Correlation between histopathological findings in C-5 and C-6 nerve stumps and motor recovery following nerve grafting for repair of brachial plexus injury

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Object. Proximal spinal nerve stumps were used as donor sites for grafts to repair brachial plexus traction lesions. The quality of the stumps was assessed histologically, and its correlation with the strength attained in the target muscle was studied.

Methods. Four histopathological parameters in frozen tissue sections of 31 C-5 or C-6 nerve stumps were examined by a neuropathologist. The total quantity of myelin was compared with normal values. Also, thick myelinated fibers, fibrosis, and misdirected axons were assessed. Stumps embedded in plastic were used in a morphometric study of myelinated fiber profiles. The fiber density, mean size, and size distribution in five donor stumps were determined; three normal C-5 spinal nerves obtained at autopsy served as controls. Finally, the relative area occupied by fiber profiles and interspace was computed. Linear regression was used as a multivariate analysis, adjusting the outcome of surgical repair for effects of age, interval between trauma and surgery, and graft length.

Histopathological examination showed that the total quantity of myelin in donor stumps used for biceps muscle reinnervation was considerably reduced. On morphometric examination the fiber density did not differ significantly between stumps obtained in patients and control stumps obtained at autopsy. However, a significant reduction of the area occupied by myelinated fibers was measured: from 46% in controls to 13% in patients (p < 0.0001). Likewise, a significant reduction was found in the mean fiber size: from 7.4 μm in controls to 3.7 μm in patients (p < 0.0001).

The relationship between the myelin quantity in the proximal stump and the grade of biceps muscle recovery was statistically significant (p = 0.02). From the 95% confidence interval it was concluded that the estimated effect of a mean increase of myelinated fibers by 25% almost equals an increase in recovery of one point on the Medical Research Council scale (grade range 0–5).

Conclusions. Both histopathological and morphometric examination showed a reduction of the quantity of myelin in C-5 or C-6 stumps used as donor sites for grafts. The amount of myelin is significantly correlated with biceps muscle function after nerve grafting. Because it is possible to assess the quantity of myelin by intraoperative examination of frozen sections, this correlation is potentially useful in the decision-making process of whether to use stumps for grafting or to use nerve transfer procedures to restore biceps muscle function.

Key Words • brachial plexus injury • histopathological analysis • morphometry • nerve graft • spinal nerve • motor function

APID and violent traction to the brachial plexus may cause extensive loss of continuity of nerve fibers. Characteristically, the damage is distributed along the length of the nerve and may involve entire segments. In addition, secondary retrograde changes may further reduce the number of viable axons. The extent of nerve defects necessitates the use of long nerve grafts, which in combination with inevitable fascicular mismatching negatively influences the outcome of repair. Although the efficacy of nerve grafting in improving the outcome in severe brachial plexus traction lesions is no longer subject to debate, the overall results remain limited.

The regenerative potential of the proximal nerve stump is of crucial importance because it constitutes the source of outgrowing axons. One of the problems encountered intraoperatively concerns the extent of proximal nerve stump shortening needed to attain viable nerve fibers. It has been stated that one of the main cause of nerve repair failure is too limited a resection of the injured nerve.

Assessment of the quality of the proximal stump remains difficult despite the use of an operating microscope, particularly in brachial plexus traction lesions. In this specific type of nerve lesion, root filaments may be partially avulsed from the cord, whereas the corresponding spinal nerve is maintained in the intervertebral foramen by fibrous attachments between epineurium and the bony cervical transverse process. Preoperative computerized tomography (CT) myelography and intraoperative somatosensory evoked potential, motor evoked potential, and nerve action potential recordings are helpful in assessing the site and extent of the lesion and facilitate decision making. However, none of these investigational methods is conclusive.

Little is known about the correlation between histopath-
ological findings in proximal spinal nerve stumps and outcome after nerve grafting in traction lesions. In this study, the quality of the proximal stump was assessed both by histopathological investigation and fiber morphometry. In addition, the histopathological score was correlated with the eventual target muscle recovery after nerve grafting.

