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A Simple and Consistent Rule for Easy Learning of Neuroanatomy: Three Neurons of Afferent Nerves

Una Regla Simple y Consistente para Facilitar el Aprendizaje de la Neuroanatomía: Tres Neuronas de los Nervios Aferentes

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SUMMARY: Many students regard neuroanatomy as a terrifying subject due to the complicated neuronal connections. Purpose of this research was to promote the easy and logical learning of neuroanatomy by systematizing a rule "three neurons of afferent nerves." The rule, in which the second neuron decussates and reaches the thalamus, was applied to as many structures as possible. The three neurons are drawn in a constant pattern to intuitively demonstrate the rule. The rule could be applied not only to the spinothalamic tract, medial lemniscus pathway, sensory cranial nerves (visual pathway, trigeminothalamic tract, taste pathway, and auditory pathway) and ascending reticular activating system, but also to the pontocerebellum (afferent to cerebrum), basal nuclei (direct pathway), and limbic system (medial limbic circuit). Exceptionally, some afferent nerves do not exactly follow the suggested rule. This simple rule, which corresponds to many pathways of the neuroanatomy, is expected to make the learning by novice students easier.

KEY WORDS: Neuroanatomy; Afferent neurons; Undergraduate medical education; Illustrated books.

NTRODUCCIÓN

Neuroanatomy is learned by countless students in the health science and bioscience fields. This is because neuroanatomy is the base of neurology, neurosurgery, neuroimaging, neurophysiology, neuropharmacology, and other related areas. Without neuroanatomy, one's understanding of neuroscience would be a house of cards (Wiertelak & Ramirez, 2008; Hazelton, 2011). Knowledge in neuroanatomy is usually accessed either from detailed books or various Internet sites such as Wikipedia (Wikipedia, 2022).

Regrettably, most students perceive neuroanatomy as a terrifying subject because of the vast amount and difficulty of the content. The representative overwhelming content is the extremely intricate neuronal connections (Flanagan *et al*., 2007; Lim & Seet, 2008; Javaid *et al*., 2018). Such neurophobia can be relieved by simple and consistent rules rather than complicated and inconsistent details.

The authors proposed a rule, named "three neurons of afferent nerves." The key of the rule is the second neuron, which decussates and reaches the thalamus. The commonsensical rule is potentially used in many chapters of neuroanatomy.

Purpose of this report was to enhance the easy and logical learning of neuroanatomy by introducing how the proposed rule is applied to various neuronal connections.

MATERIAL AND METHOD

The author tried to apply the rule "three neurons of afferent nerves" to as many structures as possible. Sometimes the first, second, and third neurons were intentionally numbered. The fitting pathways were summarized with the first, second, and third neurons in Table I.

In order to intuitively demonstrate the rule, the pathways were schematically drawn. In the schematics, the three swellings represented the cerebrum, thalamus, and

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brainstem that is continuous with the spinal cord. Among the three neurons of afferent nerves (blue color), only the second neurons were drawn with dotted lines. A head picture was added to indicate the viewing direction of each figure (Fig. 1).

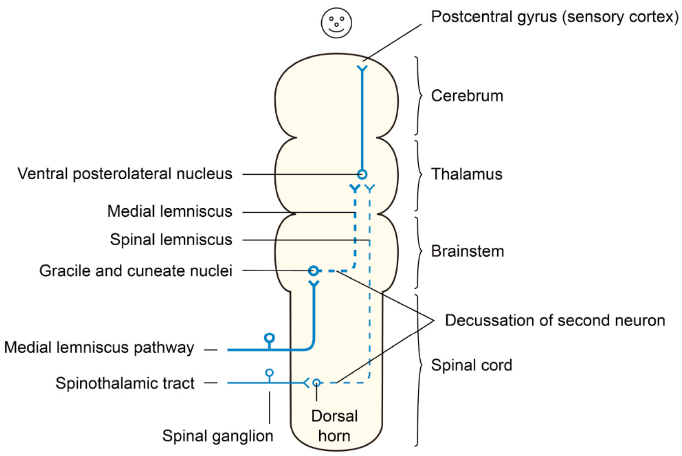

Fig. 1. Three neurons of spinothalamic tract and medial lemniscus pathway. After synapses with the first neurons, the second neurons (dotted line) of the spinothalamic tract and medial lemniscus pathway decussate and ascend to the ventral posterolateral nucleus of thalamus.

