YU - MEDICINE
PASSION ACADEMIC TEAM

Central Nervous System

SHEET# 6 - PHYSIOLOGY

LEC. TITLE : MOTOR SYSTEMS (PART 1)

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Motor systems

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- Posture and movement depend on a combination of **involuntary** reflexes coordinated by *the spinal cord* and **voluntary** actions controlled by *higher brain centres*.

- Posture and movement ultimately depend on contraction of some skeletal muscles while, simultaneously, other muscles remain relaxed.
- Activation and contraction of skeletal muscles are under the control of the **motoneurons** that innervate them.
- The motor system is designed to execute this coordinated response largely through reflexes integrated in the spinal cord.

- The unit responsible for movement and contraction is the skeletal muscle which is **the peripheral target.**
- *the motor system responsible for executing coordinated response depend on coordination between involuntary reflexes (spinal cord) and voluntary movements that come from higher brain centers.

Motor unit

- Motor unit consists of a **single motoneuron and the muscle fibers that it innervates.**

- For **fine control** (e.g., muscles of the eye), a single motoneuron innervates only a few muscle fibers.

- For **larger movements** (e.g., postural muscles), a single motoneuron may innervate thousands of muscle fibers.

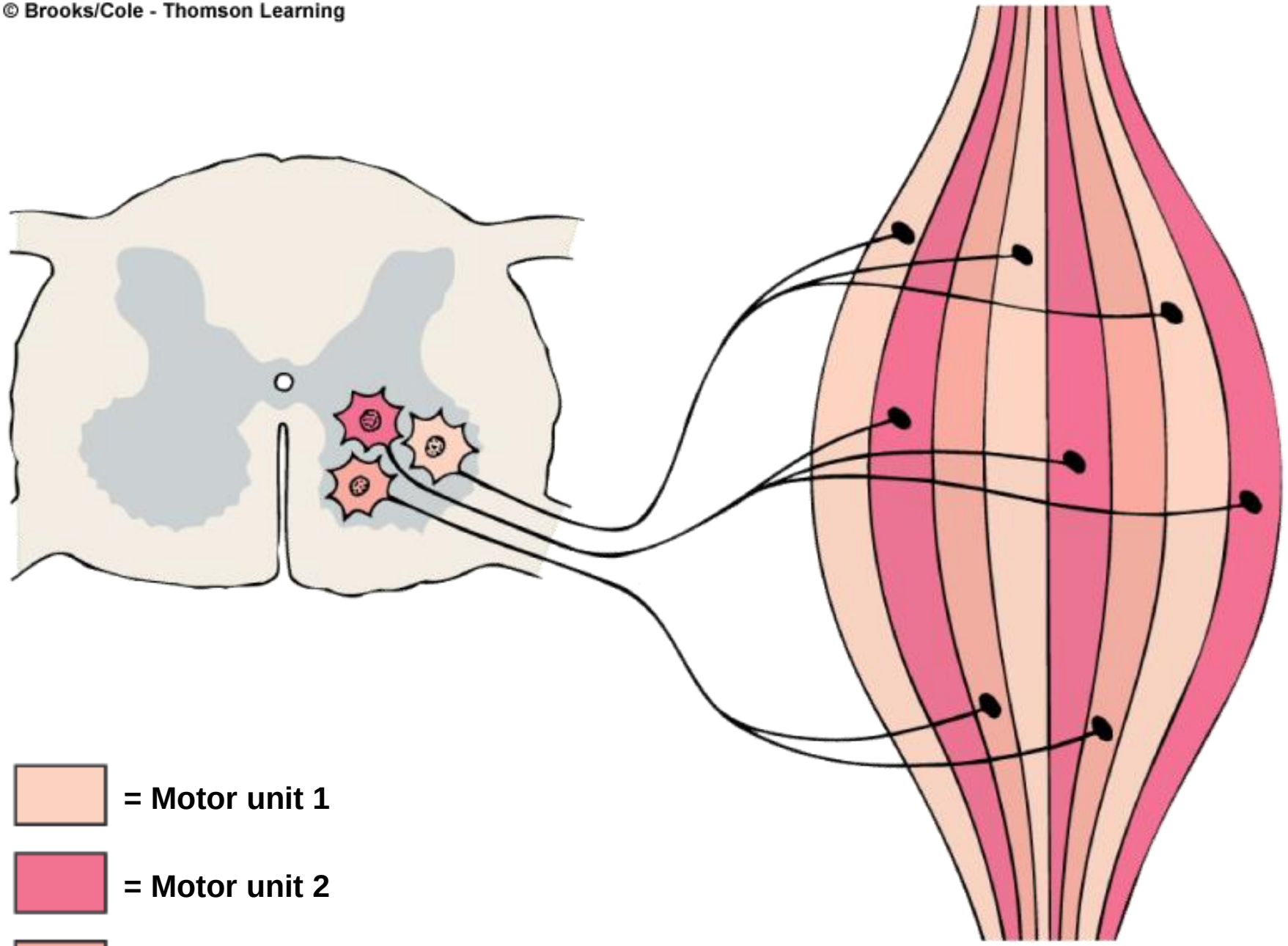
- The number of muscle fibers innervated by the single motoneuron depends on what is the target of this movement (precise and high-level regulation or powerful movement).
- *examples:
- - for controlling of very precise and higher-level movement as in muscle of the eye (a single motoneuron innervates only a few numbers of muscle fibers for very precise and highly regulated movement.)
- -For larger movements and powerful movement as postural muscles (in the thigh and leg) and the muscle that move the upper limb (a single motoneuron innervates thousands of muscle fibers).
- Fine control and more regulated movement, fewer muscle fibers innervated by a single motoneuron.

