Functional assessment of C-5 ventral rootlets by intraoperative electrical stimulation of the supraclavicular segment of the long thoracic nerve during brachial plexus surgery

Leandro Pretto Flores, M.D.

Unit of Neurosurgery, Hospital de Base do Distrito Federal, Brasilia, Distrito Federal, Brazil

Object. Anatomical and functional assessment of the intradural segment of the spinal nerves is imperative in brachial plexus surgery, as the repair of postganglionic elements in the setting of a confirmed nerve root avulsion is of no benefit. None of the current techniques to detect these avulsions can provide full information that ensures the functional status of the preganglionic segment of the roots. The objective of this study was to evaluate intraoperative electrical stimulation of the supraclavicular segment of the long thoracic nerve (LTN) as a method to differentiate C-5 nerve root extraforaminal rupture from its intradural avulsion.

Methods. The author performed a prospective analysis of data obtained in 14 patients presenting with the loss of C-5 nerve root function secondary to traumatic brachial plexus injury. The patients were divided into 2 groups: 8 patients in whom the intradural segment of C-5 nerve root was preserved (5 cases of closed traction injuries in whom the computed tomography [CT] myelograms confirmed the integrity of C-5 root and 3 cases of open sharp injuries) and a control group of 6 patients in whom CT myelography demonstrated avulsion of the root.

Results. The results of the intraoperative electrical stimulation of the LTN and the surgical outcome of each patient were recorded. The LTN electrical stimulation elicited serratus anterior muscle contraction in cases in which C-5 root was not avulsed, and there were no responses in patients whose radiological evaluation had demonstrated nerve root avulsion. In those patients in whom LTN stimulation proved to be positive, the C-5 root was used as a graftable stump to the suprascapular nerve and/or to the posterior division of the superior trunk. In these cases, favorable results were observed regarding arm abduction in all cases—Medical Research Council Grades M3 (37%) and M4 (62%). In the control group, the C-5 root was not used as a donor stump and a multiple nerve transfer technique was adopted as the preferred surgical option.

Conclusions. Intraoperative electrical stimulation of the supraclavicular segment of the LTN is a useful complementary method to test the functional status of the C-5 ventral rootlets. If the test is positive (that is, a response is present) it is indicative of extraforaminal rupture of the root, and if negative, it is suggestive of its avulsion.

(DOI: 10.3171/JNS/2008/108/3/0533)

Key Words • brachial plexus surgery • intraoperative monitoring • long thoracic nerve • root avulsion

The brachial plexus is a critical structure of the peripheral nervous system, involved in ~10–20% of all traumatic lesions of the peripheral nerves.14 Closed traction is the most common mechanism of lesions in these patients and is associated with motorcycle accidents in ~70% of the cases. Traction over the plexus structures may result in extraforaminal rupture of the nervous elements (postganglionic lesions) or avulsion of intradural nerve roots (preganglionic lesions). A pattern of combination of root extraforaminal rupture and root avulsion is generally observed, and the upper roots (C-5 and C-6) are more often ruptured than avulsed.8

Grafting is the preferred treatment for extraforaminal ruptures, and nerve transfer is the procedure of choice in cases of root avulsion. The diagnosis of root avulsion is imperative in the preoperative investigation of a patient presenting with brachial plexus traumatic injury. Today, it is based on imaging techniques (such as CT myelography or magnetic resonance imaging) and intraoperative modalities (such as SSEPs, MEPs, and histological analysis of root stumps).13 All of these techniques have limitations and none can provide fully accurate information about the functional status of the preganglionic segment of a root that is...
intended to be used to reconstruct a brachial plexus element.

Dysfunction of the LTN is considered a semiological sign of preganglionic upper root injury. As the nerve is formed by branches derived from the most proximal segments of the C-5, C-6, and C-7 spinal nerves, its function may be preserved in those situations of extraforaminal rupture of these roots. The objective of the present study was to verify the feasibility of using electrical stimuli applied to the supraclavicular segment of the LTN as an intraoperative method for differentiating C-5 nerve root extraforaminal rupture from its intradural avulsion.

Clinical Material and Methods

A prospective analysis was performed of patients presenting with complete or incomplete brachial plexus injury associated with loss of C-5 nerve root function as part of the deficit, detected clinically and electrophysiologically. The patients were divided into 2 groups: patients in whom the CT myelography demonstrated preservation of the intradural segment of C-5 nerve root and those in whom the mechanism of trauma had the potential to develop only a focal extraforaminal lesion, such as open sharp injuries; and a control group of patients in whom CT myelography demonstrated avulsion of C-5 root from the spinal cord.

