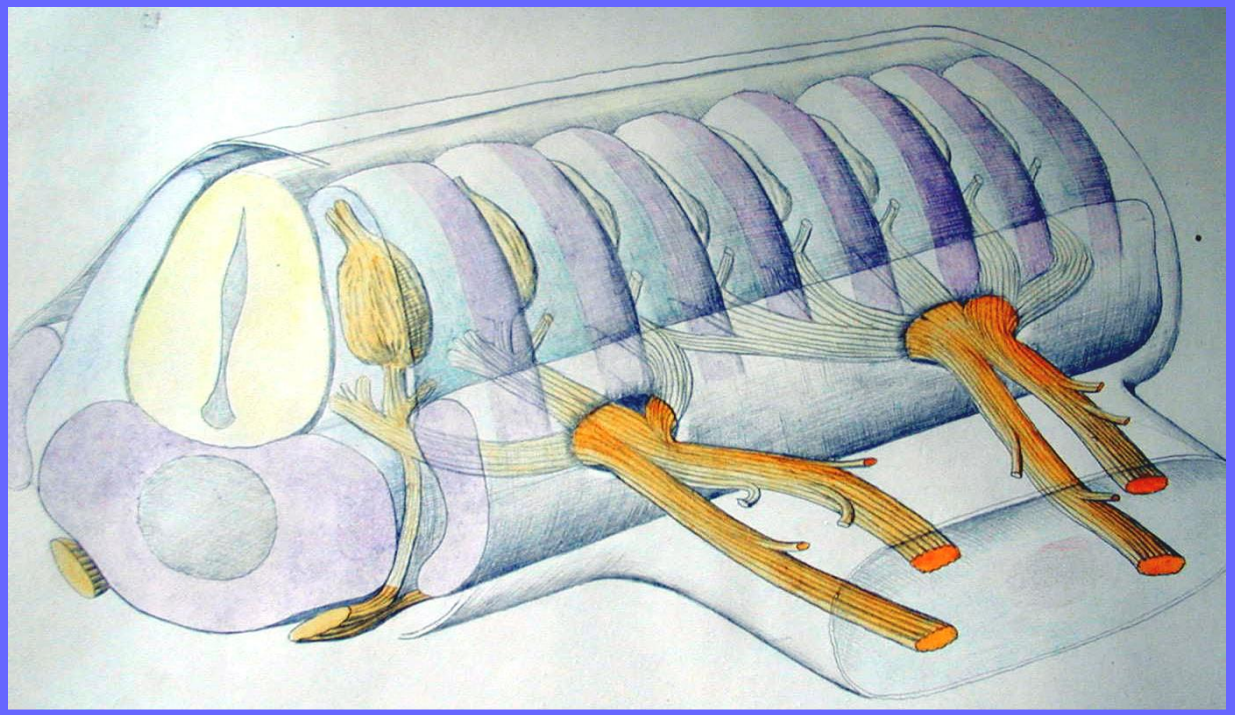
trunk of spinal nerve - mixed nerve, rootlets,
anterior root - motor root,
posterior root - sensory root, spinal ganglion