Motor unit

- The **motoneuron pool** is the group of motoneurons that innervates fibers within the same muscle.

- Motor unit: one motoneuron innervates multiple muscle fibers.
  - *a single skeletal muscle (ممكن يتم تغذيتها من أكثر من) motoneurons, these motoneurons that innervate fibers within the same muscle are called (motoneuron pool).

- # الدكتورة من سؤال :
- IS IT TRUE OR FALSE, TWO MOTONEURONS INNERVATE THE SAME MUSCLE FIBER.?
- FALSE AND THE EXPLANE IS:
- -Because the single motoneuron innervates muscle fibers that are not innervated by other motoneurons (اللي رح يروحوا لل) other group of muscle fibers that are not innervated by the first motoneuron.
- #?? Why does a single motoneuron innervate specific group of muscle fibers?
- To prevent chaos and more powerful and strong movement will occur by organization and arrangement of these motor units.



- (هذه الرسمة توضح الفرق بين) motor unit and motoneuron pool.
- *This skeletal muscle consists of three motor units that form its motoneuron pool.
- -motor unit1 : the motoneuron it will innervate number of muscle fibers but these muscle fibers it innervated by only this motoneuron.
- -motor unit2: the motoneuron it will innervate other muscle fibers are not innervated by the first motoneuron.
- * the motoneuron pool: it consists of more than one motoneuron but each motoneuron specified for specific group of muscle fibers.

Motor unit

- The force of muscle contraction is graded by **recruitment** of additional motor units (size principle).

➢ The **size principle** states that as additional motor units are recruited, more motoneurons are involved and more tension is generated.

- (Size principle)
- To initiate the muscle contraction in the certain muscle fibers or certain motor unit ببلش action potential بصير إله grading to other part until the full contraction is occurred.
- هذا يسمى(graded recruitment of the motor unit to allow the contraction of the muscle)

*كلما كان عدد muscle fibers let start to contract أكبر , بقدر اعمل واوسع recruitment for other muscle fibers and other motor unit لحد ما تصير force generated is higher.

*كلما كان the recruitment and size اللي بصير فيها spread لهذا action potential or to the stimulation أكبر و كان tension and the force of the movement أعلى .

*كل ما بتعمل recruitment and involvement of motor units كان powerful of contraction أعلى

Motor units

Small motor neurons

- **innervate a few muscle fibers.**
- have the lowest thresholds and, therefore, **fire first.**
- generate the **smallest force.**

- Small motor neurons that innervate a few muscle fibers, and have the lowest thresholds.

*بقدر اعمللهم firing أسهل وأسرع بالتالي بيعطوا smallest force

Motor units

Large motor neurons

- **innervate many muscle fibers.**
- have the highest thresholds and, therefore, **fire last.**
- generate the **largest force.**

- summation effect: summation of the smallest forces activates the large motor neurons
- The small motor units stimulated firstly then the summation of the small units forces activates the large motor units.

Types of motoneurons

- **α-Motoneurons** innervate extrafusal skeletal muscle fibers →contraction.

- **γ-Motoneurons** innervate specialized intrafusal muscle fibers → adjust the *sensitivity* of the muscle spindles (so that they respond appropriately as the extrafusal fibers contract and shorten).

- Extrafusal skeletal muscle fibers: they are muscle fibers parallel with the length of the muscle.
- Intrafusal muscle fibers: in the sensory receptors that inside the skeletal muscle and responsible for sensitivity of the muscle fibers.