Preoperative assessment was based on the standard recommendations for brachial plexus injuries. Patients underwent clinical examination and individual muscle testing. The surgical procedure was immediately indicated when the mechanism of nerve lesion was open sharp injury (such as that created by knife or glass). In cases of closed traction injuries, the patients underwent monitoring for 4 months before a decision to operate was made, except in cases involving total root avulsion when surgery was not delayed. Complementary diagnostic investigation included electrophysiological studies and CT myelography. The latter examination was indicated in the cases of closed traction injuries, and scans were obtained in axial 2-mm-thick sections in the cervical spine (from C-1 to T-1). Nerve root preservation was considered if root imprint was identified, and the presence of a pseudomeningocele was considered a criterion for avulsion only if root imprint was not visualized.

Informed consent was obtained for each study participant, and it was followed in accordance with the Declaration of Helsinki II.

Surgical Technique

After induction of general anesthesia, patients were placed in a supine position and the head was rotated to the contralateral side. Muscle relaxant drugs were avoided.
TABLE 1
Summary of demographic, imaging, intraoperative findings, and surgical results in 14 patients treated for brachial plexus injury*

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age (yrs), Sex</th>
<th>Injury Mechanism</th>
<th>CT Myelography Finding</th>
<th>Intraop Findings</th>
<th>LTN Stimulus</th>
<th>MRC Grade</th>
<th>Arm</th>
<th>Abduction</th>
<th>Flexion</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>24, M</td>
<td>sharp</td>
<td>none</td>
<td>C-5 &amp; C-6 section</td>
<td>positive</td>
<td>M4</td>
<td>M4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>45, M</td>
<td>sharp</td>
<td>none</td>
<td>C-5 &amp; C-6 section</td>
<td>positive</td>
<td>M4</td>
<td>M4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>40, M</td>
<td>sharp</td>
<td>none</td>
<td>ST section</td>
<td>positive</td>
<td>M4</td>
<td>M4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>25, F</td>
<td>traction</td>
<td>normal</td>
<td>C-5 &amp; C-6 section</td>
<td>positive</td>
<td>M4</td>
<td>M4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>21, M</td>
<td>traction</td>
<td>normal</td>
<td>ST neuroma</td>
<td>positive</td>
<td>M3</td>
<td>M3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>38, M</td>
<td>traction</td>
<td>normal</td>
<td>C-5 &amp; C-6 release</td>
<td>positive</td>
<td>M4</td>
<td>M4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>21, F</td>
<td>traction</td>
<td>C6-T1 avulsions</td>
<td>ST neuroma</td>
<td>positive</td>
<td>M3</td>
<td>M2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>31, M</td>
<td>traction</td>
<td>C-6 avulsion</td>
<td>C-5 rupture</td>
<td>positive</td>
<td>M3</td>
<td>M3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>22, M</td>
<td>traction</td>
<td>total avulsion</td>
<td>AN–SN, PN–ADST</td>
<td>negative</td>
<td>M3</td>
<td>M2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>41, F</td>
<td>traction</td>
<td>C5–7 avulsions</td>
<td>AN–SN, Oberlin</td>
<td>negative</td>
<td>M2</td>
<td>M3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>17, M</td>
<td>traction</td>
<td>total avulsion</td>
<td>AN–SN, PN–MN</td>
<td>negative</td>
<td>M1</td>
<td>M2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>28, M</td>
<td>traction</td>
<td>C-5 &amp; C-6 avulsions</td>
<td>AN–SN, Oberlin</td>
<td>negative</td>
<td>M3</td>
<td>M3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>21, M</td>
<td>traction</td>
<td>C-5 &amp; C-6 avulsions</td>
<td>AN–SN, Oberlin</td>
<td>negative</td>
<td>M2</td>
<td>M3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>30, M</td>
<td>traction</td>
<td>C5–8 avulsions</td>
<td>AN–SN, IN–MN</td>
<td>negative</td>
<td>M3</td>
<td>M3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* AN = accessory nerve; IN = intercostal nerve; MN = musculocutaneous nerve; PN = phrenic nerve; SN = suprascapular nerve; ST = superior trunk.
† Oberlin refers to the technique involving the suturing of a fascicle of the ulnar nerve to the bicipital motor branch of musculocutaneous nerve.

