

Anatomy and evolution of accessory nerve: cranial or spinal origins? – A review

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Abstract

The accessory nerve is traditionally described as having both spinal and cranial roots, with the spinal root originating from the upper cervical segments of the spinal cord and the cranial root originating from the dorsolateral surface of the medulla oblongata. The spinal and cranial rootlets converge before entering the jugular foramen or within it. This conventional view has been challenged by finding no cranial contribution to the accessory nerve. Clinical, anatomical, functional and evolutionary implications are discussed in the present study.

Keywords: accessory nerve, spinal root, cranial root.

1 Introduction

1.1 Brain stem

Although we are accustomed to thinking that human behavior originates mainly in the forebrain, many complex human responses, such as feeding, are made up of relatively simple, stereotyped motor responses governed by the brain stem. The brain stem and the motor and sensory components of the spinal cord are similar in structure. However, the portions of the brain stem related with the cranial nerves are much more complex than the corresponding portions of the spinal cord concerned with the spinal nerves, because the cranial nerves mediate more complex regulatory systems. The study of cranial nerves is an important part of the neurological examination because abnormalities of function can indicate the site in nervous system that has been damaged or injured. Therefore, it is important to know the origins of the cranial nerves, their intracranial course, and where they exit from the skull (KANDEL, SCHWARTZ and JESSELL, 2000).

1.2 Cranial nerves

In addition to the paired spinal nerves, the peripheral nervous system of vertebrates includes paired cranial nerves. Cranial nerves are traditionally numbered I-XII in rostrocaudal sequence (Figure 1). Each cranial nerve exits the brain stem at a characteristic location. Most exit in numerical order from the ventral surface of the brain stem. Some of the nerves (e.g., optic nerve) contain only sensory axons, which carry signals to the brain. Others contain sensory and motor axons, and are termed mixed nerves. For example, the vagus nerve has sensory axons leading to the brain as well as motor axons leading to the heart and smooth muscles of the

visceral organs in the thorax and abdomen (MILLER and HARLEY, 2001).

Understanding the organization of the cranial nerves and the rationale for their classification depends on an appreciation of the segmental nature of the brain and head and of the embryonic derivation of the nerves, their ganglia, and the structures that they innervate. Questions that have been debated for a long time are whether or not the brain and other tissues of the head are in fact developed in a segmental fashion and, if so, which structures are within each segment. Each segment of the spinal cord has dorsal and ventral pairs of spinal nerves that innervate each successive segment of the body, but the segmental organization of the brain has not been as easily understood (BUTLER and HODOS, 2005).

Some authors (PURVES, AUGUSTINE, FITZPATRICK et al., 2004; FOX, 2003) have described the cranial nerves fairly brief, these descriptions usually are outlined in tables and not made detailed descriptions of each nerve. The example is the accessory nerve (CN XI), which according to some authors (MOORE and DALLEY, 2007; GARDNER, GRAY and O'RAHILLY, 1988), have roots only in the spinal cord and is responsible only for the innervations of muscles neck and shoulders. However, other authors (SNELL, 2003; CARNEIRO, 2004; MILLER and HARLEY, 2001; GUTHRIE, 2007) describe the CN XI with the spinal root (innervations of muscles neck and shoulders) and cranial root (innervations of the muscles of the larynx and palate) (Table 1). Therefore, the purpose of this review is to discuss some clinical, anatomical, functional and evolutionary implications that may elucidate this paradigm.