RESULTS

Spinothalamic tract, medial lemniscus pathway. The second neurons of the spinothalamic tract and the medial lemniscus pathway start at the dorsal horn in spinal cord and the gracile and cuneate nuclei in brainstem (specifically, medulla oblongata), respectively. In both cases, the second neuron decussates and ascends to the ventral posterolateral nucleus of thalamus. The ascending part of the second neuron is called lemniscus: the spinothalamic tract includes the spinal lemniscus, while the medial lemniscus pathway literally includes the medial lemniscus (Fig. 1) (Table I).

Sensory cranial nerves. In the visual pathway, the cone cell and rod cell are regarded as receptors. The first neuron's nerve cell body is not a ganglion but a nucleus, because the visual pathway belongs to the central nervous system. The first neuron is short and synapses with the second neuron, which leaves the eyeball to become the optic nerve. The second neuron partly decussates at the optic chiasm to arrive at the lateral geniculate nucleus of thalamus (Fig. 2) (Table I).

The sensory nerve of trigeminal nerve is called the trigeminothalamic tract. The first neuron has the trigeminal ganglion that integrates pain, temperature, and touch from the ophthalmic, maxillary, and mandibular nerves. It synapses with the second neuron in the principal sensory nucleus or the spinal nucleus. The second neuron from the nuclei decussates and ascends as the trigeminal lemniscus to end at the ventral posteromedial nucleus of thalamus. Very unusually, the first neuron carrying proprioception has the mesencephalic nucleus instead of the ganglion. It immediately synapses with the second neuron, which also decussates and ascends as the trigeminal lemniscus (Fig. 3) (Table I).

Concerning the taste pathway, the facial nerve has the geniculate ganglion while the glossopharyngeal and vagus nerves have the inferior ganglion. The first neuron synapses with the second neuron at the solitary nucleus of medulla oblongata. The second neuron does not decussate (not following the rule) and ascends as the central tegmental tract. The second neuron goes to the ventral posteromedial nucleus of thalamus (Fig. 4A), like the trigeminothalamic tract (Fig. 3).

In the auditory pathway, the second neuron originating from the cochlear nucleus may decussate on the pons or not; it then ascends as the lateral lemniscus until the inferior colliculus of midbrain. It is left out of account that the second neuron may make other synapses either in the superior olivary nucleus or in the lateral lemniscus. The third neuron extends from the inferior colliculus to the medial geniculate nucleus of thalamus. If the second and third neurons (dotted lines) were united, the auditory pathway would follow the general rule of afferent nerves having three neurons (Fig. 4B) (Table I).

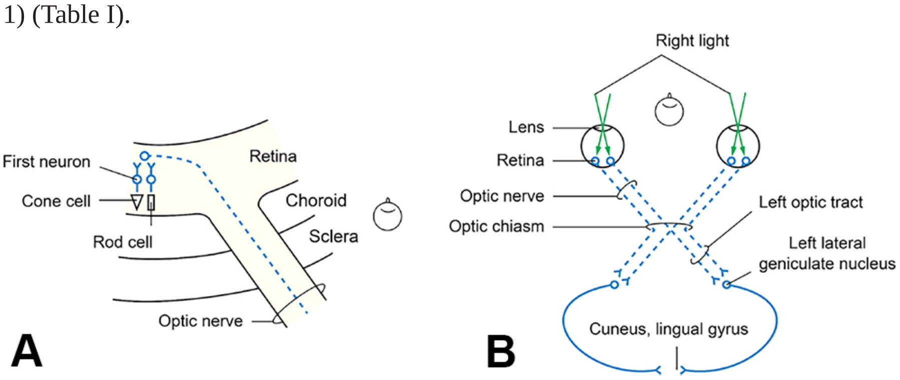

Fig. 2. Beginning part and whole part of visual pathway. In the beginning part (A) of visual pathway, the second neuron (dotted line) of visual pathway synapses with the first neuron in the retina to become the optic nerve. On optic chiasm in entire visual pathway (B), the second neuron partly decussates to arrive at the lateral geniculate nucleus of thalamus.

Table I. Three neurons of afferent nerves.