**Clinical Material and Methods**

**Patient Population**

Between 1978 and 1997, 135 adults suffering from brachial plexus traction lesions were treated at our institution. In 65 cases C-5 and/or C-6 spinal nerve stumps were used in a grafting procedure aimed at restoration of active elbow flexion and shoulder function. Inclusion criteria for this retrospective study were: 1) histological sections of the C-5 and/or C-6 nerve stumps that were of high technical quality and cut well transversely (see Histopathological Analysis); 2) grafts that had been connected from one proximal stump to a single acceptor stump (two proximal stumps used as donors to one acceptor were excluded because in these instances the contribution of the individual proximal stumps to muscle function recovery cannot be determined separately); and 3) a postoperative follow up of at least 2 years. Twenty-five patients (23 males, two females) met these criteria and constitute the basis of the present study (Table 1). All were injured in traffic accidents, 20 while riding a motorbike. Four patients had an associated vascular lesion, one of which was repaired in

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**TABLE 1**

*Nerve grafting procedures in 25 patients with brachial plexus injuries*

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Diagnosis</th>
<th>Age (yrs)</th>
<th>Interval (days)</th>
<th>Donor Site</th>
<th>Acceptor Site</th>
<th>Graft Length (cm)</th>
<th>Tissue Section Score†</th>
<th>Muscle Strength‡</th>
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‡ Tissue section scores are defined in Histopathological Analysis.

§ Indicates patients in whom nerve grafting aiming at biceps reinnervation was not applied.

* AN = axillary nerve; AV = avulsion; AX = axonotmesis; infra = infraspinatus muscle; intervert NE = rupture/neurotmesis at the level of the intervertebral foramen; MN = musculocutaneous nerve; NE = neurotmesis; SN = suprascapular nerve; supra = supraspinatus muscle; TI = inferior trunk; TS = superior trunk.

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the primary admitting hospital. The mean age at surgery was 23 years (standard deviation [SD] 6.1 years). In 24 patients C-5 was used as a donor, and in six of them C-6 was also used. In one case only C-6 was used. A needle electromyographic (EMG) examination was performed before surgery. Absence of nerve action potentials during maximal voluntary effort excluded functional continuity. The CT myelography studies demonstrated normal C-5 nerve roots in 21 cases and normal C-6 roots in 13 cases. The C-5 and C-6 roots could not be judged properly in four cases because of technical shortcomings. The C-6 roots were absent in eight cases (Fig. 1). The mean interval between trauma and referral to the Leiden University Medical Center outpatient clinic was 2.3 months (median 1.5 months, SD 2 months), and the interval between primary consultation and operation was 2.1 months (median 1.3 months, SD 2.6 months), resulting in a mean interval between trauma and operation of 4.4 months (median 3.6 months, SD 3.4 months). The mean postoperative follow up amounted to 35.1 months (median 31.6 months, SD 10.5 months). At 6-month intervals, the force exerted by the deltoid (at least one of the three parts), supraspinatus, infraspinatus, and biceps muscles was assessed according to the Medical Research Council (MRC) scale.29 In evaluating the active elbow flexion, the function of the brachioradial muscle as well as a possible Steindler effect from lower arm muscles were taken into account. Repeat- ed postoperative needle EMG studies of the target muscles were performed in all patients. Reinnervation was documented by the activity pattern at maximal voluntary effort.

Surgical Technique

In all cases, the entire trajectory of the brachial plexus was exposed.35 In cases of total rupture, the decision to perform additional resection of scarred nerve tissue depended on surgical appearance. In the case of neuromas in continuity, electrical stimulation of spinal nerves was applied, with needle EMG recording in corresponding muscles. General anesthesia did not include muscle-blocking agents. If muscle contractions or action potentials were absent, resection was continued until the architecture of the nerve stump appeared normal as seen through the operating microscope. Frozen-section examination was used to assess fibrosis/neuroma and myelin in the C-5 or C-6 proximal stump (Fig. 2). To enable the neuropathologist to cut the tissue perpendicularly and at the correct side, the stump slice was marked distally with surgical ink. The time required for frozen-section examination, which included an osmium stain,11 did not exceed 30 minutes.

The priority of repair was restoration of biceps muscle function. Active glenohumeral function was pursued by means of coaptation of grafts to deltoïd, supraspinatus, and infraspinatus innervating nerves. If only one spinal

FIG. 1. Flow chart of C-5 and C-6 nerve roots showing decision-making process on suitability for nerve grafting in 25 patients with brachial plexus injuries. The numbers represent the number of patients, and the categories are defined as follows: in CT/Rootlets, the rootlets were assessed using CT myelography (+, rootlets in continuity with spinal cord; −, complete root avulsion; ×, rootlets not displayed because of technical inadequacy of the examination). Frozen-section examinations were completed during the operation. Diagnosis: donor site means the site was judged suitable for donor grafts. Avulsion refers to complete root avulsion; empty foramens. Intervent NE = rupture/neurotmesis at the level of the intervertebral foramens; np = not performed; p = performed.