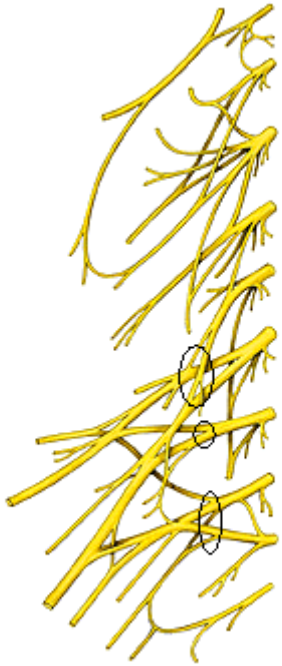




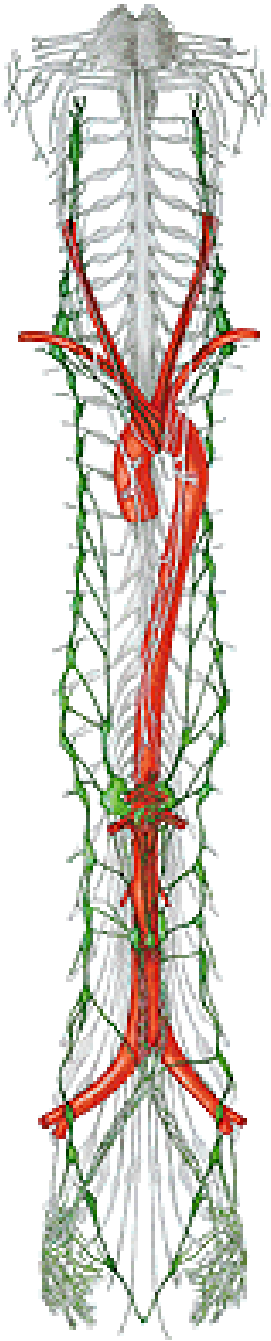
Segmental innervation – radicular areas (dermatomes)