The supraclavicular region was approached through a transverse skin incision located 2-finger breadths over the clavicle, laterally to the sternocleidomastoid muscle. The incision was deepened to transect the platysma, the cervical fat pad was dissected away from the omohyoid muscle, and this muscle was sectioned. The phrenic nerve was identified overlying the scalenus anterior muscle, and its position was used to locate the C-5 spinal nerve. Then dissection followed to C-6, superior trunk, and its divisions (anterior, posterior, and suprascapular nerves). The scalenus anterior muscle was partially removed and a foraminal inspection of the C-5 and C-6 roots was done. Each root was individually tested with the electrical stimulator. In cases involving a sharp injury, the proximal and distal stumps of the sectioned neural elements were identified. In cases involving extraforaminal roots or a superior trunk rupture, the neuroma-in-continuity was tested with nerve action potential recording (stimulation hooks were placed in the roots and recording electrodes were positioned in the suprascapular nerve or in the divisions of the superior trunk; the distance between them was always > 4 cm) to allow a decision in favor of neurolysis or grafting. The infraclavicular brachial plexus was explored via a deltopectoral incision, with sectioning of the pectoral minus muscle.

The LTN was isolated in the supraclavicular region and usually identified posterior to the superior trunk, emerging from the scalenus medius muscle (Fig. 1). The nerve was suspended by silicon loops, and a 5–10-mV electrical stimulus was applied using a peripheral nerve electrical stimulator (Aesculap) to search for signs of serratius anterior muscle contraction (such as ipsilateral shoulder protraction). If the electrical stimulus elicited a response, the C-5 nerve root was used as proximal stump for reconstruction of the posterior division of superior trunk and/or suprascapular nerve. In cases involving sharp injuries or superior trunk neuromas, the C-6 nerve root was also used as a source of axons for grafting to the anterior division of the superior trunk. If the electrical stimulation of the LTN proved to be negative, the C-5 nerve was abandoned as a donor stump and other nerves were selected for transfer.

The choices for nerve transfer used in this study utilized the following protocol. For total (C5–T1) avulsion, we used an accessory–suprascapular nerve transfer and phrenic–anterior division of superior trunk transfer, sectioning the contribution of the lateral cord to the median nerve. For C-5 and C-6 avulsions or C5–7 avulsion, we used an accessory–suprascapular nerve transfer and the Oberlin procedure (transfer of a fascicle of functioning ulnar nerve to the biceps branch of musculocutaneous nerve). In 1 case involving C5–8 avulsions, an accessory–suprascapular nerve transfer was done in conjunction with intercostal–musculocutaneous nerve transfer. The axillary nerve was not reanimated in any patient.

**Results**

**Patient Population**

There were 14 patients presenting with complete or incomplete brachial plexus injury and associated loss of C-5 nerve root function. Summaries of each patient are presented in Table 1. There were 11 male (79%) and 3 female (21%) patients, whose mean age was 28 years (range 17–45 years). Closed traction was the most common mechanism of injury, observed in 11 cases (79%).

Computed tomography myelography was performed in 11 patients (79%). It demonstrated preservation of the intradural segment of the C-5 root in 5 patients (45%) and avulsion of the C-5 spinal nerve in 6 (55%). In the study group, CT myelography findings were considered normal in 3 cases and to have indicated signs of avulsion of other roots in 2 cases. The surgical findings in this group of patients were extraforaminal root (4 cases [50%]) and superior trunk (4 cases [50%]) sharp section or closed rupture (that is, neuroma-in-continuity). The surgical strategies for treatment of these cases were grafting of the injured neu-

J. Neurosurg. / Volume 108 / March 2008

535
ral elements in 7 cases (88%) and external neurolysis in 1 (12%).

In the control group, CT myelography demonstrated complete (C5–T1) avulsion in 2 cases; avulsion of C-5 and C-6 in 2; C5–7 avulsion in 1; and C5–8 root avulsion in 1 case. Surgical strategies for these cases involved multiple nerve transfers (Table 1).

**Intraoperative Electrical Stimulation and Electrophysiological Monitoring**

Electrical stimulation of C-5 and C-6 was considered negative in all patients in both groups. Nerve action potential, tested in those cases associated with closed rupture of extraforaminal upper elements of the brachial plexus, was considered negative in 3 cases and positive in 1.