		First neuron		Second neuron		Third neuron	
Name	Sense	Start	Ganglion	Start	Decussation	Start	End
Spinothalamic tract	Pain, temperature	Free nerve ending	Spinal ganglion	Dorsal horn	Yes (spinal cord) (→spinal lemniscus)	Ventral posterolateral nucleus	Postcentral gyrus, paracentral lobule
Medial lemniscus pathway	Touch, proprioception	Encapsulated nerve ending	Spinal ganglion	Gracile, cuneate nuclei	Yes (caudal medulla oblongata) (→ medial lemniscus)	Ventral posterolateral nucleus	Postcentral gyrus, paracentral lobule
Optic nerve (visual pathway)	Vision	Cone, rod cells		Retina	Yes in half (optic chiasm) (→ optic tract)	Lateral geniculate nucleus	Cuneus, lingual gyrus
Trigeminal nerve (trigemino-thalamic tract)	Pain, temperature, touch	Face, etc.	Trigeminal ganglion	Principal sensory, spinal nuclei of CN V	Yes (spinal cord, brainstem) (→trigeminal lemniscus)	Ventral posteromedial nucleus	Postcentral gyrus
Facial nerve (taste pathway)	Taste	Taste bud	Geniculate ganglion	Solitary nucleus	No (→central tegmental tract)	Ventral posteromedial nucleus	Insula, etc.
Glossopharyngeal, vagus nerves (taste pathway)	Taste	Taste bud	Inferior ganglion	Solitary nucleus	No (→ central tegmental tract)	Ventral posteromedial nucleus	Insula, etc.
Cochlear nerve (auditory pathway)	Sound	Cochlear duct	Spiral ganglion	Cochlear nucleus	Yes in part (pons) (→ lateral lemniscus) (additional synapse in inferior colliculus)	Medial geniculate nucleus	Transverse temporal gyrus
Ascending reticular activating system	Consciousness	Body (whole)	Sensory ganglia (whole)	Reticular formation		Intralaminar nucleus	Cerebral cortex (whole)
Pontocerebellum (afferent to cerebrum)	Skilled movement	Purkinje cell		Dentate nucleus	Yes (midbrain)	Ventral lateral nucleus	Frontal lobe
Basal nuclei (direct pathway)	Appropriate movement	Striatum		Globus pallidus	No	Ventral lateral, ventral anterior nuclei	Frontal lobe
Limbic system (medial limbic circuit)	Memory, emotion	Hippocampus (→ fornix)		Mammilary body	No (→ mammillothalamic tract)	Anterior nucleus	Cingulate, parahippocampal gyri

Reticular formation. For the ascending reticular activation system, the first neuron in the cranial and spinal nerves synapses with the second neuron in the reticular formation of the brainstem. The second neuron ascends and synapses with the third neuron at the intralaminar nucleus of thalamus. The second neuron does not decussate (not following the rule), because the reticular formation is primitive and not well-organized (Fig. 4C) (Table I).

Cerebellum. Concerning the afferent nerve from the pontocerebellum to the cerebrum, the first neuron (Purkinje cell) approaches the dentate nucleus. The second neuron decussates and synapses at the ventral lateral nucleus of thalamus (Fig. 4D) (Table I).

Basal nuclei. In the direct pathway of basal nuclei, the first neuron starts from the striatum. The striatum receives preliminary neurons from the cerebral cortex and the substantia nigra of midbrain. The second neuron from the globus pallidus does not decussate (not following the rule) and goes to the ventral lateral nucleus and ventral anterior nucleus of thalamus (Fig. 5A) (Table I).

Limbic system. With regard to the limbic system, the first neuron starts at the hippocampus, runs as the fornix, and synapses with the second neuron at the mammillary body. The second neuron does not decussate (not following the rule) and goes to the anterior nucleus of thalamus. The third neuron goes to the cingulate gyrus and parahippocampal gyrus that are parts of the cerebral cortex (Table I). In succession, the neuron proceeds from the parahippocampal gyrus to return to the hippocampus, which is regarded as the preliminary neuron. In total, the pathways constitute the medial limbic circuit (Papez circuit) (Fig. 5B).

