Functional anatomy of the accessory nerve studied through intraoperative electrophysiological mapping

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OBJECTIVE Classically the 11th cranial nerve (CN XI, or accessory nerve) is described as having a cranial and a spinal root, the latter arising from the upper segments of the spinal cord through a number of very fine rootlets. According to classical knowledge, the cranial root gives motor innervation to the vocal cords, whereas the spinal root provides the motor innervation of the sternocleidomastoid muscle (SCM) and of the upper portions of the trapezius muscle (TZ). The specific function of each of the rootlets of the spinal component is not well known. Therefore the authors aimed to map, using intraoperative direct electrical stimulation and electromyographic (EMG) recordings, the innervation territory of these rootlets in relation to their exit level from the CNS.

METHODS Forty-nine patients undergoing surgery with intradural exposure at the craniocervical junction were enrolled in the study. The EMG recordings included the sternal and clavicular parts of the SCM (SCM-S and SCM-C), the superior and middle parts of the TZ (TZ-S and TZ-M), and whenever possible the vocal cords. The main trunk of CN XI, its roots (both cranial and spinal), and when possible the fine cervical rootlets, were stimulated at predetermined locations, from the jugular foramen down to the lowest cervical level exposed. The EMG responses were collected, and a map of the responses was drawn up.

RESULTS Monitoring and stimulation of the spinal root were performed in all cases, whereas for the cranial root this was possible in only 19 cases. A total of 262 stimulation sites were explored: 70 at the common trunk of the nerve, 19 at the cranial root, 136 at various levels on the spinal root, and 37 at the cervical rootlets. A vocal cord response was obtained by stimulation of the cranial root in 84.2% (16/19); absence of response was considered to have a technical origin. In no case did the vocal cords respond to the stimulation of the spinal root or rootlets. Stimulation of the cervical rootlets yielded responses that differed according to the level of stimulation: at C-1 the SCM-S responded 95.8% of the time (23/24); at C-2 the SCM-C responded 90.0% of the time (9/10); at C-3 the TZ-S responded 66.6% of the time (2/3); and below that level only the TZ-M responded. The spinal root stimulated at its various levels responded accordingly.

CONCLUSIONS The function of each of the rootlets of CN XI appears to be specific. The cranial root contributes, independently of the spinal root, to the innervation of the vocal cords, which makes it a specific entity. The spinal root innervates the SCM and TZ with a cranio-caudal motor organization of its cervical rootlets.

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KEY WORDS intraoperative neurophysiology; accessory nerve; neuroanatomy; craniovertebral junction; cranial nerve; peripheral nerve
Intradural exposure of the nerve is performed during craniovertebral junction surgeries in patients who have apparently normal anatomy and function of the nerve also constituted malformations of the nervous system, such as Chiari malformation Type II and his coworkers had performed stimulations during intradural rhizotomies for spasmodic torticollis, they did not publish data on systematic mapping of the spinal root. Interestingly, clinical observations of dissociated deficits of the trapezius muscle (TZ) and sternocleidomastoid muscle (SCM) in patients with high cervical lesions favor a cranio-caudal organization of the nerve in such a way that it can be postulated that intrinsic functional differences between the various components of the nerve exist. These functional differences would be in accordance with data from developmental studies suggesting segregated maturation pathways for neurons of the cranial and the spinal root.

The present study attempts to describe the myotopic organization of CN XI through electromyographic (EMG) mapping, when intradural exposure of the nerve is performed during craniovertebral junction surgeries in patients who have apparently normal anatomy and function of the nerve.

Methods
Patient Selection
All adult patients undergoing surgery between November 2009 and March 2013 at the craniocervical junction with intradural exposure allowing access to CN XI, and with an apparently normal function of the nerve, were considered candidates. The study protocol was approved by the institutional ethics committee and informed consent was signed by each enrolled patient.

