Anatomical feasibility of using the ninth, 10th, and 11th intercostal nerves for the treatment of neurological deficits after damage to the spinal cord

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Object. The topographic anatomy of the lower intercostal nerves is less well known than that of the upper ones, except for the 12th intercostal nerve. It is possible to use the lower intercostal nerves to perform a neurotization of the lumbar roots. The authors studied the anatomy of the ninth, 10th, and 11th intercostal nerves to obtain descriptive and topographic anatomical data to aid in establishing optimal conditions for harvesting.

Methods. The ninth, 10th, and 11th intercostal nerves of 50 cadavers were dissected. The proximal part of the nerve in the posterior intercostal space (ICS) was exposed through a posterior approach. The lateral ICS was exposed through a lateral approach, under the latissimus dorsi, which made it possible to harvest the intercostal nerves using a stripping technique. A histological study was conducted on 10 pigs to evaluate the risk of nerve lesions during the stripping procedure.

Conclusions. The proximal course of the nerve in the posterior ICS was the same in all cases. The mean total length of the intercostal nerves harvested was 17.96 cm for the ninth, 17.14 cm for the 10th, and 15.94 cm for the 11th intercostal nerve. The harvested nerve length was sufficient in 297 of the 300 cases to perform lumbar root neurotization. The histological study showed no difference between the “open” and the “stripping” techniques regarding the risk of histological lesions in harvested nerves.

KEY WORDS • spinal cord lesion • intercostal nerve • lumbar root neurotization • anatomical study • pig

The 12 ventral branches of the thoracic nerves are known as intercostal nerves. There are sensory and motor fibers within these nerves, and authors have described performing the neurotization of injured brachial plexus roots when it is necessary to take three to four intercostal nerves and transfer them to the axillary fossa. The anatomy of the first six intercostal nerves has been described well in the literature. The ventral branches of the second through the sixth thoracic nerves and the small branch of the first thoracic are confined to the parietes of the thorax, and are named thoracic intercostal nerves. They pass forward in the ICSs caudal to the intercostal vessels. The ventral branches of the seventh through the 11th thoracic nerves are continued anteriorly from the ICSs into the abdominal wall; hence, they are named thoracoabdominal intercostal nerves. It is possible to use the lower intercostal nerves to carry out a neurotization of the lumbar roots, as proposed by Zhao and recently reported by Lang, et al; however, these experiments were performed in animals and cadavers, and they concern a limited number of cases. It is inaccurate as well as oversimplified to extrapolate the known anatomy of the higher to that of the lower intercostal nerves; the aim of this study is to define more precisely the anatomy of the ninth, 10th, and 11th intercostal nerves. We have studied 50 cadavers in order to describe and clarify the topographic anatomy, which will facilitate nerve harvesting in the future if neurotization is indicated. We devised a stripping procedure that allows us to harvest a segment long enough to perform multiple neurotizations of the lumbar roots near the conus medullaris. The results of and perspectives on this original surgical procedure are reported and discussed.
Materials and Methods

Thirty-seven embalmed and 13 fresh specimens (28 male and 22 female) of undetermined age were dissected by the same author (RV). The thoracic and lumbar spine was exposed through a median posterior approach. The ninth, 10th, and 11th intercostal nerves were localized at the point of emergence from the intervertebral foramen. The intercostal arteries and veins were also dissected and identified. The initial course of the nerve through the posterior ICS was visualized by this posterior approach. Right and left latissimus dorsi muscles were exposed through two lateral incisions, detached, and taken medially in order to visualize the ninth, 10th, and 11th ICSs. The external intercostal muscle was detached from the caudal edge of the cranial rib to expose the intercostal vein, artery, and nerve in the lateral ICS. The lateral cutaneous branch of the intercostal nerve was isolated and sectioned just after its exit from the external intercostal muscle. The dissection of the deep medial branch of the intercostal nerve was continued as distally as possible. The intermediate part of the nerve between the medial and lateral approach was dissected subcutaneously by means of a stripper (Fig. 1). After release of the intermediate part of the nerve, that portion was pulled backward using a posterior medial approach.