Thalamus as a summary of the afferent nerves. In the proposed rule, the second neurons of afferent nerves go to the thalamus. Therefore, all afferent nerves can be summarized in the thalamus

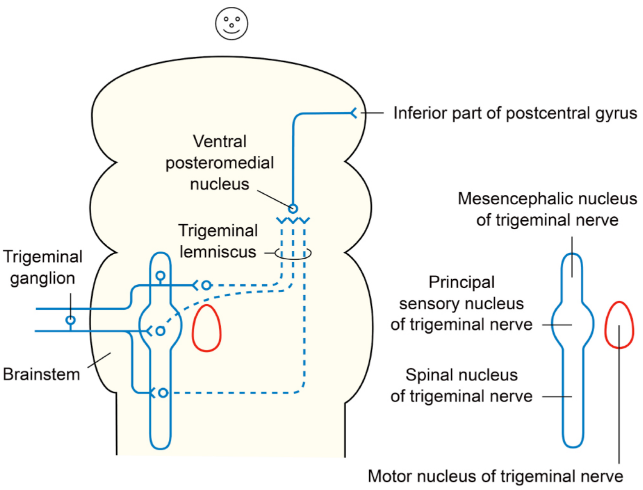

Fig. 3. Three neurons and nuclei of trigeminothalamic tract. After synapse with the first neuron of the trigeminothalamic tract, the second neuron (dotted line) decussates and ascends as the trigeminal lemniscus to end at the ventral posteromedial nucleus of thalamus.

(Sherman & Guillery, 2006) (Fig. 6) as follows. Intralaminar nucleus is the place where ascending reticular activating system passes (Fig. 4C). The lateral and medial geniculate nuclei receive the visual pathway (Fig. 2) and auditory pathway (Fig. 4B), respectively (Table I).

Regarding the remaining nuclei, the more "cranial" (anterior) nucleus, the more "cranial" structures (or pathways) are related (Fig. 6) as follows. The ventral posterolateral nucleus is for spinal nerve (spinothalamic tract, medial lemniscus) (Fig. 1). The ventral posteromedial nucleus is for trigeminal nerve (trigeminothalamic tract) (Fig. 3) and for facial, glossopharyngeal, vagus nerves (taste pathway) (Fig. 4A). The ventral lateral nucleus is for pontocerebellum (Fig. 4D). The ventral lateral and ventral anterior nuclei are for basal nuclei (direct pathway) (Fig. 5A). The anterior nucleus is for limbic system (medial limbic circuit) (Fig. 5B) (Table I).

The third neurons from the thalamus go to the allocated cerebral cortex as follows. Neurons from most nuclei (sensory nerve) go to the parietal, occipital, and temporal lobes (Figs. 1-3, 4B). Neurons from the ventral lateral and ventral anterior nuclei (cerebellum, basal nuclei) go to the frontal lobe (Figs. 4D, 5A). Neurons from the anterior nucleus (limbic system) go to the cingulate and parahippocampal gyri (Fig. 5B) (Table I).