Exclusion criteria were all situations that potentially changed the normal morphology of the nerve, such as tumor invasion of lower CNs, or intrinsic malformations of the nervous system, such as Chiari malformation Type II (CM-II). Factors such as neuropathies that may have influenced the normal function of the nerve also constituted exclusion criteria.

Systematic clinical examination of every muscle group was performed in all patients to verify that there was no deficit. When doubt was raised, an EMG examination was performed preoperatively, and any abnormality constituted an exclusion criterion. All patients underwent examination of the vocal cords by laryngoscopy. In cases with deficits, the patients were excluded.

Intraoperative Neurophysiological Monitoring
The technique for intraoperative monitoring was the standard technique used at our institution for CN monitoring, with triggered electromyography and free-running EMG recordings, the latter with compound muscle action potentials. Monitoring of the cranial root required that the anesthetist place an endotracheal tube with incorporated laryngeal electrodes. Once installation was complete, bipolar needle electrodes were inserted in the neck muscles. Figure 1 illustrates the implantation sites for the EMG electrodes. All recordings and stimulations were performed using a Nimbus i-Care intraoperative EMG monitoring system (Newmedic-Haemodia SAS).

The anesthesia protocol was the standard one for all patients undergoing electromyography-neurophysiology monitoring. Short-lasting muscle relaxants were administered only for induction of anesthesia. The use of gaseous agents was limited to a minimum alveolar concentration (MAC) of 0.8.

Connections and impedances were checked once the electrodes were fixed. After the surgical approach was completed and the dura mater opened according to the specific surgery, the possibility of access to CN XI was examined. At first, CN XI was identified at the jugular foramen, and then it was followed caudally down to the lowest cervical level accessible, according to the exposure. Planned stimulation sites are indicated in Table 1; sites depended on the access allowed by the particular approach for each of the patients. Stimulation was performed with a large bipolar probe for the cranial and spinal roots (5 mm between tips), and with a fine-tipped bipolar probe for the cervical rootlets (2 mm between tips). Stimulation parameters were the standard ones for motor root stimulation: i.e., a rate of 2 Hz with a pulse width of 60 μsec. Intensity started at 0.1 mA and was progressively augmented by increments of 0.1 mA until either a significant response was obtained or a maximum intensity of 2.5 mA was reached. The threshold for a positive response was considered to be a triggered EMG response with amplitude of 150 μV in at least 1 muscle. Above-threshold stimulations were not performed because they could endanger the fine neural structures of the nerve due to brisk contractions.

Recorded Muscles
Electromyography was recorded using bipolar needle electrodes, either uni- or bilaterally according to pathology and exposure. Muscles were as follows: the sternal (medial) and the clavicular (lateral) components of the SCM (SCM-S and SCM-C, respectively), and the superior (descending) and middle (horizontal) parts of the TZ (TZ-S and TZ-M, respectively). The inferior part of the TZ was not recorded because it is classically known to receive innervation through anterior cervical roots. The vocal cords were recorded through an endotracheal tube with inbuilt electrodes facing the cords. Figure 1 shows the implantation sites.

Stimulation Sites
Stimulations were performed according to the available access to sites (Fig. 2). The nerve structures were stimulated with the same sequence for each of the patients, and responses were sought in all recording channels at all times.

The planned sequence was the following. First, at the cranial level, the common trunk was identified at the jugular foramen and then stimulated. Whenever vocal cord electrodes had been implanted the cranial root was stimulated at its exit from the medulla. Next, the spinal root was stimulated before its junction with the cranial root at the level of the foramen magnum.