The LTNs were isolated and tested in all the cases, with the following results. In the study group—the patients in whom the clinical examination and/or the CT myelography suggested that the C-5 root was not avulsed—the stimulus proved to be positive in all 8 patients, eliciting protraction of the scapula. In the control group—those patients in whom the C-5 root was considered avulsed—the electrical stimulus of the LTN did not produce muscle contraction in any patient.

**Surgical Results**

The surgical results regarding arm abduction and elbow flexion are demonstrated in Table 1. In those patients in whom the C-5 nerve was not avulsed—those in whom there was the possibility of using 1 or occasionally 2 proximal stumps of nerve roots (C-5 and/or C-6) for grafting (study group)—the observed results were considered favorable. For arm abduction, an MRC grade of M3 in 3 (37%) and M4 in 5 (62%) cases was noted. In the patient presenting with C6–T1 root avulsions, grafting was performed from C-5 to suprascapular nerve and nerve transfer from the phrenic to musculocutaneous nerve, and the results were considered fair for elbow flexion (MRC Grade M2) and acceptable for arm abduction (MRC Grade M3). In the patient presenting with only a C-6 avulsion, the surgical strategy was to place a graft from C-5 to the suprascapular nerve, associated with the Oberlin procedure, and the surgical results were also considered good (MRC Grade M3 for both arm abduction and elbow flexion).

The results observed in the control group were not as favorable, as would be expected in cases involving multiple nerve transfers. The accessory–suprascapular nerve transfer (used for restoration of the shoulder abduction function) demonstrated variable results ranging from MRC Grade M1 to M3. Multiple techniques were used for elbow flexion restoration, and the Oberlin procedure was associated with the best results (MRC Grade M3 in all cases).

**Discussion**

**Anatomical Basis**

The LTN, also known as external respiratory nerve of Bell, has been described in anatomical textbooks since the last century. The nerve is formed by branches derived from the most proximal segments of the C-5, C-6, and C-7 spinal nerves (Fig. 2A). It is also supplied by the C-4 or C-8 spinal root in 8% of the cases.9 The branches of C-5 and C-6 unite behind the scalenus medius muscle and emerge from it 1 cm posterior to the superior trunk. At this point, the nerve usually divides into a branch to innervate the upper portion of the serratus anterior muscle—the so-called upper division of the LTN (Fig. 1). The branch from C-7 spinal root usually joins the upper division of the nerve in the axillary region, and it will innervate the inferior portion of the serratus anterior muscle.3 This branch may be absent in 4–8% of the cases.9 The upper portion of the serratus anterior muscle is responsible for the scapular protraction and the lower portion for the scapular stabilization.3 These detailed anatomical descriptions have important surgical significance: 1) the electrical stimulation of the supraclavicular segment of the LTN will test only the functionality of C-5 and C-6 nerve roots, excluding C-7 as a confounding element of the analysis; and 2) as recently demonstrated in anatomical studies,15 the LTN has its supraclavicular course parallel to the superior trunk, not perpendicular to the brachial plexus as represented in anatomical textbooks. Hence, the dissection of the superior trunk must be carefully performed to avoid injury of the LTN and consequent misinterpretation of the results about its electrical stimulation.

**Limitations of the Current Methods for Detection of Root Avulsion**

The diagnosis of root avulsion is based in electrophysiological and imaging data (CT myelography and magnetic resonance imaging) that are used together to provide evidence to support functional and anatomical considerations of a preganglionic injury. Computed tomography myelography is a radiological method based on evidence of root imprints to check the integrity of the intradural spinal nerves, and according to Carvalho et al.,3 the technique has values of 85% for sensitivity and 95% for specificity. Misdiagnosis can occur, especially at the C-5 and C-6 levels, in the following situations: 1) pseudomeningoceles are often indicative of root avulsion, but there is evidence that intact roots can exist in a formed one, providing a false-positive result; 2) it is difficult to be sure about the functional assessment of the roots identified in pseudomeningoceles because the preserved anatomical continuity does not necessarily guarantee function; and 3) false-negative results may be found when an avulsion of the ventral rootlets of a spinal nerve occurs without concomitant avulsion of its dorsal rootlets.13 Magnetic resonance imaging is another imaging technique used to evaluate spinal nerve avulsions, but although the modality has been improved over the past years, its sensitivity and specificity are still weaker than CT myelography.2