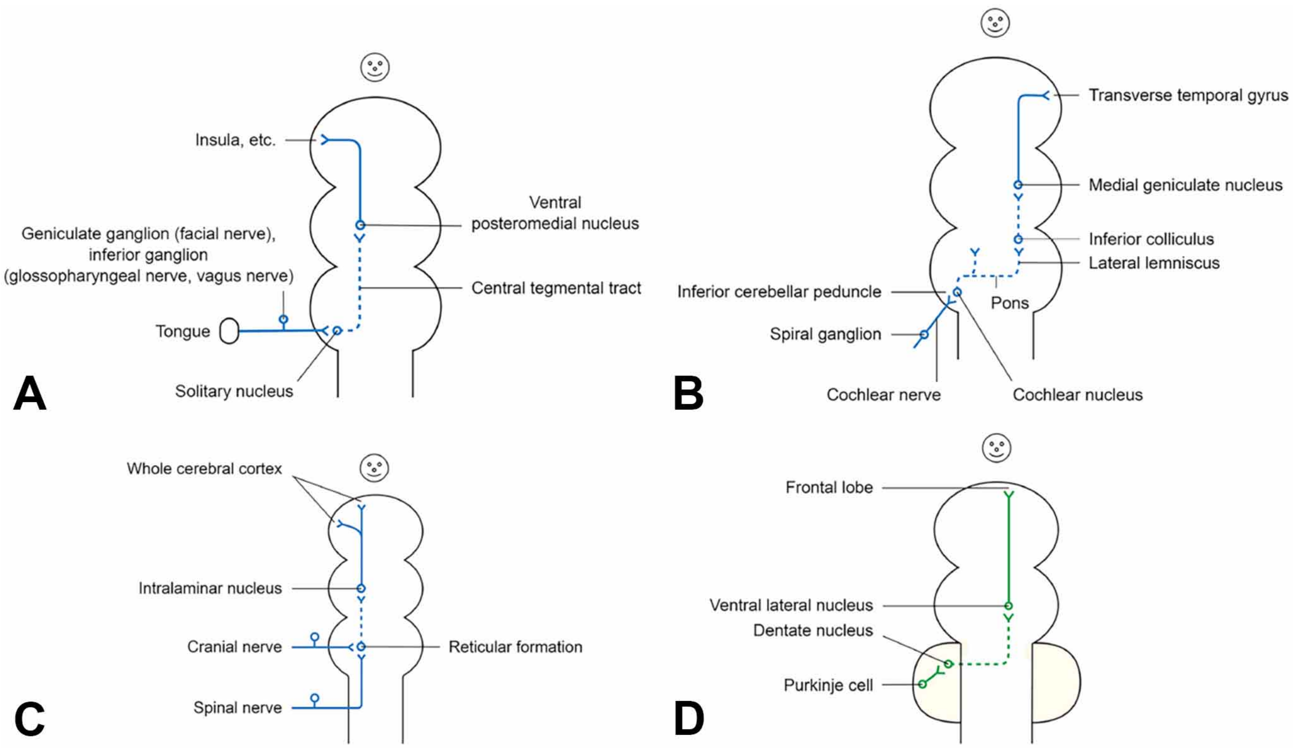

Fig. 4. Three neurons of four afferent nerve pathways. In the taste pathway (A), its second neuron (dotted line) does not decussate in the brainstem. In auditory pathway (B), its second neuron (dotted line) partly decussates in the brainstem. The third neuron is also drawn with dotted line in (B). In the ascending reticular activation system pathway (C), its second neuron (dotted line) does not decussate. In the pathway of the pontocerebellum (D), its second neuron (dotted line) decussates.

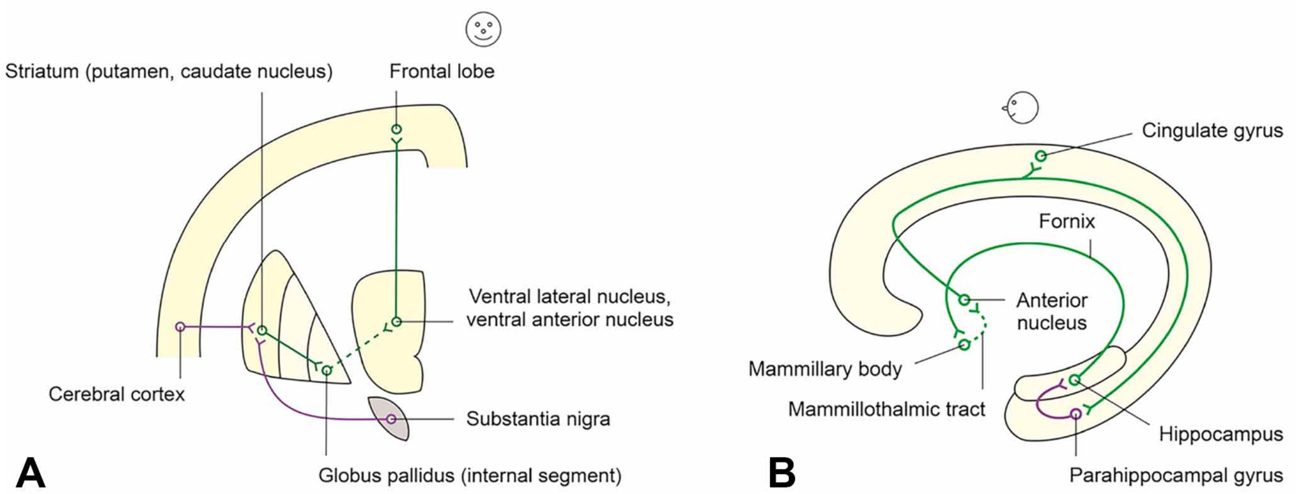

Fig. 5. Direct pathway of the basal nuclei and medial limbic circuit. In the direct pathway of the basal nuclei (A), the second neurons (dotted line) from globus pallidus do not decussate and goes to the ventral lateral nucleus and ventral anterior nucleus of thalamus. In the medial limbic circuit (B), the second neuron (dotted line) does not decussate and goes to the anterior nucleus of thalamus.