Second, at the cervical level, stimulation of the CN XI
Rootlets was attempted at each spinal cord segment exposed. The level of origin of each rootlet was defined according to the metameric spinal cord level. The C-1 rootlets were defined as those exiting above the dorsal root entry zone (DREZ) of C-2; C-2 rootlets as those exiting at the level of the C-2 DREZ and down to the mid-distance between the DREZ of C-2 and the DREZ of C-3; and C-3 rootlets as those exiting below this line and down to the mid-distance between the DREZ of C-3 and the DREZ of C-4. The C-4 medullary segment and below were not explored because of insufficient exposure in the series. Each of the accessible rootlets was stimulated, progressing down from the foramen magnum. Finally, the spinal root was stimulated at each segmental level, above the uppermost rootlets exiting from C-1, C-2, C-3, and C-4, successively.

In total, 9 possible stimulation sites were defined; in each of the patients, stimulation was attempted only if the intended site was clearly identifiable without stretching the neural structures. A summary of stimulation sites can be found in Fig. 2.

**Recordings and Data Processing**

All recordings were performed by a trained neurophysiologist (A.B.) who was blinded to the stimulation sites. Unblinding occurred at the end of the procedure when the operating surgeon announced the stimulated sites.

Responses were monitored in all muscles for each of the stimulation sites. Muscles were considered as responding if an EMG response with amplitude above 150 μV was observed. An all or nothing system was applied; muscles were considered as either responding or nonresponding for each of the stimulated sites. The sites that could not be stimulated were labeled as inaccessible.

Lack of response was considered a technical failure in 2 circumstances. First, if a clinical response was obtained without a clear EMG response, because the specific muscular component responding to the stimulation could not be identified, the case was categorized as a technical failure. Second, in the eventuality of the complete absence of a response (both clinical and electrophysiological) and after checking of impedances showed abnormal values, the case was also considered a technical failure.

For each of the stimulation sites, attempts and the positive responses were summed up. Percentages were calculated as the number of above-threshold responses out of the total number of stimulation attempts for that specific site in the entire series.

Stimulation sites were divided into 2 groups: stimulation of cervical rootlets together with the cranial root on the one hand, and stimulation sites on the spinal root on

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**TABLE 1. Stimulation sites used in accessory nerve study**

<table>
<thead>
<tr>
<th>Stimulation Site</th>
<th>Designation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cranial root</td>
<td>CR</td>
</tr>
<tr>
<td>Cervical rootlets at C-1</td>
<td>C-1</td>
</tr>
<tr>
<td>Cervical rootlets at C-2</td>
<td>C-2</td>
</tr>
<tr>
<td>Cervical rootlets at C-3</td>
<td>C-3</td>
</tr>
<tr>
<td>Main nerve trunk at the foramen jugulare</td>
<td>FJ</td>
</tr>
<tr>
<td>Spinal root at the foramen magnum</td>
<td>FM</td>
</tr>
<tr>
<td>Spinal root below C-1</td>
<td>SR-C1</td>
</tr>
<tr>
<td>Spinal root below C-2</td>
<td>SR-C2</td>
</tr>
<tr>
<td>Spinal root below C-3</td>
<td>SR-C3</td>
</tr>
</tbody>
</table>
FIG. 2. Drawings and bar graphs showing stimulation sites and results. **Upper:** Responses to stimulation of the common trunk and at various sites on the spinal root. Responses at the different sites of stimulation on the spinal root are reported as percentages of the total number of stimulations resulting in a positive response of the recorded muscle sites. **Lower:** Responses to cranial root and cervical rootlet stimulation. Responses resulting from the specific stimulation of the several rootlets forming the spinal root and from specific stimulation of the cranial root, reported as percentages of the total number of positive responses for each stimulation site. CR = cranial root; CV = vocal cord; C-1, C-2, and C-3 = cervical rootlets of CN XI exiting the C-1, C-2, and C-3 segments; FC1, FC2, and FC3 = stimulation sites at the spinal root facing C-1, C-2, and C-3; FJ = common nerve trunk at foramen jugulare; FM = spinal root at foramen magnum; n.s. = not significant; SR = spinal root of CN XI. Drawings copyright Andrei Brînzeu. Published with permission.
the other. Further subgroup analyses were performed as detailed in the Results section.