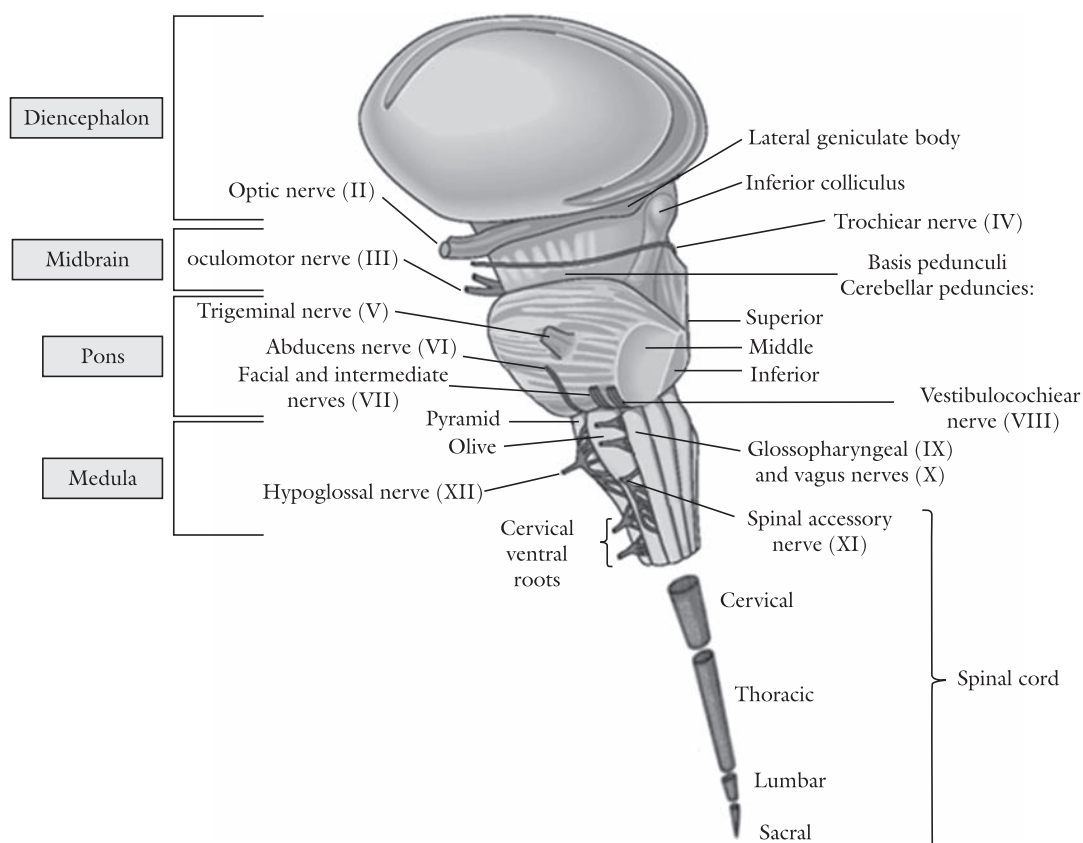


Figure 1. A lateral view of the brain stem illustrating the location of the cranial nerves. The olfactory nerve (I) is not shown because it terminates in the olfactory bulb in the cerebral hemispheres (Adapted from KANDEL, SCHWARTZ and JESSELL, 2000).

2 Material and methods

For the preparation of this paper were consulted scientific articles published in English and textbooks. The articles were accessed from a basic search in the *PubMed* database (<http://www.ncbi.nlm.nih.gov/pubmed/>), using terms like “accessory nerve”, “spinal root” and “cranial root”.

3 Results

3.1 Clinical significance

Knowledge of anatomy of the CN XI is important for surgical interventions in the anterior and posterior triangle of the neck. The integrity of CN XI prevents anatomical deformities and mobility dysfunctions that occur when the CN XI is injured during neck dissections, as Inoue, Nibu, Saito et al. (2006) have shown. Nahum, Mullally and Marmor (1961), described the “shoulder syndrome” which consists of pain in the shoulder joint, limitation to active abduction of the shoulder, absence of limitation to passive mobilization of the shoulder and dropping of the shoulder. Given this, surgical techniques based on the anatomic parameters of the aponeurotic system of the neck have become more popular to preserve CN XI during neck dissections (BOCCA and PIGNATARO, 1967).

The CN XI is purely a motor nerve, which originates from motor neurons in the upper cervical spinal cord. It innervates the trapezius and sternocleidomastoid muscles.

The sternocleidomastoid is the only muscle in the body whose action is toward the opposite side of space (it turns the head to the opposite side). Thus an injury of the right XI nerve causes weakness of turning the head to the left. In contrast, a cortical lesion causing weakness of the entire right side of the body will involve the left sternocleidomastoid (because the left cerebral cortex is related with movement toward the right side of the body). The sternocleidomastoid is the only muscle with this predominantly ipsilateral cortical control (KANDEL, SCHWARTZ and JESSELL, 2000).