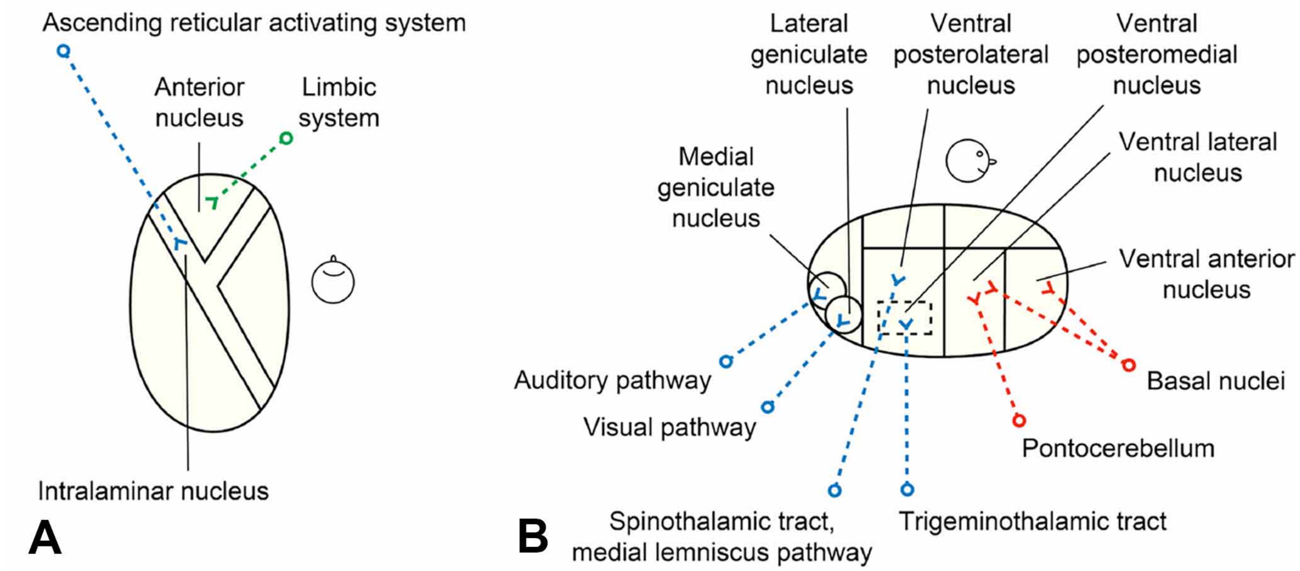

Fig. 6. Afferent nerves to the thalamus. In the horizontally (A) and sagittally (B) sectioned schematics of thalamus, afferent nerves and related thalamic nucleus are summarized.

DISCUSSION

The rule "three neurons of afferent nerves" is mostly consistent in various chapters of neuroanatomy. Originally, the rule had been called "three neurons of sensory nerves." The name is appropriate in the spinothalamic tract, medial lemniscus pathway (Fig. 1), sensory cranial nerves (Figs. 2, 3, 4A, 4B), and reticular formation (Fig. 4C). However, the name is not appropriate in the case of the pontocerebellum (Fig. 4D), basal nuclei (Fig. 5A), and limbic system (Fig. 5B). The name was then changed to "three neurons of afferent nerves" (Table I).