For each of the muscles monitored, all responses were summed up, and we drew up a table of all of the sites activating that specific muscle. Percentages were calculated based on the total number of activations for each muscle.

Statistical Analysis

A chi-square test was used to determine if the patterns of response to the stimulation were different between the stimulation sites, and the Fisher exact test was used if the number of stimulations was too low to use a chi-square test. A 0.05 threshold of significance was used.

Results

Patient Population

A total of 49 patients were included in the study. The patient population consisted of 33 women (67.3%) and 16 men. The mean age was 48.1 ± 13.3 years (mean ± SD). A summary of patient demographic data can be found in Table 2.

The pathology leading to surgery was a CM-I in a majority of cases (22 patients). Current procedure in our department is to perform far-lateral decompression of tonsils at the foramen magnum in addition to posterior decompression, followed by a Y-shaped dural incision without opening the arachnoid. Such an approach permits us to access the level of the jugular foramen after gentle retraction of the cerebellar tonsil medially. Stimulation was performed bilaterally in all cases, with the exception of 2 patients in whom only a unilateral exposure of the jugular foramen was deemed safe (see Fig. 3 for details).

Other pathologies were meningiomas of the posterior fossa (17 patients), vestibular schwannomas (6 patients), posterior fossa arachnoid cysts (3 patients), and pericytoma (1 patient).

TABLE 2. Characteristics in 49 patients who underwent surgery with intradural exposure at the cranio cervical junction

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total patients</td>
<td>49</td>
<td></td>
</tr>
<tr>
<td>Sex</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>16</td>
<td>32.7</td>
</tr>
<tr>
<td>Female</td>
<td>33</td>
<td>67.3</td>
</tr>
<tr>
<td>Age in yrs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean ± SD</td>
<td>48.1 ± 13.3</td>
<td></td>
</tr>
<tr>
<td>Range</td>
<td>20.5–73</td>
<td></td>
</tr>
<tr>
<td>Pathology</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CM-I</td>
<td>22</td>
<td>45</td>
</tr>
<tr>
<td>Meningioma</td>
<td>17</td>
<td>35</td>
</tr>
<tr>
<td>Cerebellopontine angle</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>Foramen magnum</td>
<td>11</td>
<td>22</td>
</tr>
<tr>
<td>Cervical</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Vestibular schwannoma</td>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td>Pericytoma</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Posterior fossa arachnoid cyst</td>
<td>3</td>
<td>6</td>
</tr>
</tbody>
</table>

Stimulations were performed according to the access given by the specific approach of each surgery. Exposure for CM-I generally allowed stimulation without opening the arachnoid at the jugular foramen, at the foramen magnum, and facing C-1. Rootlet stimulation and cranial root stimulation were seldom performed in cases with CM-I, with the exception of the few cases in which the arachnoid was opened purposefully during the surgery to check and liberate the foramen of Magendie. In cases with vestibular schwannoma or cerebellopontine angle meningioma, the cranial root could be stimulated as well as the rootlets coming from C-1 or C-2. In these cases the trunk of the nerve was stimulated as well. Foramen magnum meningiomas and upper cervical tumors usually required exposure that permitted stimulation of rootlets down to C-3.

Figure 4 shows intraoperative stimulation in 2 cases: one of CM-I and the other involving a foramen magnum meningioma.

Responses According to Stimulation Sites

Responses to Stimulation of the Common Trunk

Stimulation at the jugular foramen indiscriminately stimulated both the spinal and the cranial roots. Seventy stimulations were performed. In 90% of the 70 stimulations a simultaneous response in all muscles was recorded (SCM-S, SCM-C, TZ-S, and TZ-M). A response in only some of the muscles was noted for the rest of the stimulations, as detailed in Fig. 2 upper.

Of the 19 patients in whom the vocal cords were monitored, a response was observed in 16 for the stimulation of the common trunk at the jugular foramen. In the 3 others there was no response in the vocal cords, probably for technical reasons.