The overall length of each harvested nerve and the level of the bifurcation between the deep medial region and the lateral cutaneous branch were measured. Measurements were taken from the point at which the nerve emerged from the intervertebral foramen. For each cadaver, the size of the specimen was designated by the length of the trunk, as determined by the distance between the spinous process of the seventh cervical vertebra and the posterior superior iliac spine. The nerve length necessary to perform an intradural lumbar root neurotization was estimated by the use of two measurements. A “direct” length was measured between the nerve’s emergence from the intervertebral foramen and the nerve roots under the conus medullaris. An “indirect” length was noted by means of a surgical suture placed from the intervertebral foramen to the conus medullaris and passing laterally in the costovertebral angle (Fig. 2).

A histological study was performed to evaluate the risk of lesions in the harvested nerves associated with the use of a stripper. Thirty intercostal nerves were harvested by means of the stripper in five pigs killed just before the surgical procedure to avoid postmortem histological lesions. Thirty intercostal nerves, which represent the control group, were harvested with an open technique. After the nerves had been embedded in paraffin, cut into 1-μm sections, and stained with thionin, the 60 histological fragments were analyzed by an independent neuropathologist and the principal author, who were blinded to the method involved (Fig. 3). The number of fascicles and the fascicular crush lesions were noted for each harvested nerve.

All parameters were collected in a computerized database and analyzed using SPSS software (SPSS Inc., Chicago, IL). The population distribution was normal with respect to trunk size. The statistical analysis was made using the Pearson correlation coefficient. Correlations between nonbinary and binary numeric variables were made using unpaired t-tests for equality of means and a one-way analysis of variance. Differences with probability values less than 0.05 were considered statistically significant. Because of the distribution, statistical analysis focusing on sex was conducted using nonparametric tests.

Results

Descriptive and Topographic Anatomy

The mean distance between the spinous process of the seventh cervical vertebra and the posterior superior iliac spine was 48.56 cm (range 40–58 cm). This value was significantly higher in men than in women (p < 0.001, Wilcoxon test). The location of nerve and vascular elements in the posterior ICS was the same in all of the cases. Intercostal nerves and vessels were located in all cases on the contact of the parietal pleura, in a space filled with fatty tissue and separated from the intervertebral and vertebrocostal muscles by a thin membrane, the internal intercostal membrane.

The course of the nerve through the posterior ICS was the same for the ninth and the 10th intercostal nerves (Fig. 4). In all specimens, the nerve within the posterior ICS had its origin at the cranial end. The nerve coursed laterally to reach the lower border of the rib. The vessels were...
in all cases cranial to the emergence of the nerve, close to the lower border of the rib. In all instances, the 11th intercostal nerve followed the same direction as the ninth and 10th intercostal nerves in the posterior ICS. On the other hand, its emergence in the posterior ICS was more distal, in the caudal half of the posterior ICS. In all specimens, the 11th intercostal nerve was farther away from the vessels of the posterior ICS than the 10th and the ninth nerves were.

The intercostal nerve exited the posterior ICS, running forward along the thoracic wall between the internal and external intercostal muscles. Through the lateral ICS, the course of the intercostal nerve and vessels was, in all cases, close to the caudal edge of the cranial rib. In all specimens, the intercostal nerve was easily found after disinsertion of the external intercostal muscle from the lower border of the cranial rib. In all specimens, the nerve and the vessels were in the same space, between the deep and the superficial intercostal muscles. This space was partitioned by a fine fascia, which formed a tunnel under the rib (Fig. 5).

**Harvested Nerve Length and Theoretical Necessary Length**

The mean total length of intercostal nerve harvested was 17.96 cm (range 10–27 cm) for the ninth intercostal nerve, 17.14 cm (range 10–20 cm) for the 10th intercostal nerve, and 15.94 cm (range 10–25 cm) for the 11th intercostal nerve. The length of harvested nerve was not correlated with the size of the trunk. The values for the harvested nerve length and for the direct and indirect lengths necessary to perform neurotization are summarized in Table 1.
The length of the harvested nerve was sufficient to perform lumbar root neurotization in 297 of the 300 cases of nerve harvesting. In two cases of ninth (Fig. 6 left) and in one case of 10th intercostal nerve harvesting (Fig. 6 center), the length was insufficient to perform a satisfactory lumbar root neurotization. Regarding the 11th intercostal nerve, the harvested length was sufficient in all cases (Fig. 6 right).