Muscle sensor

- Types of muscle sensors

1. **Muscle spindles** (groups Ia and II afferents) are arranged in parallel with extrafusal fibers. They detect both **static and dynamic changes in muscle length.**
2. **Golgi tendon organs** (group Ib afferents) are arranged in series with extrafusal muscle fibers. They detect **muscle tension.**
3. **Pacinian corpuscles** (group II afferents) are distributed throughout muscle. They detect **vibration.**
4. **Free nerve endings** (groups III and IV afferents) detect **noxious stimuli.**

- -muscle spindles (muscle stretch receptors and mechanosensitive receptors)
- -Golgi tendon organs responsible for relaxation of the muscle by detection the contraction of the muscle (muscle tention) then stop it and induce relaxation.
- -Pacinian corpuscles: they are very rapidly adapting responsible for detection the frequency of vibration especially for high frequency of vibrations.
- - Free nerve endings related to pain (detect noxious stimuli).

Types of muscle fibers

- **Extrafusal fibers**
  - make up the bulk of muscle.
  - are **innervated by α-motoneurons.**
  - generate the **force for muscle contraction.**

- **Intrafusal fibers**
  - are smaller than extrafusal muscle fibers.
  - are **innervated by γ-motoneurons.**
  - are encapsulated in sheaths to form **muscle spindles.**
  - run in parallel with extrafusal fibers, but not for the entire length of the muscle.
  - are too small to generate significant force.

- Intrafusal fibers can regulate the extrafusal movement and control the internal environment of the muscle.

Muscle spindles

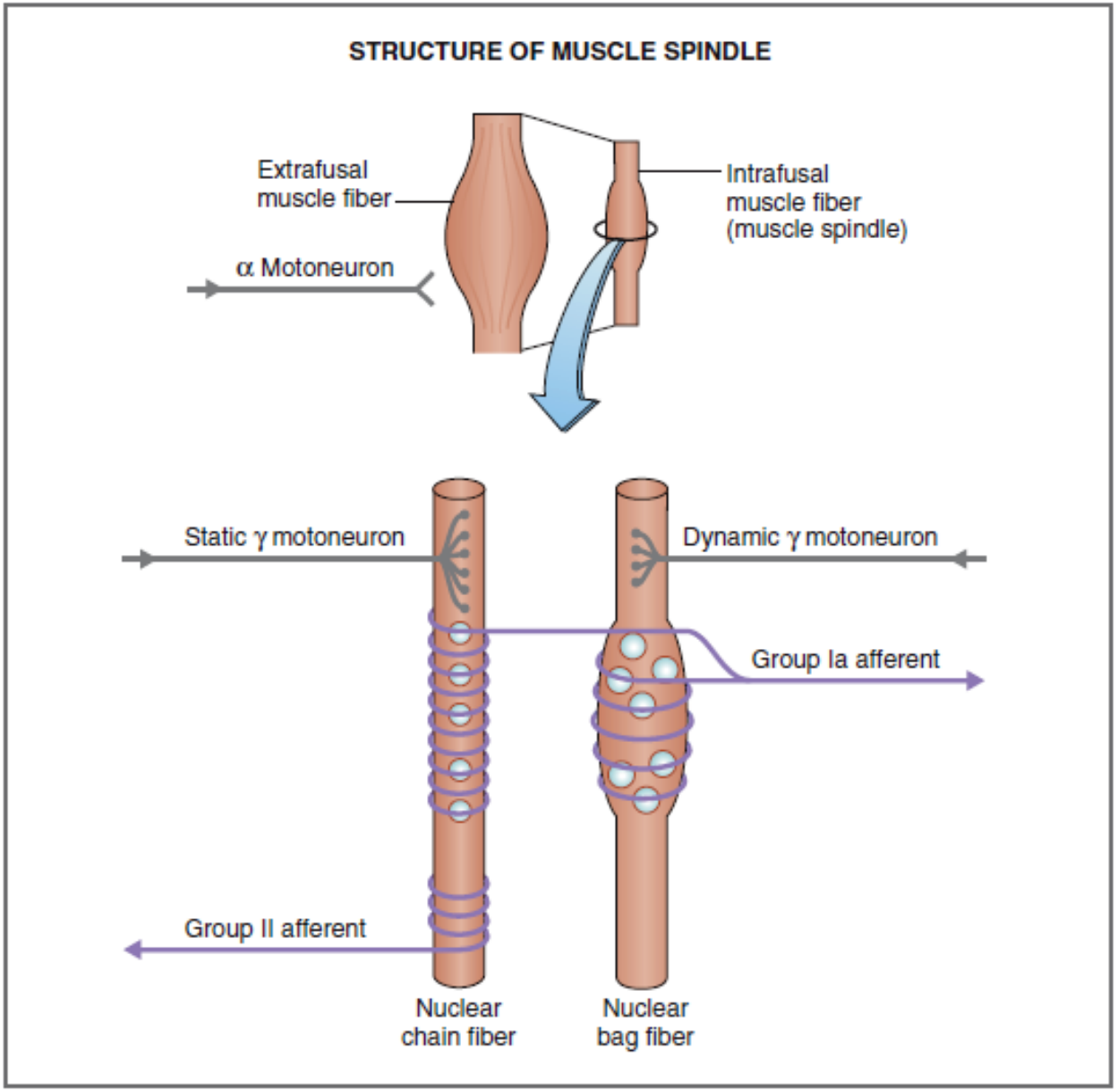
- are spindle-shaped organs composed of small, encapsulated intrafusal muscle fibres and innervated by sensory and motor nerve fibres.