The most common cause of isolated accessory nerve palsy is iatrogenic injury, often incurred during biopsy of a lymph node lying at the posterior border of the sternocleidomastoid muscle. The mild motor impairment or shoulder pain on movement are generally not noticed by the patient until a few weeks later, when he or she begins to use the arm again. The findings include a shoulder drop, a scapular tilt, and atrophy of the upper portion of the trapezius, without any sensory deficit and with preserved function of the sternocleidomastoid muscle. Accessory nerve palsy can also be due to anomalies of the craniocervical junction, tumors at the foramen magnum, and the jugular foramen syndrome. In such cases, it is accompanied by other neurologic findings (MUMENTHALER and MATTLE, 2004).

3.2 Anatomical and evolutionary aspects of CN XI

The length of the CN XI in the posterior triangle of the neck is the most commonly studied measurement of the CN XI.

Table 1. The cranial nerves and their primary functions (Extracted from Miller and Harley (2001)).

Nerve	Type	Innervation and function
I Olfactory	Sensory	Smell
II Optic	Sensory	Vision
III Oculomotor	Primarily motor	Eyelids, eyes, adjustments of light entering eyes, lens focusing (motor)
IV Trochlear	Primarily motor	Condition of muscles (sensory) Eye muscles (motor)
V Trigeminal	Mixed	Condition of muscles (sensory)
Ophthalmic division		Eyes, tear glands, scalp, forehead, and upper eyelids (sensory)
Maxillary division		Upper teeth, upper gum, upper lip, lining of the palate, and skin of the face (sensory)
Mandibular division		Scalp, skin of the jaw, lower teeth, lower gum, and lower lip (sensory)
VI Abducens	Primarily motor	Jaws, floor of the mouth (motor) Eye muscles (motor)
VII Facial	Mixed	Condition of muscles (sensory) Taste receptors of the anterior tongue (sensory) Facial expression, tear glands, and salivary glands (motor)
VIII Vestibulocochlear	Sensory	Equilibrium; vestibule Hearing; cochlea
Vestibular branch		
Cochlear branch		
IX Glossopharyngeal	Mixed	Pharynx, tonsils, posterior tongue, and carotid arteries (sensory) Pharynx and salivary glands (motor)
X Vagus	Mixed	Speech and swallowing, heart, and visceral organs in the torax and abdomen (motor) Pharynx, larynx, esophagus, and visceral organs of the torax and abdomen (sensory)
XI Accessory	Motor	Soft palate, pharynx, and larynx
Cranial branch		
Spinal branch		Neck and back
XII Hypoglossal	Motor	Tongue muscles

Using ultrasonography, Kessler and Gray (2007) estimated the length of the CN XI in the posterior triangle of the neck at 3.5 cm in 18 healthy adult volunteers. In a cadaveric study, Lu, Haman and Ebraheim (2002) reported that the length of the CN XI in the posterior triangle was 3.47 cm. Studying 30 cadavers, Tubbs, Salter, Wellons et al. (2005) also found the mean length of the CN XI in the posterior triangle of 3.5 cm (ranging from 2 to 5 cm).

The traditional description of the CN XI is that it consists of both a spinal and cranial root. The spinal part arises as a series of rootlets from the lateral aspect of the upper cervical spinal cord as low as the sixth cervical nerve and forms a distinct nerve trunk that travels through the foramen magnum (ROMANES, 1979; STANDRING, 2005). Then, it runs superolaterally along the base of the posterior cranial fossa to enter the posterolateral dural perforation of the jugular foramen, along with the vagus nerve (CN X). In the jugular foramen, the spinal part of CN XI lies posterior to CN X and anteromedial to the jugular bulb in its own connective tissue sheath (AYENI, OHATA, TANAKA et al., 1995; BERRY, BANNISTER and STANDRING, 1995).

The cranial part of the accessory nerve arises as four or five rootlets from the postolivary groove of the dorsolateral medulla, caudal to the rootlets of CN X (AYENI, OHATA, TANAKA et al., 1995; LACHMAN, ACLAND and ROSSE, 2002). The cranial rootlets have been described as coalescing with the spinal part of CN XI at variable points,

either before entering the jugular foramen or within the jugular foramen itself (ROMANES, 1979; AYENI, OHATA, TANAKA et al., 1995; STANDRING, 2005).