Responses to Stimulation of the Cranial Root

Responses to cranial root stimulations are summarized in Fig. 2 lower. Among the 19 patients with electrodes in the vocal cords, EMG responses were recorded in 16, thus accounting for a response rate of 84.2%. In the 3 patients without an EMG response in the vocal cords, the absence of a response was related to technical failure. It is noteworthy that no EMG response was recorded in the other muscle groups on stimulation of the cranial root.

Responses to Stimulation of the Spinal Root

The spinal root nerve was stimulated a total of 262 times in the 49 patients. Stimulations were performed at different sites, from the foramen magnum down to the last cervical level exposed. Results are summarized in Fig. 2 upper.

At the level of the foramen magnum (67 stimulations), in 88.1% (59 stimulations) all monitored muscles responded. Specifically, the SCM-S responded 59 times (88.1%), the SCM-C 63 times (94%), the TZ-S 62 times (92.5%), and the TZ-M 63 times (94%). There was no significant difference between response frequencies.

At the level of C-1 the spinal root was stimulated 44 times. All muscles responded in only 29.5% (13 cases). At this level the responses in the SCM-S were less frequent than at the level above (only 31.8% [14/44] at this level ver-
sus 88.1% above); this was significantly less frequent than the responses in the other muscles that responded when being stimulated at this level ($p < 0.00001$, chi-square test). Responses in the SCM-C were recorded in 75% (33 cases), whereas the TZ responded in 90.9% (40 cases) in the TZ-S and 97.7% (43 cases) in the TZ-M.

At the level of C-2 the spinal root was stimulated 20 times. Responses in the SCM were significantly less frequent than at the level above (10% for the SCM-S and 25% for the SCM-C), whereas in 95% of cases a response in both of the monitored parts of the TZ was recorded (chi-square test: $p < 0.000001$ when comparing globally the SCM vs TZ, and $p < 0.001$ when comparing all 4 components).

At the level of C-3 the number of stimulations (5) was too low to perform statistical analysis; however, the larger proportion of responses was in the TZ-M, suggesting a decrease in the frequency of the responses of the TZ-S (100% for TZ-M vs 40% for TZ-S).

Responses to Stimulation of the Cervical Rootlets

Cervical rootlets of the spinal nerve were stimulated 37 times in total, and in 19 of these, vocal cord monitoring had been set up. Results are shown in Fig. 2 lower. The rootlets

![FIG. 3. Bar graph showing the contribution of specific rootlets to the motor innervation of monitored muscles. The contribution of each of the rootlets to the innervation of the monitored muscles is reported as a percentage of the total number of responses recorded in that muscle.](image-url)

![FIG. 4. Intraoperative images of CN XI stimulations. Left: A foramen magnum meningioma on the right side. The figure shows bipolar stimulation of the cranial root. Right: A CM-I; posterior and lateral decompression with dura mater and arachnoid opening. Operative view of the lesion on the left side. The figure shows stimulation of the common trunk before entering the jugular foramen. C2-DR = dorsal root of C-2; FJ = foramen jugulare; T = cerebellar tonsil.](image-url)
were located at the level of C-1 (24 rootlets), C-2 (10 rootlets), and C-3 (3 rootlets).

Stimulation of the 24 rootlets at C-1 yielded a response in the SCM-S 23 times (95.8%), and 8 times (33.3%) in the SCM-C. No contraction of the trapezius was recorded. Of the 10 rootlets stimulated at the C-2 level, 3 responded with a contraction of the SCM-S (30%) and 9 with contraction of the SCM-C (90%); in 1 patient the SCM-S responded alone. Only 3 rootlets located at the C-3 metamer level were found and stimulated. One stimulation led to a contraction of the SCM-C and 2 led to contraction of the TZ-S, with no contractions recorded in the TZ-M or the SCM-S. No vocal cord responses were found after stimulating the cervical rootlets of CN XI.