Intraoperative monitoring techniques, such as SSEP and MEP mapping, are also used to determine the presence of root avulsion. Somatosensory evoked potential monitoring can only indicate the continuity of the dorsal rootlets; the actual state of ventral ones cannot be tested by the modality.16 Motor evoked potential monitoring can detect the integrity of the root, but there are still technical hurdles to overcome before this modality can be applied routinely, because the sensitivity of MEPs to inhalational anesthetics and the excessive stimulus artifact16 generated confuses its interpretation. The analysis of the extent of myelin in the
Fig. 2. Diagrams demonstrating the expected results with intraoperative electrical stimulation in various scenarios of pre- or postganglionic C-5 spinal nerve injuries. A: The C-5 spinal nerve is formed by contributions from the dorsal (sensory) and the ventral (motor) rootlets that emerge from the spinal cord, coalesce into a cervical root, and exit the spine from the C4–5 intervertebral foramen. The LTN is represented as a very proximal branch of the spinal nerve, and its electrical stimulation—with a bipolar stimulator—can be used to test the integrity of the intradural segment of the C-5 ventral rootlets. B: In cases in which both roots are avulsed, the stimulation elicits no muscle response, as there is no continuity of ventral rootlets to the cord. C: A muscle contraction may also be absent if there is only avulsion of the ventral rootlets. In this case, intraoperative SSEP monitoring may provide a false-positive result. D: If there is only a posterior rootlet avulsion, the integrity of the ventral rootlets can be determined by a positive response to electrical stimulation of the LTN. E: In cases of postganglionic injury of the C-5 root, electrical stimulation of the LTN elicits a positive response because this nerve is formed by a branch derived from a segment of the C-5 that is proximal to the level of the rupture. F: A rupture of the C-5 spinal nerve at the level of the intervertebral foramen (that is, proximally from the emergence of the branches to the LTN) may provide an anatomically false-negative result. However, functionally it should not be considered to be false negative because in these situations the root is usually not available for grafting.
root stump has been positively correlated to functional recovery; however, this is an indirect measure of motor component, as myelin is also present in sensory axons. Direct intradural root inspection means an additional surgery (cervical hemilaminectomy), it only shows the anatomical aspects of the lesion, and it cannot yield functional information about a root in question.

In conclusion, to date there is no definitive method that can confirm root avulsion without occasional misinterpretation of the results. Electrical stimulation of LTN is an easily performed test that offers an intraoperative opportunity to check the functional status of the motor axons of the roots that form the nerve, especially at C-5 level. Its results may raise the confidence in other concomitant pre- and intraoperative methods to detect the avulsion of the referred spinal nerve.

**Root Avulsion Epidemiology**

Closed traction is by far the most common mechanism of brachial plexus damage due to trauma. This kind of injury produces vectors of force applied over the roots that may tear them away from the spinal cord, which is observed in 75% of the supraclavicular lesions. The lower roots (C-8 and T-1) are more likely than the upper roots (C-5 and C-6) to become avulsed, as the former are protected by ligaments in the transverse process of the upper cervical vertebrae. As previously described, the combined incidence of lower root avulsion is ~48%, in contrast to the incidence of C-5 avulsion (17%) and C-6 avulsion (14%). Multiple root avulsions is commonly observed in brachial plexus injuries; the resulting combination of root avulsion is dependent on individual anatomical particularities and on the traumatic mechanism itself, and different patterns can be observed.

There are few data about the epidemiology of brachial plexus trauma, but the pattern of isolated of C-5 root avulsion without concomitant C-6 root avulsion is quite rare. In a study of 250 cases of preganglionic lesions in brachial plexus surgery, Herzberg et al. found no cases of isolated avulsion and only 2 cases of C-5 root avulsion in conjunction with C-6 preservation (1 case of C5–8 root avulsion and 1 of C5–T1 root avulsion). In our previous study involving 35 consecutive patients who presented with brachial plexus trauma, we identified no cases of isolated C-5 avulsion. This pattern of root avulsion is very important for the interpretation of the results observed after a LTN electrical stimulation; in case of doubts—if there is C-5 and/or C-6 avulsion—a positive result can ensure the integrity of C-5 nerve root, considering the very lower probability of avulsion of C-5 without an associated C-6 avulsion. This is especially interesting in those cases involving root avulsions when there are doubts about the integrity of the C-5 root on the CT myelography—a negative result for LTN stimulation is highly predictive that the C-5 ventral rootlets are not in continuity with the spinal cord. In these cases, if the posterior roots are not avulsed, the SSEPs may provide false-negative information (Fig. 2C).