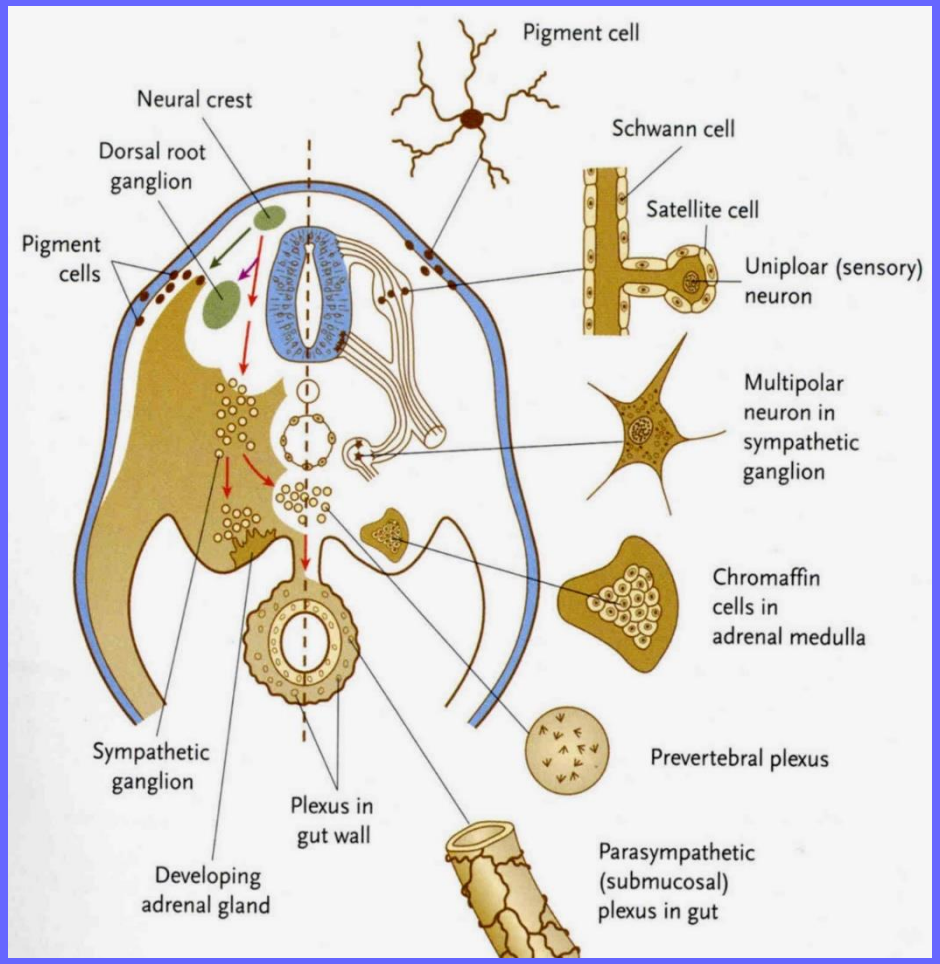


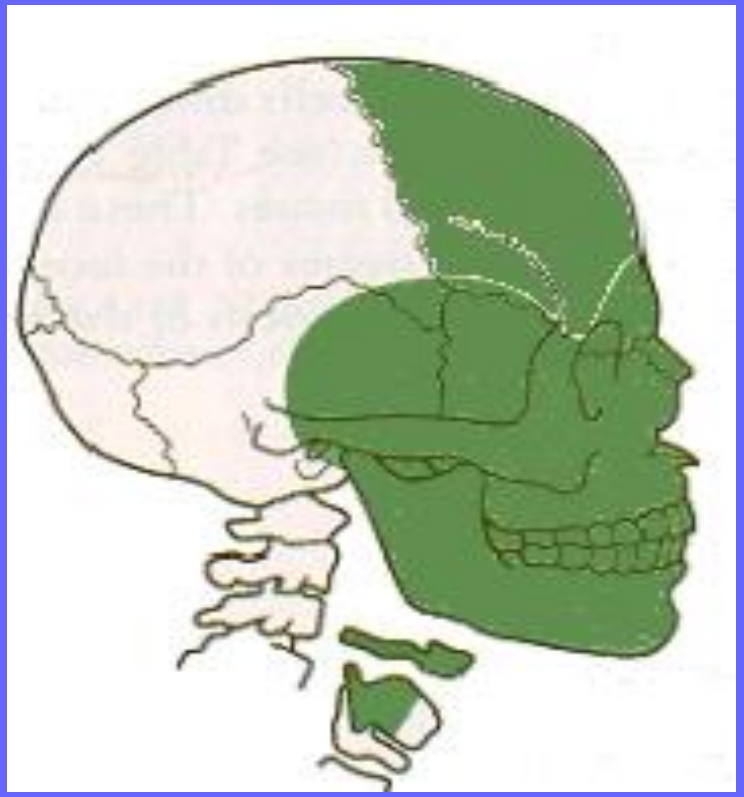
spinal nerve plexuses,
autonomic plexuses,
perivascular plexuses