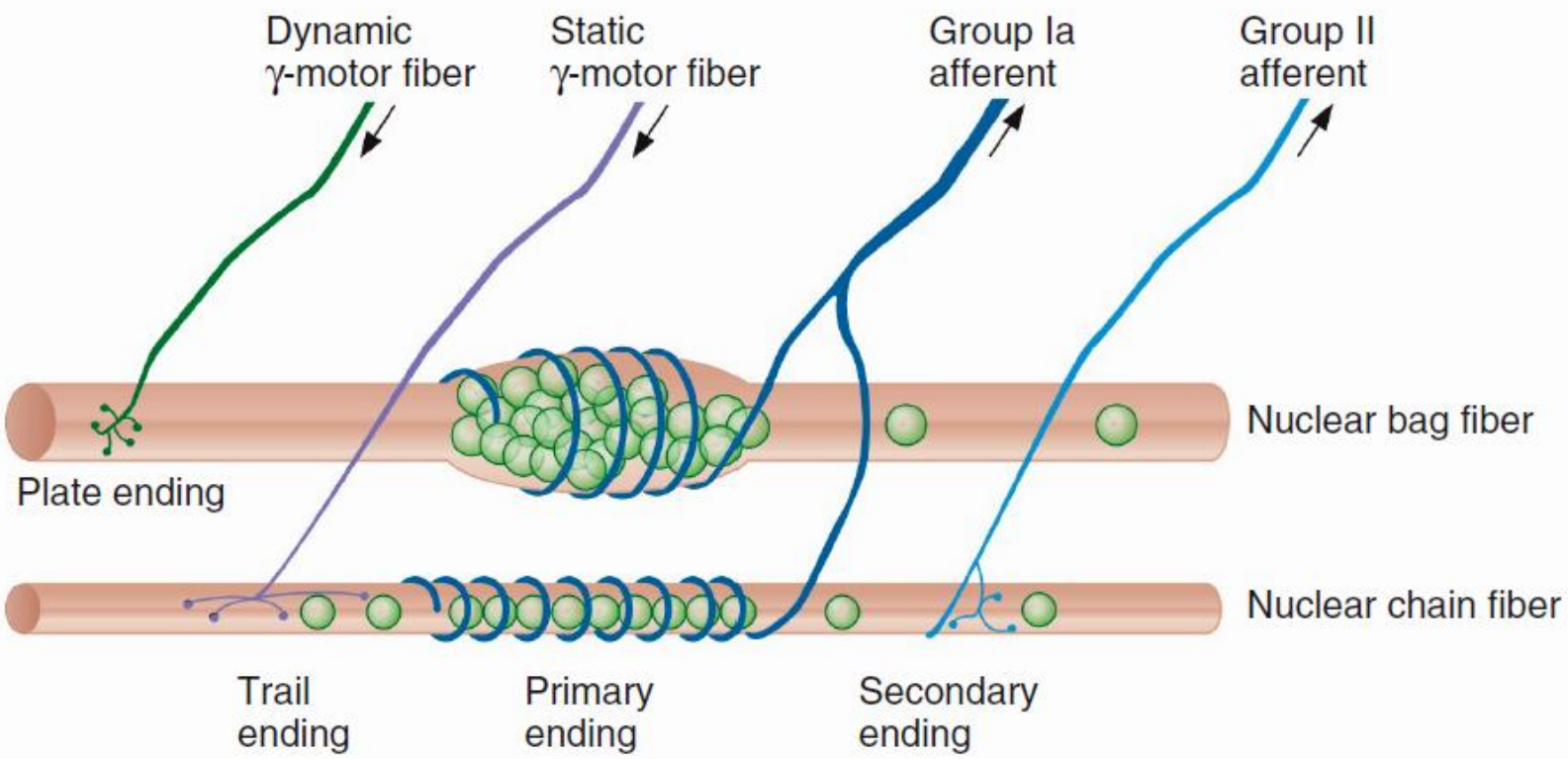
- distributed throughout muscle.
- connected in parallel with large (force-generating) extrafusal fibers.