**Relevance of the Method of the Study**

The present study was designed to evaluate the possibility of using LTN stimulation as a technique to test the functional status of the ventral rootlets of the C-5 spinal nerve only. Computed tomography myelography was chosen as the gold-standard method to ensure the preservation of C-5 nerve root in those cases in which stimulation results were expected to be positive and for confirmation of avulsion when the results were expected to be negative. To lower the possibility that partial avulsion of the ventral roots of C-5 could confuse the interpretation of the results, we selected a study group in which patients had sustained open sharp injuries and patients in whom preoperative imaging studies had not demonstrated any root avulsion. These situations are strongly suggestive of an extraforaminal injury, and consequently the LTN should be functional, except if it was involved by the lesion itself (which was not observed in any case). A case of C-5 root preservation associated with multiple other root avulsions was also included as was a case of an isolated C-6 root avulsion. In these last 2 patients, a positive response to LTN stimulus in the supraclavicular region should be considered due the preservation of C-5 nerve root motor axons.

The control group included patients whose CT myelography unequivocally demonstrated that C-5 root was torn away from the spinal cord, which was always associated with C-6 avulsion. These cases were useful to demonstrate, in this specific situation, that a negative response to stimulus of the LTN is associated with C-5 avulsion. The best support of this would be the absence of muscular reinnervation in the control patients, using C-5 spinal nerve as graftable stump for the distal targets. To use this criterion, however, would not be acceptable for clinical research in humans because it would not be ethical to use a proven avulsed spinal nerve as proximal stump for grafting. Thus, the conclusions of this study are based on the results obtained with the LTN stimulation compared with the imaging studies results, because we considered there to be no doubt about the avulsion of the C-5 and C-6 roots identified on CT myelography in the control group and about the preservation of C-5 root in the study group.

The C-5 nerve root was used as proximal stump for grafting to the suprascapular nerve and/or to the posterior division of superior trunk in all patients in whom LTN electrical stimulation proved to be positive during the brachial plexus exploration. The surgical results obtained in our cases were associated with good outcomes in the patients in whom this approach was used, confirming the potential of the C-5 spinal nerve as a source of motor axons for the distal targets. Good outcomes were also observed regarding elbow flexion in those cases associated to sharp injuries or to extraforaminal closed rupture of C-6 or superior trunk. In these cases, the C-6 nerve root was used as donor nerve for grafting the anterior division of superior trunk, and the positive result of the stimulus to LTN may also be understood as a sign of integrity of this root. On the other hand, in cases of closed traction associated to lower roots avulsion—in which CT myelography cannot confirm the integrity of C-6—a positive result of the electrical stimulus of LTN cannot guarantee the functionality of the ventral roots of this root, as avulsion of C-6 with preservation of C-5 is not so infrequently observed and a positive response of the test may be consequence of the C-5 root integrity. For example, the patient in Case 8 (Table 1) presented with only C-6 avulsion, and the LTN stimulation was considered positive only due the continuity of C-5 to spinal cord.

In summary, a positive result of applying electrical stimu-
ulation to the supraclavicular segment of the LTN may guarantee the intradural integrity of the C-5 root only. This affirmation is based on the statistical analysis, which demonstrated a lower probability of a C-5 nerve root avulsion without an associated C-6 root avulsion. A positive response may be associated with the integrity of C-6 intradural root only in cases in which CT myelography allows complete identification of the imprints of the dorsal and the ventral rootlets of this spinal nerve. If preoperative imaging does not provide enough evidence to ensure C-6 root intradural continuity, a positive result of the electrical stimulation of the LTN should not be considered as an indicator of its integrity and, consequently, C-6 should not be used as a graftable stump to distal neural elements.