Derivatives of neural crest cells

trunk head



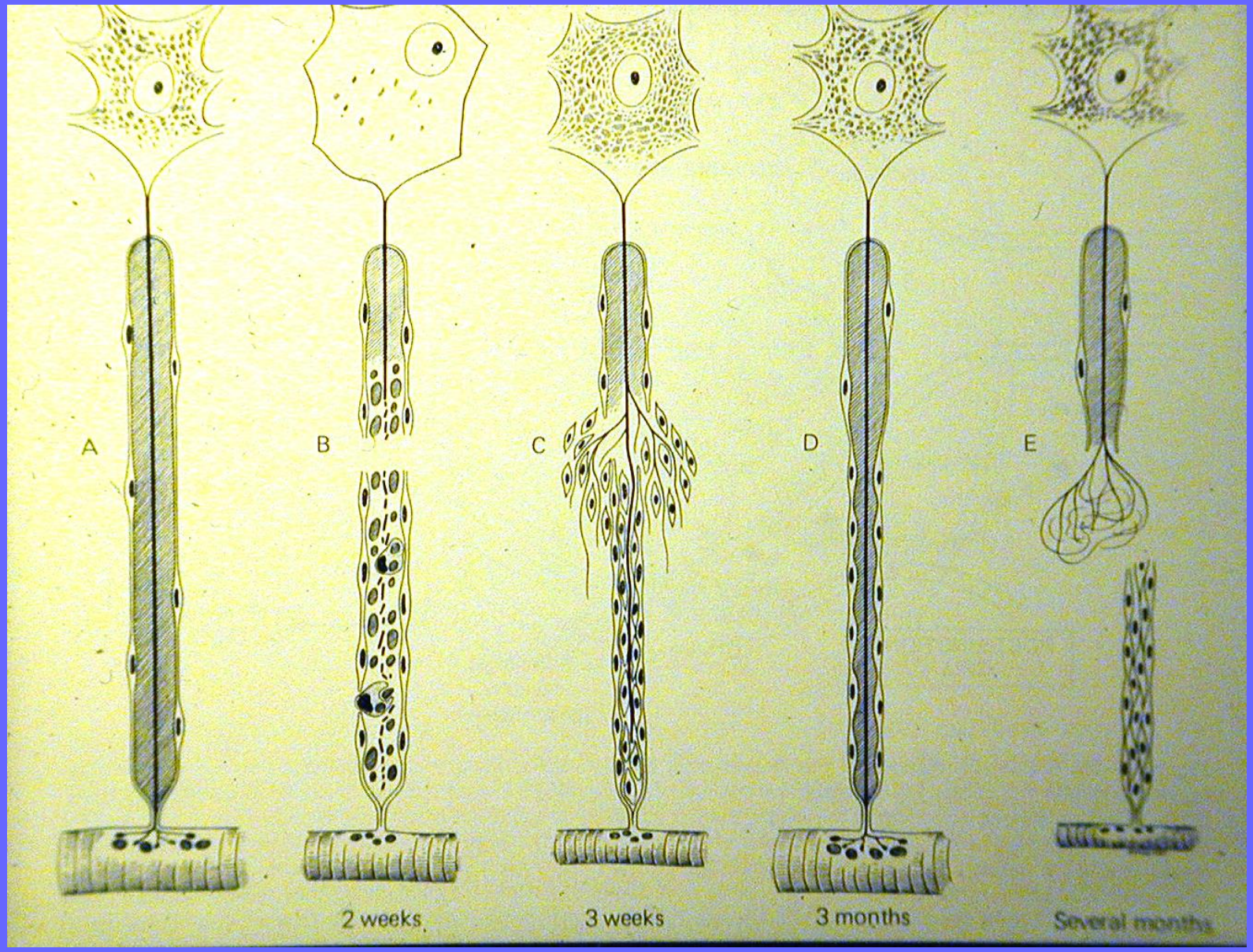


ectomesenchyme

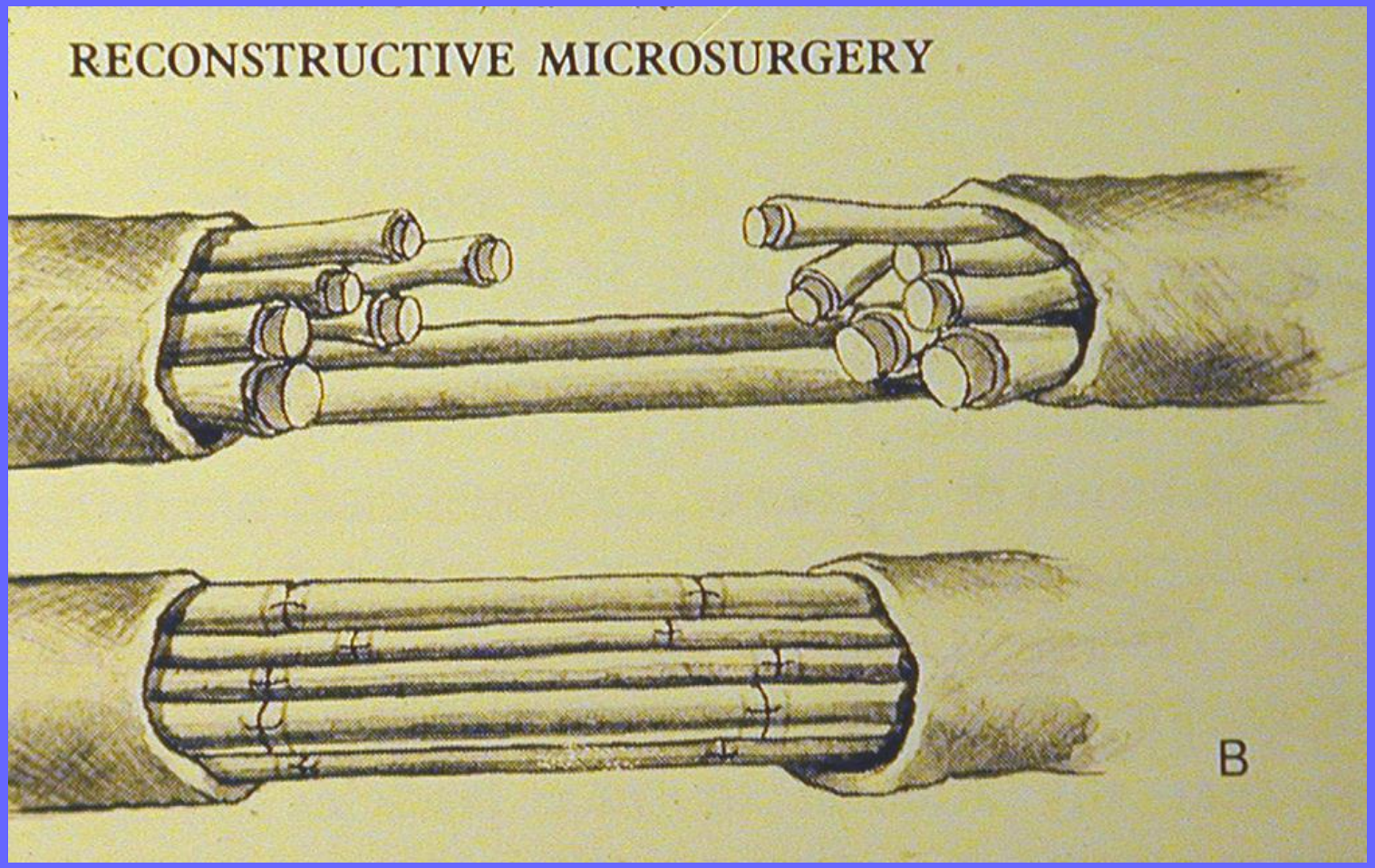
Neurons of spinal ganglia, of autonomic ganglia, enteric neurons, Schwann cells, pigment cells, cells of adrenal medulla