To maintain simplicity and consistency, the first, second, and third neurons have been artificially numbered. In the case of the visual pathway, the authors defined the neuron exiting the retina as the second neuron, because it partially decussates and goes to the thalamus. Consequently, the neuron from the cone or rod cell becomes the first neuron (Fig. 2). In the case of the auditory pathway, the four neurons were hypothetically simplified into the three neurons by uniting two neurons (Fig. 4B). Additionally, in the complicated pathways, the three neurons were intentionally highlighted. In the pathway of the pontocerebellum, the three afferent neurons to the frontal lobe are emphasized (Fig. 4D). In the direct pathway of the basal nuclei and the medial limbic circuit, the preliminary neurons are defined (Fig. 5). The deliberate numbering for simplicity and consistency helps beginners understand the big picture of neuroanatomy (Table I).

The suggested rule has exceptions. For example, the second neuron may not decussate in many cases (Figs. 2, 4A, 4B, 4C, 5). Moreover, the rule's incompleteness has been hidden. For example, in the auditory pathway, the nucleus of lateral lemniscus for additional synapse is not illustrated because the detailed description becomes more distant from the rule (Fig. 4B). After all, the rule needs to be supplemented with other neuroanatomy books or other learning contents having more detail. The supplementation can be achieved during the neuroanatomy course or subsequent courses such as neurophysiology, neurology, and neurosurgery (Estes, 2007; Arantes *et al*., 2020).

In our proposal, the rule is accompanied by the simple and consistent drawings where the cerebrum, thalamus, and brainstem are depicted with three swellings and the cerebellum is depicted as semicircles beside the brainstem. That would be the new, effective symbolization of the central nervous system (Figs. 1, 3, 4). It is hoped that the drawings are not confused with the conventional drawing of the forebrain, midbrain, and hindbrain. In addition, neurons are drawn in the same pattern, including dotted lines for the second neurons.

Such highly simplified drawings have pros and cons. The drawings are like rough maps for first visitors. Students are expected to easily redraw the illustrations, which is helpful for memorization (McLachlan, 2004; Ainsworth *et al*., 2011; Alsaid & Bertrand, 2016). The problem is that the drawings are not true. For example, in the auditory pathway, the neuron from the inferior colliculus to the medial geniculate nucleus (the inferior brachium) is not vertical in reality (Fig. 4B). Nonetheless, the simplified drawings and consistent rule would be suitable for anatomy course having short duration which is a global trend (Chung *et al*., 2020). Comparing the schematic figures to the realistic ones and cadaveric specimens is mandatory for gaining accurate insight.

After being acquainted with the rule "three neurons of afferent nerves," another rule "two neurons of efferent nerves" can be easily comprehended. The representative example is the corticospinal tract that is composed of the upper and lower motor neurons. It implies that the rule can be expanded to get better understanding of neuroanatomy.

The limitation of the present study is that it did not prove the learning effect of the suggested rule. So as to prove it, a suitable experiment including a questionnaire survey on the rule is required in a future study.

The simple and consistent rule "three neurons of afferent nerves" shown in the schematic figures and table is expected to contribute to neuroanatomy learning. It is like the well-known rule "sulcus limitans" that systematically demarcates the motor and sensory nuclei in the brainstem and spinal cord (Carlson, 2013; Moore *et al*., 2015). Such rules need to be devised and applied more in order to facilitate organized learning of neuroanatomy.

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RESUMEN: Muchos estudiantes consideran la neuroanatomía como un tema aterrador debido a las complicadas conexiones neuronales. El propósito de esta investigación fue promover el aprendizaje fácil y lógico de la neuroanatomía mediante la sistematización de una regla "tres neuronas de los nervios aferentes". La regla, en la que la segunda neurona se decusa y llega al tálamo, se aplicó a todas las estructuras cuando esto fue posible. Las tres neuronas se dibujan en un patrón constante para demostrar la regla intuitivamente. La regla podría aplicarse no solo al tracto espinotalámico, la vía del lemnisco medial, los nervios craneales sensoriales (vía visual, tracto trigeminotalámico, vía gustativa y vía auditiva) y el sistema de activación reticular ascendente, sino también al pontocerebelo (aferente al cerebro), núcleos basales (vía directa) y sistema límbico (circuito límbico medial). Excepcionalmente, algunos nervios aferentes no siguen exactamente la regla sugerida. Se espera que esta simple regla, que corresponde a muchas vías de la neuroanatomía, facilite el aprendizaje de los estudiantes principiantes.

PALABRAS CLAVE: Neuroanatomía; Neuronas aferentes; Educación médica de pregrado; Libros ilustrados.

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