After uniting and crossing the jugular foramen, the accessory nerve has been described as dividing into external and internal branches (AYENI, OHATA, TANAKA et al., 1995; BERRY, BANNISTER and STANDRING, 1995). The external branch is principally made up of fibres from the spinal part of the accessory nerve; it travels down through the neck to innervate the sternocleidomastoid and trapezius muscles. The internal branch is composed of fibers from the cranial part of the accessory nerve; it branches off the main trunk of CN XI and connects to the vagus at approximately the level of the upper border of the transverse process of the atlas (AYENI, OHATA, TANAKA et al., 1995) (Figure 2). It contributes to the motor supply of the branchiomeric muscles via the pharyngeal and laryngeal branches of the vagus nerve and also carries parasympathetic fibers (ROMANES, 1979; CALIOT, BOUSQUET, MIDY et al., 1989; AYENI, OHATA, TANAKA et al., 1995; STACEY, O'LEARY and HAMLYN, 1996; GARDINER, IRVINE and MURRAY, 2002; STANDRING, 2005).

In a study of 15 cadavers by Lachman, Acland and Rosse (2002), this traditional description was challenged. It was found that there was no distinct cranial portion of the accessory nerve. In all studied cases, the cranial portion of the traditionally described CN XI made no connection with

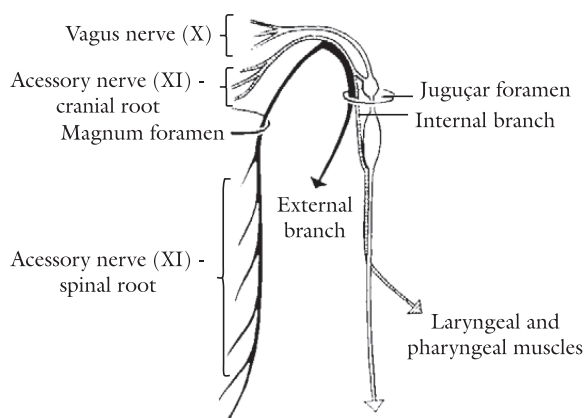


Figure 2. Schematic representation of the relationship of the accessory nerve with the vagus nerve (Extracted from GARDNER, GRAY and O'RAHILLY, 1988).

the spinal accessory nerve either before entering or within the jugular foramen. Instead, it was found that the widely spaced caudal posterior medullary rootlets of the cranial part merged with other rootlets from the medulla, which, in turn, formed the vagus nerve within the jugular foramen (LACHMAN, ACLAND and ROSSE, 2002).

Connections and considerable variations have been reported in the anatomy of the glossopharyngeal, vagus and accessory nerves rostral to the jugular foramen, within the foramen and caudal to the foramen (STACEY, O'LEARY and HAMLYN, 1996; BROWN, HIDDEN, LEDROUX et al., 2000; GARDINER, IRVINE and MURRAY, 2002). The course and peripheral distribution of CN X and CN XI in the neck have been reported extensively (ROMANES, 1979; HOLLINSHEAD, 1982; KRAUSE, BREMERICH and HERRMANN, 1991; STANDRING, 2005).

According to Kandel, Schwartz and Jessell (2000), the CN XI can be considered a cranial nerve anatomically, but is really a spinal nerve, originating from the higher cervical motor rootlets that innervates the trapezius and sternocleidomastoid muscles in the neck (Figure 3).

The cranial root of the CN XI has been traditionally described as a partner of the spinal root of the accessory nerve. Other results (KITAMURA, OKUBO, OGATA et al., 1987; LACHMAN, ACLAND and ROSSE, 2002) strongly suggest that this description is no longer valid, because no connections were found between the two roots in the majority of cases studied. Thus, these combined results reinforce the view that the cranial part of the accessory nerve should actually be regarded as a portion of the vagus nerve (BRODAL, 1981; HOLLINSHEAD, 1982; KITAMURA, OKUBO, OGATA et al., 1987; BUTLER and HODOS, 2005). This view is also reinforced by the separate peripheral distributions of the vagus and spinal accessory nerves and by the separate locations of their parent cell bodies in nucleus ambiguus and upper cervical spinal cord gray matter, respectively. The cranial accessory root has a peripheral distribution similar to that of the vagus nerve and very different from that of the spinal accessory root. The cranial accessory root fibers form the internal ramus of the accessory nerve and then join the vagus nerve to supply the branchiomeric muscles