Studies About LTN Semiological Tests

The idea of evaluating LTN function to test the integrity of C-5, C-6, or C-7 is not new, as the functional preservation of muscles innervated by branches derived directly from the roots is highly suggestive of extraforaminal root rupture. The deficit of the serratus anterior function has been classically described as a semiological sign of upper root avulsion (C-5 and C-6). Unfortunately, in cases of complete arm palsy, the classic maneuver of winging the scapula during a forced pushing movement against resistance cannot be feasible (as a functional triceps muscle is needed), and the test of LTN function is not precise. In this situation, clinical examination may not yield sufficient information to confirm the functional assessment of superior roots. Moreover, as previously reported, the scapular stabilization is given by the lower portion of serratus anterior muscle (innervated by the C-7 root), and it is possible that scapular winging may develop in cases in which preservation of the C-5 nerve is associated with avulsion of the C-6 and/or C-7 spinal nerves.

Recently reported by Bertelli and Guizoni, the Shoulder Protraction Test was designed to clinically evaluate the integrity of the upper division of the LTN in cases of total brachial plexus palsy. If the result of the test is considered positive, the authors suggested that this is an indication of an extraforaminal rupture of C-5. However, the test may be inconclusive in partial brachial plexus lesions, such as in Erb–Duchenne syndrome, because it has been reported that other muscles (the pectoralis major and minor) may participate in the shoulder protraction action.

Of importance is the fact that the semiological tests to evaluate the LTN function must be carefully considered, and their results cannot be used as a definitive marker of C-5 root avulsion in every patient.

Limitations of the Technique

Testing the function of LTN during brachial plexus surgery is a simple and feasible maneuver because a peripheral nerve stimulator is usually found in most operating rooms. The test can provide very useful information, but it has limitations that must be borne in mind when analyzing its results. If the LTN stimulus proved to be positive, it is a positive predictive sign of the integrity of the ventral rootlets of C-5 (Fig. 2D and E), and the only exception to this rule is the very rare case of C-5 root avulsion associated with C-6 root intradural integrity. The positive response may also represent the integrity of C-6 nerve root, especially in those cases in which CT myelography findings were considered normal; however, it does not ensure the functional status of the ventral roots of this spinal nerve in cases of multiple root avulsions, because CT myelography misdiagnosis and false-negative results may occur, predominantly at the C-5 and C-6 root level. In the study by Carvalho et al., for example, the authors compared the direct intradural inspection of the roots to CT myelography findings and found that 73.3% of all partial root avulsions occurred at the C-5 or C-6 nerve roots. They suggested that this fact—associated with consequent intradural fibrosis formation and with the narrowing of the subarachnoid space at the upper levels of the spinal cord due to the cervical intumescentia—might play important roles in the false-positive or false-negative radiological diagnosis at these spinal levels.

If the stimulus yields no serratus anterior muscle contraction, it is highly predictive of C-5 ventral rootlet avulsion (Fig. 2B and C). A false-negative result, however, may be identified in the following situations: 1) The LTN may be injured by the trauma itself or during the dissection of the supraclavicular plexus, or it may be involved by scar tissue; these situations may prevent LTN function. 2) There are reports of anatomical variations of the LTN in the retroscalene (as branches to the upper portion of serratus anterior muscle arising directly from C-5 or from the C-5 contribution to LTN, or also branches arising from C-4 spinal root) and these variations may confuse the interpretation of the results. 3) The C-5 root may be ruptured at the level of the intervertebral foramen, even without being avulsed. However, in these cases it should not be considered a “false-negative” result in practical terms, because usually this root is not useful for grafting anyway, unless an intradural approach is proposed (Fig. 2F). These possibilities were not observed in any of the cases in this study, as the LTN was carefully localized and isolated in all of them, and no anatomical variations were observed.

It is very important to realize that the intraoperative stimulation of the LTN should not be used as a single modality to determine if the C-5 root is a viable stump for grafting. This decision must be made in association with the results of the preoperative imaging, with others intraoperative electrophysiological monitoring findings, and with the surgical findings. As it was stated above, the modality may raise confidence in the other techniques, and it must be used only to provide additional information to assist the surgeon in the decision-making process.

Conclusions

Intraoperative electrical stimulation of the supraclavicular segment of the LTN is a useful complementary method to test the functional status of C-5 ventral rootlets in brachial plexus surgery. If the test is considered positive, it is an indication of the integrity of the intradural ventral rootlets of C-5 and may be indicative of extraforaminal rupture of this spinal nerve; if negative, it is highly suggestive of avulsion of the nerve root. There are limitations to the interpretation of the test, but they are infrequently observed.

Acknowledgments

I gratefully acknowledge Prof. Dr. Joaquim Brasil for valuable
technical assistance in editing the manuscript and Dr. Roberto Martins for important advice and discussion.

References