The division of the intercostal nerve into two branches was found in 89 of the 100 ninth intercostal nerves, 80 of the 100 10th intercostal nerves, and 82 of the 100 11th intercostal nerves (Fig. 7). The length values of each nerve and its bifurcation localization are summarized in Table 2.

The distance between the emergence of the nerve and the bifurcation was not statistically higher in men than in women. Neither was it higher in cadavers presenting the longest trunks for the ninth and 10th intercostal nerves. On the other hand, the distance between the emergence of the 11th intercostal nerve and its bifurcation was significantly positively correlated with the distance between the spinous process of the seventh cervical vertebra and the posterior superior iliac spine ($r = 0.298$ and $p = 0.006$, Pearson test).

**Histological Results**

The results of the histological study are summarized in

<table>
<thead>
<tr>
<th>Type of Nerve Length</th>
<th>Min</th>
<th>Max</th>
<th>Mean</th>
<th>SEM</th>
<th>SD</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>ninth</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>total</td>
<td>10.0</td>
<td>27.0</td>
<td>17.96</td>
<td>0.250</td>
<td>2.50</td>
<td>6.25</td>
</tr>
<tr>
<td>direct</td>
<td>7.0</td>
<td>14.0</td>
<td>11.25</td>
<td>0.150</td>
<td>1.53</td>
<td>2.36</td>
</tr>
<tr>
<td>indirect</td>
<td>9.8</td>
<td>15.8</td>
<td>13.16</td>
<td>0.162</td>
<td>1.61</td>
<td>2.61</td>
</tr>
<tr>
<td>10th</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>total</td>
<td>6.0</td>
<td>25.0</td>
<td>17.09</td>
<td>0.260</td>
<td>2.57</td>
<td>6.60</td>
</tr>
<tr>
<td>direct</td>
<td>4.0</td>
<td>11.0</td>
<td>8.41</td>
<td>0.160</td>
<td>1.62</td>
<td>2.63</td>
</tr>
<tr>
<td>indirect</td>
<td>7.5</td>
<td>13.0</td>
<td>10.53</td>
<td>0.140</td>
<td>1.41</td>
<td>2.00</td>
</tr>
<tr>
<td>11th</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>total</td>
<td>10.0</td>
<td>25.0</td>
<td>15.94</td>
<td>0.250</td>
<td>2.50</td>
<td>6.26</td>
</tr>
<tr>
<td>direct</td>
<td>2.0</td>
<td>8.0</td>
<td>5.15</td>
<td>0.142</td>
<td>1.45</td>
<td>2.11</td>
</tr>
<tr>
<td>indirect</td>
<td>5.0</td>
<td>10.0</td>
<td>7.81</td>
<td>0.140</td>
<td>1.40</td>
<td>1.97</td>
</tr>
</tbody>
</table>

*Measurements are in centimeters; 300 harvesting procedures were performed (100 each for the ninth, 10th, and 11th intercostal nerves). Abbreviations: M = mean; SEM = standard error of the mean; SD = standard deviation.
Table 3. In all cases, the lesions concerned peripheral fascicles (Fig. 8). Electron microscopy performed on damaged fascicles revealed splitting of myelin, as well as intramyelinic and periaxonal edema (Fig. 9). Because of the small number of damaged fascicles, the difference between the group in which the stripper was used and the one in which the open technique was used was statistically nonsignificant.

Discussion

Contribution to the Anatomical Description of Lower Intercostal Nerves

The topographic anatomy of the thoracic intercostal nerves (the ventral branch of the second through the sixth thoracic nerves) has been well described in the literature.\(^3,4\) The topographic anatomy of the lower intercostal nerves is less familiar. They have the same arrangement as the upper ones as far as the anterior ends of the ICSs, where they pass behind the costal cartilages and between the internal (oblique internus) and transversus abdominis muscles to the sheath of the rectus abdominis muscles, which they perforate. They supply the rectus abdominis muscles and end as the anterior cutaneous branches of the abdomen; they also supply the skin of the front of the abdomen. Results of various studies reveal that the lower intercostal nerves supply the intercostal and abdominal muscles; the last three send branches to the posterior serratus inferior.\(^11-13\) Around the middle of their course they give off lateral cutaneous branches. These pierce the external intercostal and oblique muscles in the same line as the lateral cutaneous branch of the upper thoracic nerves, and they divide into anterior and posterior branches, which are distributed to the skin of the abdomen and back. The lateral cutaneous branch supplies the digitation of the external oblique muscle and extends downward and forward nearly as far as the margin of the rectus abdominis; the posterior branches pass backward to supply the skin over the lattissimus dorsi.