- The finer the movement required, the greater the number of muscle spindles in a muscle.

- -Muscle spindles(mechanoreceptors) they are innervate by sensory and motor fibers to regulate the internal environment of the skeletal muscle and to regulate the movement of the skeletal muscle.
- -the muscle spindles distributed throughout muscle for more detection and precise of the movement.
- *Precise and high-level regulated movement as in the eye muscles ,the motor unit(motoneuron) innervates a small number of muscle fibers and the number of the muscle spindles are larger. (The finer the movement required, the greater the number of muscle spindles in a muscle).

Muscle spindles





Organization of the muscle spindle. (Modified with permission from Matthews PBC. Muscle spindles and their motor control. Physiol Rev 1964;44:232.)

- Muscle spindles consist of intrafusal muscle fibers that contain group Ia afferent and group II afferent and innervated by static gamma motoneuron (on nuclear chain fibers) and dynamic gamma motoneuron (on nuclear bag fiber), they are two types of intrafusal muscle fibers: nuclear bag fiber and nuclear chain fiber.
- - Group Ia afferent for static and dynamic changes
- - Group II afferent only for static changes

Types of intrafusal fibers in muscle spindles

1. ***Nuclear bag fibers***
   - detect the rate of change in muscle length (fast, **dynamic changes).**
   - are innervated by group IA afferents.
   - have nuclei collected in a central "bag" region.

2. ***Nuclear chain fibers***
   - detect **static** changes in muscle length**.**
   - are innervated by group II afferents.
   - are more numerous than nuclear bag fibers.
   - have nuclei arranged in rows.

- They are two types of intrafusal fibers in muscle spindles:
- **- nuclear bag fibers** they detect transient and rapid changes in the muscle length.
- **- nuclear chain fibers** they detect continuous changes in the muscle length (not fast change).

How the muscle spindle works

- Muscle spindle reflexes oppose (correct for) increases in muscle length (stretch).
  1. Sensory information about muscle length is received by group IA (velocity) and group II (static) afferent fibers.
  2. When a muscle is stretched (lengthened), the muscle spindle is also stretched, stimulating group IA and group II afferent fibers.
  3. Stimulation of group IA afferents stimulates α-motoneurons in the spinal cord. This stimulation in turn causes contraction and shortening of the muscle. Thus, the original stretch is opposed and muscle length is maintained.

- Muscle spindles are stretch receptors that detect any changes in muscle length .
- -Stretch (increases in muscle length) is the stimulus for muscle spindles to initiate oppose action against this stretch.

Function of γ-motoneurons

- innervate intrafusal muscle fibers.
- adjust the sensitivity of the muscle spindle so that it will respond appropriately during muscle contraction.
- **α-Motoneurons and γ-motoneurons are coactivated** so that muscle spindles remain sensitive to changes in muscle length during contraction.