Peripheral nerve regeneration, suture

Regeneration of interrupted nerve fiber



peripheral nerve, endoneurium, perineurium, epineurium

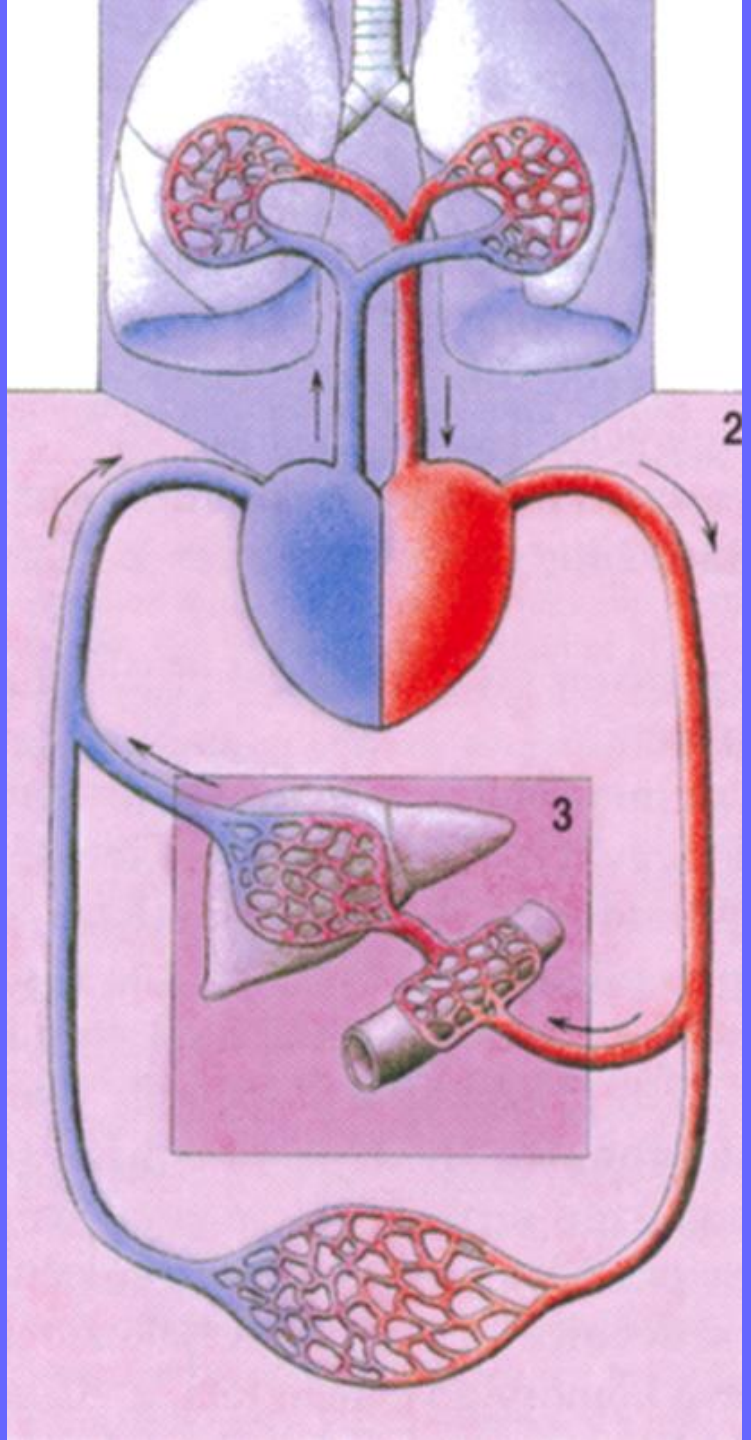


Nerve graft bridging the partial defect, suture of perineurium

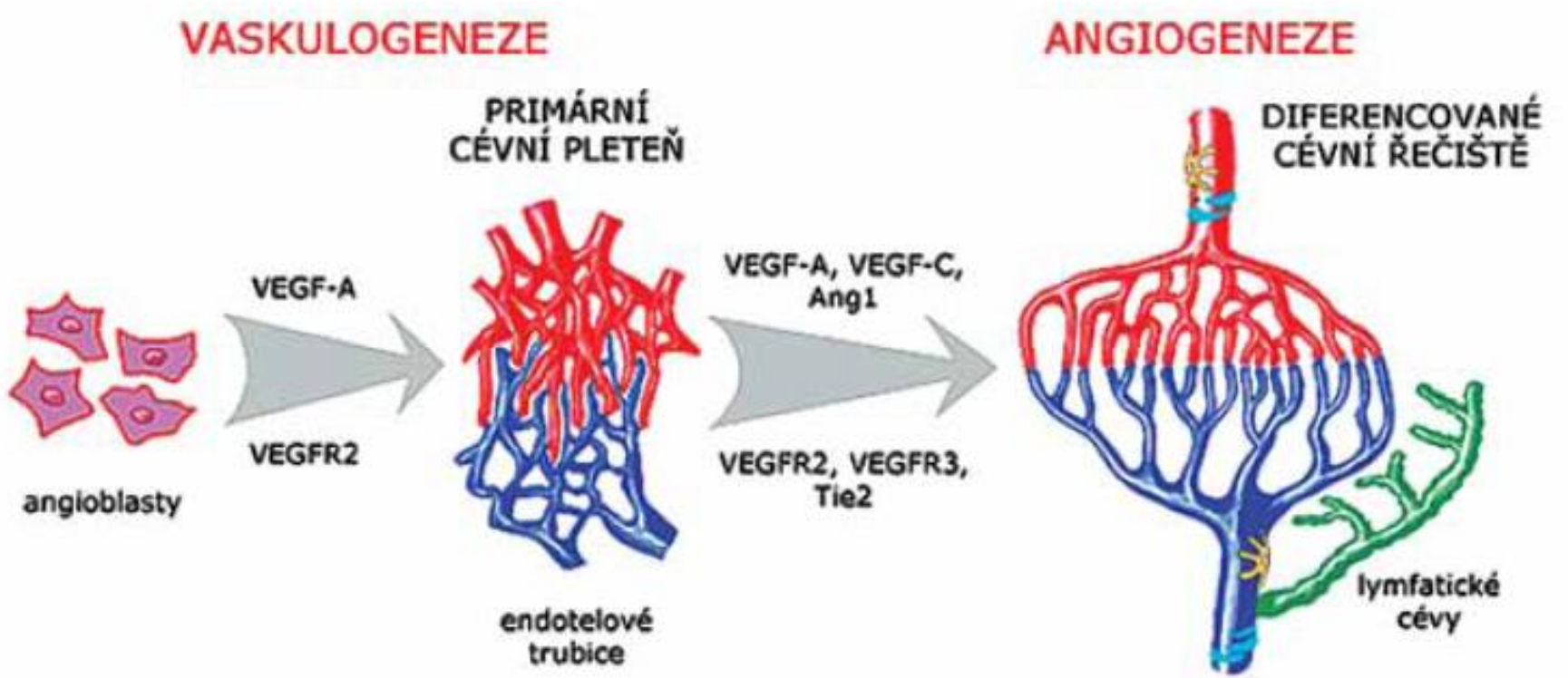
General angiology

blood vessels,
arteries, veins, capillaries,
hepatic portal vein,
fetal circulation