Only the 12th intercostal nerve has been well described previously.\(^2\) Its greater diameter and its significant contribution to the innervation of the abdominal wall is the anatomical basis of the sensitive cutaneous flaps reported in Yan and Zhong’s work.\(^17\)

In contrast with Hardy,\(^4\) we always found the same anatomical configuration of the intercostal nerves in the posterior ICSs. Their direction is more oblique, to the top and laterally, allowing them to reach the lower border of the cranial rib higher before exiting the posterior ICS. Knowledge of the anatomy of the proximal portion of the lower intercostal nerves in the posterior ICS makes it possible to approach them surgically without risk of injury. Careful opening of the posterior intercostal membrane makes it possible to identify the nerve easily as it crosses obliquely in the fatty space. It is necessary to be particularly careful to avoid injuring the posterior parietal pleura, which is located just under the nerve. The exit from the posterior ICS is a fibrous strait that marks the entry of a channel between two muscular layers. In contrast with the traditional anatomical description by Rouvière and Delmas\(^10\) of a wide, free area between the deep and superficial intercostal muscles, we describe an aponeurotic channel in which the nerve and the vessels are adjacent to the lower border of the cranial rib. The nerve and the vessels are
located in the same space, the nerve being the most caudal element.

**Harvesting Technique and Harvested Nerve Length**

The overall length of nerve that we succeeded in harvesting with an incision at the lateral border of the latissimus dorsi varied from 10 to 27 cm, with a mean value ranging from 17.96 cm for the ninth to 15.94 cm for the 11th intercostal nerve. Even if the harvested nerve length was not positively correlated with the trunk size, it was largely sufficient to carry out an anastomosis between the harvested intercostal nerve and the roots at the level of the cauda equina. In only three of the 300 harvesting procedures was the length insufficient to perform root neurotization successfully (in these we had technical difficulties because of especially thin nerves).

The bifurcation of the intercostal nerve between the deep branch and the lateral cutaneous branch was found in the majority of cases and occurred from 9.5 to 21 cm from the emergence of the intercostal nerve in the posterior ICS. The bifurcation was more proximal for the lower ICSs. Statistical analysis of our results does not make it possible to describe this bifurcation perfectly. It would seem logical that this bifurcation is farther away from the emergence of the nerve in the posterior ICS of the largest trunk. This correlation was found only in the bifurcation of the 11th intercostal nerve. The bifurcation localization was a good landmark, indicating the length necessary to perform lumbar root neurotization. Except for the ninth intercostal nerve, in which the main bifurcation was localized proximally (Fig. 10 upper), the nerve bifurcation was usually located distal to the theoretical localization of the nerve anastomosis area (Fig. 10 center and lower).

**Histological Study**

Only a small number of fascicles were damaged during the harvesting procedure. The histological lesions were all located in superficial fascicles. The stripping technique was not statistically associated with a higher risk of lesions caused by fascicles being crushed. The stripping

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**TABLE 2**

Harvested intercostal nerve lengths and distances from the vertebral foramen to the bifurcation*

<table>
<thead>
<tr>
<th>Nerve &amp; Variable</th>
<th>No. of Nerves</th>
<th>Min</th>
<th>Max</th>
<th>Mean</th>
<th>SEM</th>
<th>SD</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>ninth length</td>
<td>100</td>
<td>10</td>
<td>27</td>
<td>17.96</td>
<td>0.25</td>
<td>2.50</td>
<td>6.25</td>
</tr>
<tr>
<td>distance to bifurcation</td>
<td>89</td>
<td>11</td>
<td>21</td>
<td>16.18</td>
<td>0.19</td>
<td>1.86</td>
<td>3.48</td>
</tr>
<tr>
<td>10th length</td>
<td>100</td>
<td>6</td>
<td>25</td>
<td>17.09</td>
<td>0.26</td>
<td>2.57</td>
<td>6.60</td>
</tr>
<tr>
<td>distance to bifurcation</td>
<td>80</td>
<td>11</td>
<td>19</td>
<td>15.08</td>
<td>0.20</td>
<td>1.84</td>
<td>3.42</td>
</tr>
<tr>
<td>11th length</td>
<td>100</td>
<td>10</td>
<td>25</td>
<td>15.94</td>
<td>0.25</td>
<td>2.50</td>
<td>6.26</td>
</tr>
<tr>
<td>distance to bifurcation</td>
<td>82</td>
<td>9</td>
<td>19</td>
<td>13.20</td>
<td>0.26</td>
<td>2.43</td>
<td>5.90</td>
</tr>
</tbody>
</table>