Muscle reflexes

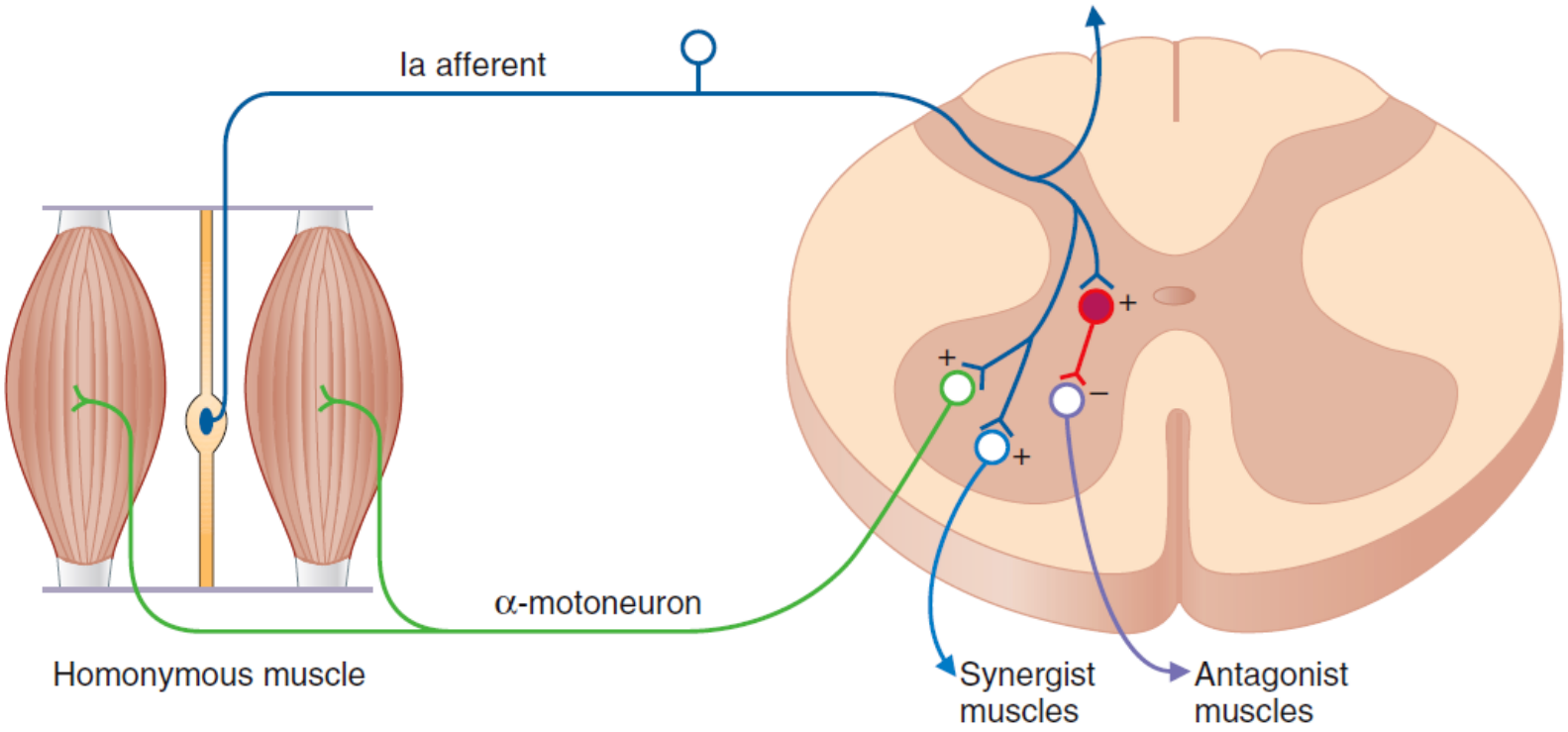
table Summary of Muscle Reflexes

Reflex	Number of Synapses	Stimulus	Afferent Fibers	Response
Stretch reflex (knee-jerk)	Monosynaptic	Muscle is stretched	Ia	Contraction of the muscle
Golgi tendon reflex (clasp-knife)	Disynaptic	Muscle contracts	Ib	Relaxation of the muscle
Flexor-withdrawal reflex (after touching a hot stove)	Polysynaptic	Pain	II, III, and IV	Ipsilateral flexion; contralateral extension

Muscle reflexes

1. Stretch (myotatic) reflex - knee jerk

- Is monosynaptic



The stretch reflex.

1. Stretch (myotatic) reflex - knee jerk

- **Muscle is stretched,** and the stretching stimulates **group IA** afferent fibers.

- Group I a afferents synapse directly on **α-motoneurons** in the spinal cord. The pool of α-motoneurons that is activated innervates the homonymous muscle.
- Stimulation of α-motoneurons causes **contraction in the muscle that was stretched.** As the muscle contracts, it shortens, decreasing the stretch on the muscle spindle and returning it to its original length.
- At the same time, synergistic muscles are activated and antagonistic muscles are inhibited.