Statistical testing showed a significant difference between responses of C-1, C-2, and C-3 rootlets when monitoring the various components of the SCM and TZ (p = 0.00006, Fisher exact test). Subgroup analysis between C-1 and C-2 rootlets also showed a significant difference (p = 0.0027, Fisher exact test) when analyzing for all responding muscles. The difference was still significant even when only the 2 components of the SCM were taken into account (p = 0.0051, Fisher exact test).

Responses According to Monitored Muscles

Responses in every single muscle after stimulation of the various neural sites were summed up. Stimulation sites were dichotomized into rootlet stimulation (cranial root, C-1 rootlets, C-2 rootlets, C-3 rootlets) and spinal root stimulation. Specifics are given in Table 3.

The vocal cords responded only to the stimulation of the cranial root (16 times in all). The SCM-S responded a total of 26 times; 23 times at the stimulation of C-1 rootlets (88.5%) and 3 times at the stimulation of C-2 rootlets (11.5%). The SCM-C responded a total of 18 times. It responded 8 times (44.4%) at the stimulation of C-1 rootlets, 9 times (50%) at the stimulation of C-2 rootlets, and 1 time (5.6%) at the stimulation of C-3 rootlets. The TZ-S responded twice, both times at the stimulation of C-3 rootlets.

The pattern of innervation of the different monitored muscles is statistically different according to the Fisher exact test (p < 0.0001). More specifically, we analyzed whether any difference could be found between the sternal and clavicular parts of the SCM; a Fisher exact test shows a significant difference between the two (p = 0.0002).

Distribution of the responses among the spinal root stimulation sites is summarized in Fig. 2. By stimulating the spinal root at different sites, the SCM-S responded a total of 77 times. The SCM-C responded a total of 103 times, and the TZ-S and TZ-M responded 123 and 131 times, respectively. The Fisher exact test showed a significant difference between the activating sites of the different muscles along the spinal root (p < 0.0001).

Complications

No neurological complications in direct relation to the stimulation were noted. There were no postoperative infections. In 2 patients in whom there was CSF leakage that needed surgical repair, biological study of the CSF showed no signs of meningitis.

Discussion

The present study shows functional segregation between the several components of CN XI. The cranial root is confirmed to participate in the innervation of the vocal cords, whereas none of the spinal rootlets give innervation for these muscles. Within the spinal root a cranio-caudal myotopic organization is demonstrated, with rootlets destined to innervate the SCM situated superiorly to those for the TZ. An even more detailed cranio-caudal structuring was shown, with the fibers destined for the SCM-S exiting at the higher cervical levels, followed below by the fibers for the SCM-C, and then in order by the fibers for the TZ-S and finally the TZ-M.

Because this study was performed in patients undergoing various types of surgery at the craniocervical junction, application of the study protocol was limited by the surgical exposure, and not all patients received the same pattern of stimulation. Moreover, the lower cervical rootlets of CN XI could rarely be stimulated; in particular the rootlets exiting at C-4 were never directly stimulated, although they are known to participate in forming CN XI. Nevertheless the spinal root itself parallel to C-3 (i.e., receiving fibers from the C-4 level) was stimulated, yielding responses in the TZ-M and thus providing information as to the function of the cervical rootlets of CN XI exiting below C-3. Also, to avoid manipulation of the fragile structures of the nerve, the ventral cervical roots were not stimulated. Classically, ventral cervical roots are considered not to innervate the SCM and the upper 2 portions of the TZ. The inferior part of the TZ was not monitored because its innervation is known to be mostly from the ventral cervical roots.

From a technical point of view, stimulations were all performed with a bipolar probe in an attempt to be as specific as possible; diffusion of the stimulation to other muscles was not observed. It should be mentioned that in some of the stimulations no interpretable responses could be obtained; this was considered a technical failure.