* Measurements are in centimeters.

**TABLE 3**

Results of the histological study

<table>
<thead>
<tr>
<th>Harvesting Technique</th>
<th>No. of Harvested Nerves</th>
<th>Mean No. of Fascicles in Each Harvested Nerve</th>
<th>Total No. of Harvested Fascicles</th>
<th>No. of Damaged Fascicles</th>
</tr>
</thead>
<tbody>
<tr>
<td>open</td>
<td>30</td>
<td>7.4 (3–19)</td>
<td>222</td>
<td>3</td>
</tr>
<tr>
<td>stripping</td>
<td>30</td>
<td>7 (4–11)</td>
<td>210</td>
<td>13</td>
</tr>
</tbody>
</table>

---

Fig. 8. Photomicrograph obtained with light microscopy depicting a specimen of a pig intercostal nerve harvested using the stripping technique. Note the partial-crush lesion of the superficial fascicle (all arrowheads). Thionin, original magnification × 200.

Fig. 9. Electron micrographs depicting specimens of pig intercostal nerves, one harvested using the open technique (A) and the other harvested using the stripping technique (B). Note the normal appearance (NA) and the split appearance (SA) of the myelin sheath associated with intramyelinic and periaxonal edema. Original magnification × 800.
Multiple lumbar neurotizations of the lower intercostal nerves

technique seems to be a reliable and safe one for obtaining a sufficient nerve length through a minimally invasive approach.

Clinical Relevance

Multiple lumbar root neurotizations with lower intercostal nerves has been proposed by some authors as a new surgical procedure for treating neurological deficits following spinal cord lesions. In this strategy of nervous system repair, the use of the spinal cord and the intercostal nerves above the spinal cord lesion avoids axonal regrowth by going through the injured central nervous system. As a consequence, only lesions of the cauda equina and conus medullaris can be treated by such lower intercostal nerve neurotizations. The real functional benefit of the procedure described in this paper should be assessed in further experimental studies. Although brachial plexus neurotization may provide some clinically meaningful benefit (for example, in shoulder animation and elbow flexion), the size of the intercostal nerves and the distance of the muscle endplate from the proximal cauda equina could be responsible for unsatisfactory results in terms of a clinically meaningful somatic recovery of leg function. Lang, et al., have, however, recently reported on their use of lower intercostal nerves for neurotization of the lower limb in humans. According to the recent preliminary clinical applications reported by Livshits and Sievert, a more viable strategy may be through neurotization of the sacral plexus to improve bladder and sexual dysfunction after spinal cord lesions. Animal studies are needed to demonstrate axonal regeneration and functional improvement using this surgical procedure. Such a study is currently being conducted in our research unit in a large mammal model. In previous experiments, we used a collagen tube surrounding the epineural suture to guide axonal regrowth from the spinal cord to the periphery.
Conclusions

The current anatomical study of the ninth, 10th, and 11th intercostal nerves in the posterior and lateral ICSs appears to us to predict the realization of a reliable form of surgical harvesting. The length of nerve obtained by means of a second incision at the lateral border of the latissimus dorsi muscle appears sufficient to use in carrying out a nerve anastomosis on the level of the conus medullaris (Fig. 11).

Acknowledgments

This study profited from the financial support of the Société Française de Chirurgie Orthopédique et Traumatologique and of the Fondation pour la Recherche Médicale.

References


Manuscript received December 22, 2004. Accepted in final form December 21, 2005. Address reprint requests to: Raphaël Vialle, M.D., 105 Avenue André Morizet, 92100 Boulogne, Billancourt, France. email: ravialle@noos.fr.