- **Example of the knee-jerk reflex**

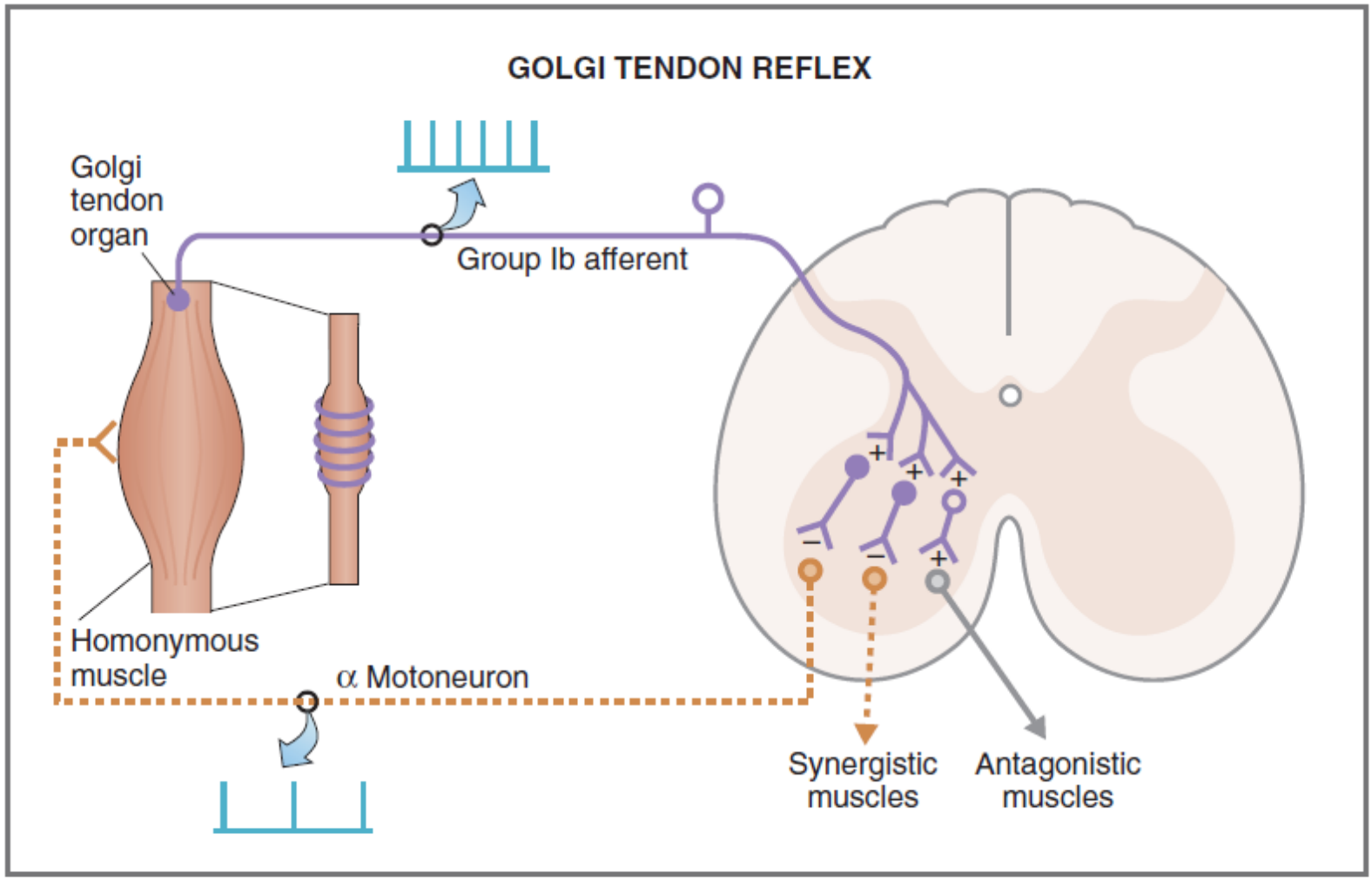
- Tapping on the patellar tendon causes the quadriceps to stretch. Stretch of the quadriceps stimulates group IA afferent fibers, which activate α-motoneurons that make the quadriceps contract. Contraction of the quadriceps forces the lower leg to extend.
  - **Increases in γ-motoneuron activity** increase the sensitivity of the muscle spindle and therefore exaggerate the knee-jerk reflex.

2. Golgi tendon reflex (inverse myotatic)

- Is disynaptic

- Is the opposite, or inverse, of the stretch reflex
  A. **Active muscle contraction** stimulates the Golgi tendon organs and **group Ib** afferent fibers.
  B. The group Ib afferents **stimulate inhibitory interneurons** in the spinal cord. These interneurons **inhibit α-motoneurons** and cause relaxation of the muscle that was originally contracted.
  C. At the same time, antagonistic muscles are excited.

2. Golgi tendon reflex (inverse myotatic)



Operation of the Golgi tendon reflex. *Solid lines* show excitatory pathways; *dashed lines* show inhibitory steps. *Open* neurons are excitatory; *filled* neurons are inhibitory.

3. Flexor withdrawal reflex

- is **polysynaptic.**

- results in **flexion on the ipsilateral side** and **extension on the contralateral side.**

  Somatosensory and pain afferent fibers elicit withdrawal of the stimulated body part from the noxious stimulus.