The literature on the functional anatomy of CN XI is limited. A cranio-caudal segregation within CN XI has previously been described through clinical observations in patients with high cervical lesions, in whom deficits in the TZ and SCM were dissociated, depending on the location of the lesion between C-4 and C-2. From these observations permitted investigators to establish that lower lesions...
spared the SCM, whereas there was a deficit in the TZ. These observations could not determine, however, whether this was due to lesions to the nucleus of CN XI or to intradural lesions of the roots of the nerve.

Several detailed EMG studies of the peripheral branches of the nerve have been published. To our knowledge our study is the first systematic mapping of the functional anatomy of the intradural components of CN XI by direct stimulation and EMG recordings. Although a previous work by McKenzie mentioned the use of direct intraoperative stimulation during intradural CN XI rhizotomies for spasmodic torticollis, no data were reported.

According to our data, the cranial root innervates only the vocal cords and does not participate in the innervation of the SCM or TZ. Moreover, at no point did stimulation of any of the spinal components yield responses in the vocal cords. It appears that there is a completely independent functioning of the 2 main components (cranial and spinal). This is in accordance with newer human dissection studies showing a clear separation of the cranial and spinal root along their common path. This is also supported by gene expression studies that show different development pathways for the cranial root neurons and for the spinal neurons. A gene knockout study by Pabst et al. showed that the Nkx2.9 homeobox gene is essential for the development of the neurons in the spinal accessory nucleus but not for the cranial nucleus neurons. These authors were therefore able to create knockout mice with an absent spinal accessory but a normal cranial accessory nerve. As a result, some authors now view the cranial root as more closely related to the vagus nerve (CN X) than to the CN XI.

Cranio-caudal organization between the rootlets is in concordance with the central anatomy of the spinal component of the nerve. Retrograde labeling of axons innervating the SCM and TZ in rats localizes the soma of the neurons in the cervical second motor column. Histological studies performed in humans have morphologically confirmed this same type of organization. Such a vertical organization probably results from the mixed embryological origin of the target muscles from both branchial arches and somites, making the spinal component a particular type of nerve that is transitional between cranial and spinal nerves per se.

Knowledge of the detailed function of the nerve can be useful, making the clinical examination of patients with craniocervical lesions more accurate, whether these lesions are traumatic, vascular, tumoral, or malformative. This knowledge can also be applied to intraoperative neurophysiological monitoring during surgery of the craniocervical junction that puts these or neighboring structures at risk. In addition, in functional neurosurgery these data could serve to better understand pathological patterns in dystonia and to tailor rhizotomies in patients with spasmodic torticollis.

Conclusions

The CN XI pair has an organization around 2 components: a cranial root and a spinal root with several cervical rootlets. Each of these has a specific motor function, with an intrinsic structured organization of the spinal component. The cranial component independently contributes at least to the motor innervation of the larynx and does not seem to contribute to the motor control of the SCM and TZ. The spinal component largely contributes to the innervation of the SCM and TZ with a precise cranio-caudal myotopic organization; the rootlets destined to innervate to the SCM are more cranial.

References

Disclosures

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author Contributions

Conception and design: both authors. Acquisition of data: both authors. Analysis and interpretation of data: both authors. Drafting the article: Brînzeu. Critically revising the article: both authors. Reviewed submitted version of manuscript: both authors. Approved the final version of the manuscript on behalf of both authors: Brînzeu. Statistical analysis: Brînzeu. Administrative/technical/material support: both authors. Study supervision: both authors.

Supplemental Information

Previous Presentations

Portions of this work have been delivered as oral presentations at the Annual Meeting of the French-Speaking Society of Neurosurgery in Paris, France, on November 26–28, 2012, and at the "Congrès de l’Association des Morphologistes" in Amiens, France, on March 20–22, 2012. Portions of this work have been presented at the 64th Annual Meeting of the CNS in Boston, Massachusetts, on October 18–22, 2014.

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