FIG. 2. Photomicrographs showing osmium-hematoxylin-stained frozen sections of C-5 spinal nerve donor and control stumps. Original magnification × 500. Myelin is stained gray-black to gray-brown, cytoplasm is stained homogeneously gray, and the nuclei (predominantly Schwann cells) are stained blue. Upper: Part of the donor stump with only a few large myelinated fibers. The histopathological score of the total quantity of myelin in the entire cross-sectional area was 25 to 50%. Lower: A normal C-5 spinal nerve.
nerve (most often C-5) emerged from the intervertebral foramen, it was used to reinnervate the biceps muscle preferentially if 1) CT myelography demonstrated intact roots; 2) the fascicular pattern of the nerve cross-section on frozen-section examination appeared normal; 3) the frozen section showed more than 50% myelin and only slight fibrosis (see Histopathological Studies); and 4) the size of the cross-sectional area was equal to or larger than that of the fascicles to the biceps muscle in the distal stump. Otherwise, the proximal stump was used for restoration of glenohumeral abduction and exorotation. If both C-5 and C-6 contained myelinated fibers, the stump with the highest quantity of myelin and best-fitting cross-sectional area was selected to reinnervate the biceps muscle. The donor stump was not used for grafting when frozen-section examination after resection up to the foramen continued to show predominant neuromatous tissue or revealed ganglion cells.

For distal coaptation, cords or end nerves were preferred to trunks and divisions. The latter were bypassed to reduce misrouting of axons, despite the disadvantages of increased graft length. In the vast majority of cases, cabled sural grafts were used to bridge the gap. The length of the graft was documented in the surgical record. Coaptations were secured by means of No. 10.0 sutures and/or fibrin glue.

Intraoperative Findings

Of the 25 patients, 12 presented with rupture of C-5 and 13 with rupture of both C-5 and C-6 spinal nerves. In the initial part of the series, frozen-section examination was not routinely performed. Twenty of 25 C-5 and nine of 13 C-6 stumps were examined intraoperatively by means of frozen sections. Twenty-four C-5 and nine C-6 stumps were used as donor sites for grafts. Advanced resection of the remaining C-5 and four C-6 stumps up to the intervertebral foramen continued to show fibrosis and no myelin. Eleven patients were shown to have an avulsion of C-6, which was confirmed by the emptiness of the intervertebral foramen. In one case C-6 was normal (Fig. 1). The spinal nerves C7–T1 were totally avulsed in 12 cases and severed to a lesser degree in all other cases.

Reconstructive Procedures

A total of 39 grafting procedures were performed in 25 patients. The specifications of the various grafting procedures in each individual are listed in Table 1. The C-5 nerve was used as donor to reinnervate the biceps 12 times and to reinnervate deltoid, supraspinatus, and infraspinatus muscles 20 times. Grafts from C-6 to biceps muscle, innervating nerve fibers, were used seven times. Two other grafting procedures from C-6 were excluded from the statistical analysis. In one patient (Case 25) in whom C-5 was grafted to the musculocutaneous nerve, C-6 was used as a donor to the median nerve. In the other one (Case 22) in whom C-5 was grafted to the axillary nerve, both C-5 and C-6 were donors to the lateral cord. Nerve transfers (for example, accessory to suprascapular or intercostal to medial pectoral) have been performed in addition to the grafting procedure but their evaluation is beyond the scope of this study.

The mean graft length used to reinnervate the biceps muscle measured 11.8 cm (median 11.5 cm, SD 6.8 cm), 8.8 cm to the deltoid (median 8.7 cm, SD 3.6 cm), and to the combined supraspinatus and infraspinatus muscles it was 6 cm (median 6 cm, SD 1.5 cm).

Histopathological Studies

Sections obtained from the C-5 and C-6 proximal stumps in 65 patients were collected from the archives of the Department of Pathology. Only sections suited to proper analysis were selected, that is, those with transverse orientation and successful technical embedding and staining procedures. Twenty-four C-5 and seven C-6 proximal stumps met both the surgical and histopathological criteria. If necessary, more sections were cut and stained. In addition, three C-5 stumps were acquired at autopsy from control individuals who had no history of brachial plexus lesion or other diseases that might affect peripheral nerves.