via its pharyngeal and laryngeal branches, whereas the spinal accessory root fibers form the external ramus and then innervate the sternocleidomastoid and trapezius muscles (ROMANES, 1979; HOLLINSHEAD, 1982; BIEGER and HOPKINS, 1987; AYENI, OHATA, TANAKA et al., 1995; CALIOT, BOUSQUET, MIDY et al., 1989; STACEY, O'LEARY and HAMLYN, 1996; GARDINER, IRVINE and MURRAY, 2002; STANDRING, 2005).

In rabbits, the cell bodies of origin of accessory root fibers, together with cells bodies of origin of fibers of the vagus and glossopharyngeal nerves, are located in the dorsal motor nucleus of the vagus nerve and the nucleus ambiguus, with the former neurons extending more caudally than the latter, but with a partial overlap in rostrocaudal distribution (KITAMURA, OKUBO, OGATA et al., 1987; KITAMURA, NISHIGUCHI, OGATA et al., 1989). However, cell bodies of origin of fibers in the spinal accessory root form the spinal accessory nucleus from the first to the sixth cervical segments (NISHIGUCHI, KITAMURA, OKUBO et al., 1986), which occupies a position different from that of both the dorsal motor nucleus of the vagus and the nucleus ambiguus. These observations suggest that, in humans, likewise, the cell bodies of origin of the cranial accessory root fibers are likely to occupy a position similar to that of the origin of vagal fibers, being very different from that of spinal accessory nucleus.

These descriptions corroborate the evolutionary description of CN XI. Reptiles, birds, and mammals have 12 pairs of cranial nerves. Fishes and amphibians have only the first 10 pairs (MILLER and HARLEY, 2001). The absence of CN XI in fish and amphibians may explain the limitation of neck movement in these animals. The emergence of this nerve and the muscles associated with it may have privileged reptiles, birds and mammals in the preparation of neck movements. Thus, the accessory nerve really would be associated only to the movements of the neck; and the muscles of the pharynx and larynx was associated with the CN X, which is, in evolutionarily terms, more primitive.

Still regarding the evolutionary aspects of CN XI, according to Moyes and Schulte (2010), it is absent in fish, except in Crossopterygian. The subclass Crossopterygian is a group of fish with pectoral fins and pelvic articulated, supported by an internal skeleton. It is believed that they could rely on the land with their fins and walk the bottom of rivers and lakes. This peculiar mode of handling them would have allowed raids on the mainland in search of food. Gradually adapted to conditions of the air, their fins evolved, becoming articulate locomotion possible. Changes in the structure of fins helped these fish to move around the earth (PURVES, SADAVA, ORIONS et al., 2002). However, these changes needed for more complex movements of the neck for a better exploitation of the land environment, such as muscles that would aid in breathing cycles. Maybe that's when the CN XI appeared with the aim of controlling the muscles of neck (e.g., sternocleidomastoid), which also aid in inspiratory function (WILLIAMS, WARWICK, DYSON et al., 1995).

In the evolutionary developmental sense, the vertebrate neck can be defined as the domain of the cucullaris and hypobranchial muscle systems attached to either the branchial arch skeleton or the pectoral girdle, along with the contribution of cephalic crest cells (i.e. circumpharyngeal