arteriovenous anastomosis,
collateral vessels,
collateral circulation,

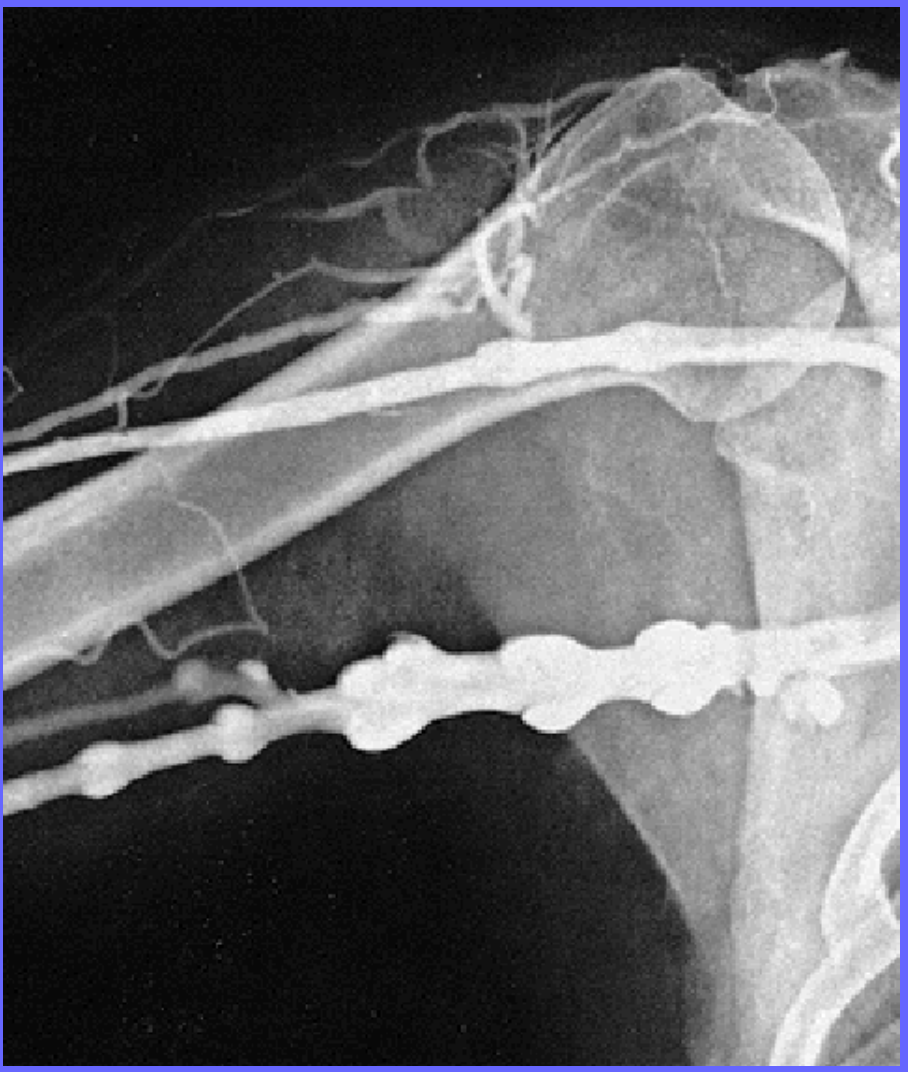


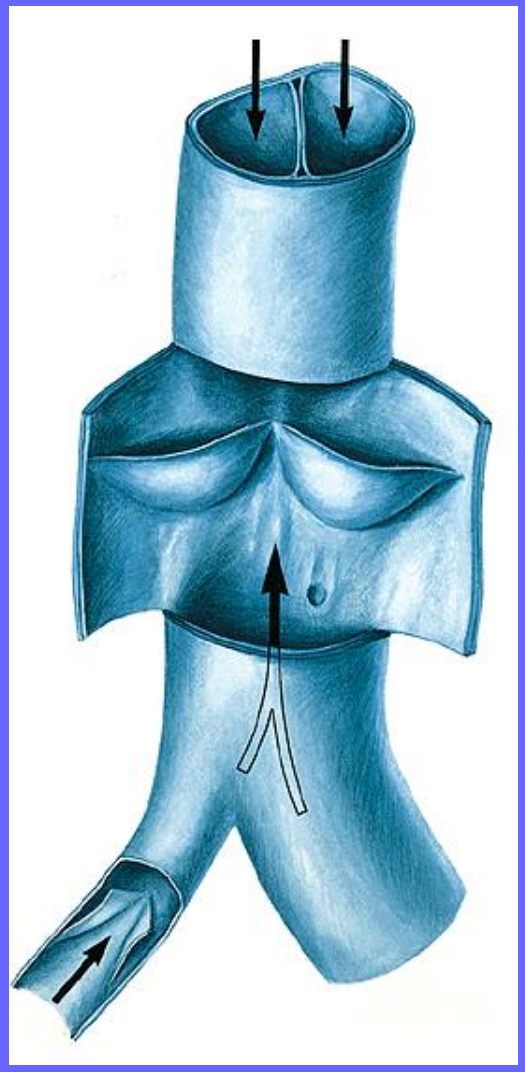
development of blood vessels

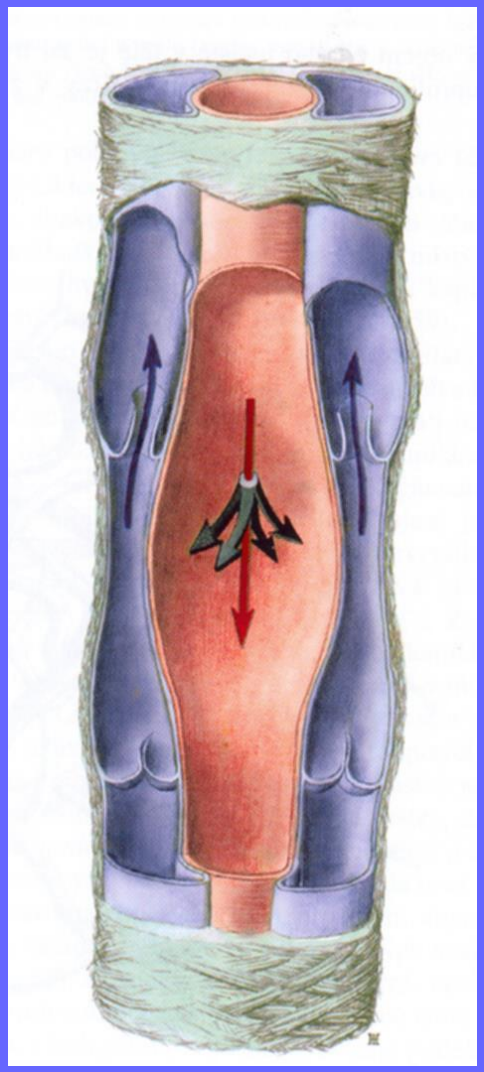


Obr. 1. Schéma vývoje krevních a lymfatických cév
Primární cévní pleteně vznikají procesem vaskulogeneze z angioblastů pod vlivem růstového faktoru VEGF. Termínem angiogeneze je označován vznik diferencovaného řečiště remodelací a růstem primárních pletení. Ve stěně větších cév se objevují pericyty a hladké svalové buňky. Lymfatické cévy vznikají většinou pučením z venózního endotelu. Zkratky jsou vysvětleny v textu článku.

Vasculogenesis, angioblasts, vascular endothelial growth factors, primary vascular plexuses, remodelation, angiogenesis, formation of blood vessels







Venous valves

Literature:

Sadler: Langman´s Medical Embryology, 11th Edit. 2009
Carlson: Human embryology and developmental biology, 2014
Mescher: Junqueira´s Basic Histology 12th Edit., 2010
Grim, Naňka, Helekal: Atlas of human anatomy I., II, Grada ,