3. Flexor withdrawal reflex

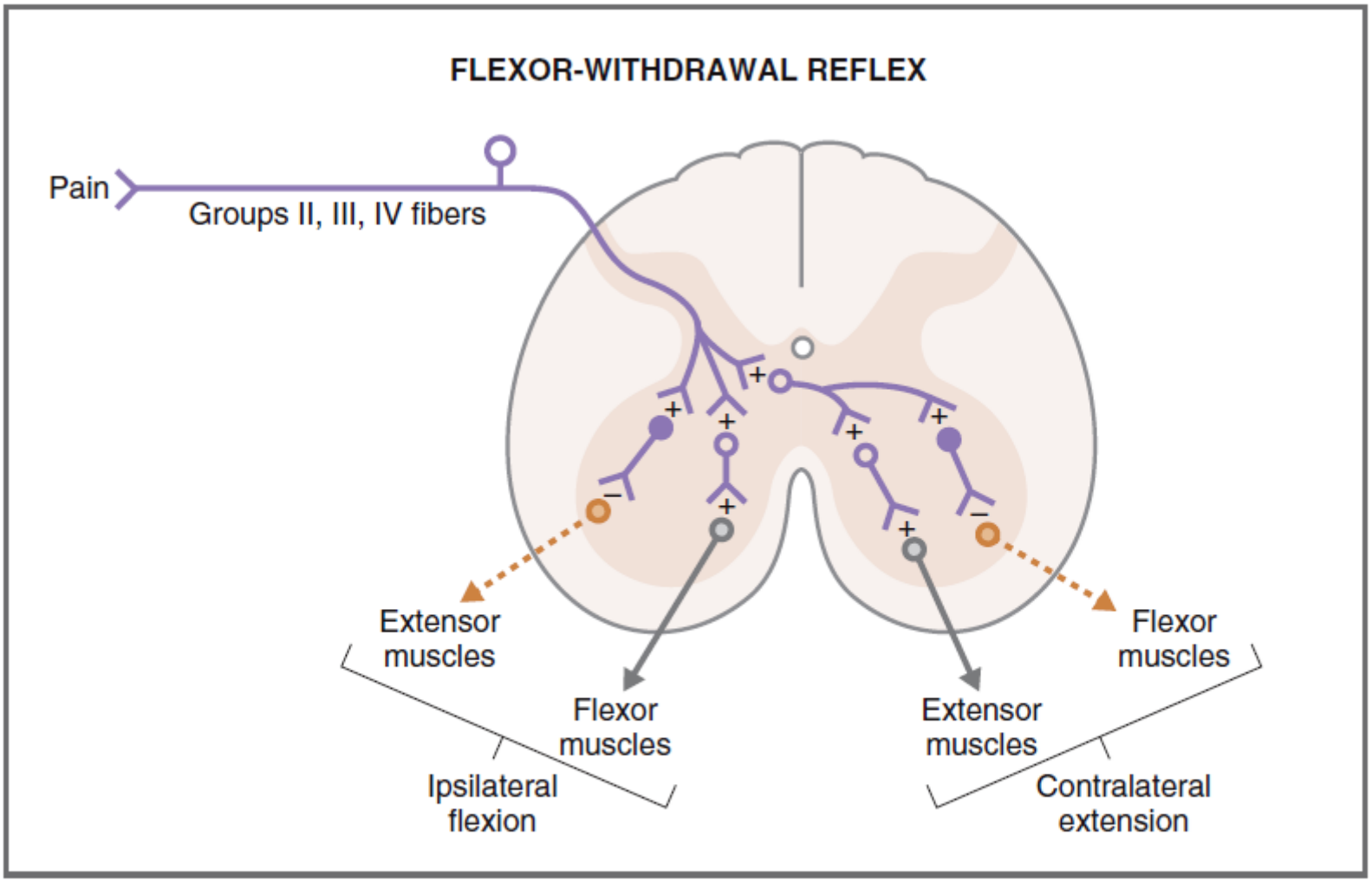
A. **Pain** (e.g., touching a hot stove) stimulates the flexor reflex afferents **of groups II, III, and IV.**
B. The afferent fibers synapse polysynaptically (via interneurons) onto motoneurons in the spinal cord.
C. On the **ipsilateral side** of the pain stimulus, flexors are stimulated (they contract) and extensors are inhibited (they relax), and the arm is jerked away from the stove. On the **contralateral side**, flexors are inhibited and extensors are stimulated (crossed extension reflex) to maintain balance.

- -the stimulus is noxious stimuli (after touching a hot stove)
- *the response is:
- - ipsilateral flexion by inhibition of extensor muscles and stimulation of the flexor muscles:

*حتى تبعد العضلة القريبة عن pain stimulus

- Contralateral extension bye stimulation of the extensor muscles and inhibition of the flexor muscles (crossed extension reflex):
- *To balance this rapid flexion in the ipsilateral side

3. Flexor withdrawal reflex



Operation of the flexor-withdrawal reflex. *Solid lines* show excitatory pathways; *dashed lines* show inhibitory steps. *Open* neurons are excitatory; *filled* neurons are inhibitory.