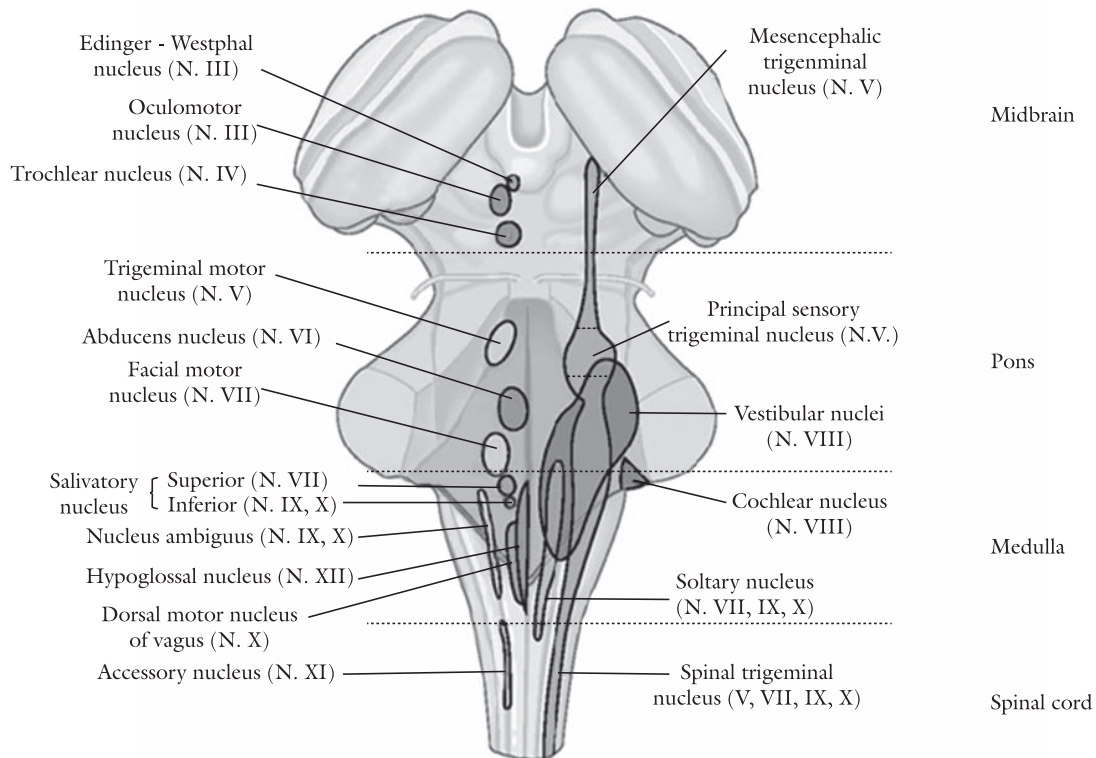


Figure 3. This dorsal view of the brain stem shows the organization of the cranial nerve sensory columns (right) and motor columns (left) (Adapted from KANDEL, SCHWARTZ and JESSELL, 2000).

crest cells), which produce connective tissue. The term cucullaris muscle is a general name referring to a gnathostome-specific muscle that is a homologue of sternocleidomastoid and trapezius muscles in mammals. Derived from some rostral somites and innervated by cervical spinal nerves, the cucullaris is primarily a somitic trunk muscle, as are typical skeletal muscles. However, this muscle is innervated by the CN XI (which is also missing in cyclostomes) that appears as a branch of the vagus nerve, and this muscle is often mistakenly interpreted as a branchial arch muscle (KURATANI, 2008).

Kuratani (2008) describes in his review that the appearance of CN XI contributed to the formation the vertebrate cucullaris muscle and that these are interconnected (or evolutionarily and developmentally coupled) to each other under the context of the evolution and development of the “neck” in gnathostomes.

It's interesting to note that the cells of origin of the spinal accessory root are not ventral horn motor neurons, but motor neurons lying more dorsolaterally in the spinal gray matter. More rostrally, this position is occupied by cells in nucleus retroambiguus, whose axons, like those of the spinal accessory motor neurons more caudally, exit the brain stem laterally (WILD, JOHNSTON and GLUCKMAN, 1991). The implication of this is that, if a spinal nerve is defined in terms of dorsal and ventral roots, then the spinal accessory nerve cannot be considered a true spinal nerve. Its only claim to being a cranial nerve is its transit through the foramen magnum and its brief course though the cranium.

4 Conclusion

The knowledge of the route of accessory nerve and its relations with the adjacent anatomic structures facilitates determination of the exact cause of injury and allows a safe surgery. Finally, this review shall be important for clinicians, surgeons and academicians who handle this particular anatomical site.

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Received January 12, 2011
Accepted October 31, 2011