The majority of frozen sections had been prepared with hematoxylin and eosin, Verhoeff van Gieson’s, and, during the last 4 years, osmium–hematoxylin stains. All three staining techniques allow identification of myelin: in frozen sections myelin stains purple with hematoxylin and gray-black to gray-brown with the van Gieson’s and osmium stains; fibrosis stains red with the van Gieson’s stain. In four cases only paraffin-embedded tissue was available; these were stained with hematoxylin and eosin, Verhoeff van Gieson’s, and Klüver-Barrera stains.

Histological Analysis

The tissue sections were examined and scored by one of the authors (S.G.v.D.) without knowledge of the previous histopathological diagnosis and clinical data. We focused on four different aspects. 1) The total quantity of myelin in the entire cross-sectional area of the donor stump represented by the stained myelin of the thin and thick fibers was scored semi-quantitatively on a scale of 0 to 3 (0 = nil; 1 = slight; 2 = moderate; 3 = intense). The amount of stained myelin in a normal spinal nerve is 100%. 2) The percentage of thick myelinated fibers among the total number of myelinated fibers. In two arbitrarily chosen areas of each stump the number of thick myelinated fibers in a total of 100 myelinated fibers was counted. The size of the myelinated fibers was assessed using the maximum diameter of a large Schwann cell nucleus (≥ 5 μm) in the area of interest as a reference. Normal peripheral nerves consist of a bimodal distribution of myelinated fiber sizes with a peak at 4 μm and a peak at 11 μm. Based on these data we considered a myelinated fiber to be thick when it was at least 1.5 times larger than the maximum diameter of a large Schwann cell nucleus (≥ 7.5 μm). This method ensured an unbiased internal control in each section. 3) The total amount of fibrosis within the endoneurium, perineurium, and epineurium on a scale of 0 to 3 (0 = nil; 1 = slight; 2 = moderate; 3 = large/neurona). 4) Aberrant or misrouted myelinated axons in the perineurium on a scale of 0 to 3 (0 = absent; 1 = few; 2 = moderate number; 3 = many).

Statistical Analysis

Linear regression was used as a multivariate analysis.
Histological parameters of C-5 and C-6 proximal stumps used as donor sites to reinnervate the biceps muscle*

<table>
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<tr>
<th>Parameter</th>
<th>C-5 Score</th>
<th>C-6 Score</th>
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<tr>
<td>myelin</td>
<td>1.6 ± 1.2</td>
<td>1.7 ± 0.9</td>
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<tr>
<td>thick fibers</td>
<td>9.7 ± 9.9</td>
<td>9.0 ± 13.5</td>
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<tr>
<td>fibrosis</td>
<td>1.6 ± 0.9</td>
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<td>aberrant fibers</td>
<td>1.3 ± 1.1</td>
<td>0.8 ± 1.2</td>
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* Myelin, fibrosis, and aberrant fibers were scored on a scale ranging from 0 to 3. Thick fibers are expressed as a percentage of the total number of myelinated fibers (see Histological Analysis). Values are expressed as the mean ± SD.

For each grafting procedure, the simultaneous association between the four aforementioned histological parameters and the strength of the target muscle (Table 1) was analyzed separately. All statistical tests were performed within the framework of linear regression models to determine the significance of the association of each histological parameter with the muscle strength. Outcome was adjusted for the possible confounding effects of other independent variables including patient age, interval between trauma and operation, and graft length. The degree of biceps muscle reinnervation apparently does not depend on the choice of proximal stump C-5 or C-6,28 thus allowing clustering of grafting procedures. A significance level of 0.05 was applied.

The attained muscle strength may be influenced by an increase or decrease of 1 U on the scoring scale in one of the four histological parameters assessed in the donor stump. Therefore, the regression coefficient with the 95% confidence interval (CI) was determined, enabling the measurement of a difference in muscle strength in the hypothetical situation of two patients who are identical in all variables except in 1 U of a histological parameter. Using the regression coefficient, the effect of a difference of 1 U on the 0 to 3 myelin scale on muscle strength was estimated.

Fiber Morphometry

From the group of 31 proximal spinal nerve stumps selected for histopathological analysis (see Histological Studies), four C-5 and one C-6 deeply frozen stumps (−80°C) were randomly taken for morphometric analysis of myelinated fibers.

The deep-frozen stumps obtained from patients treated for brachial plexus traction injury and retrieved from the tissue bank were thawed and fixed in a modified Karnovsky fixative at room temperature for 7 days. The fixative was refreshed several times. The control stumps obtained at autopsy were treated identically, including initial deep freezing. After fixation, the stumps were cut perpendicular to their long axis into 200-μm slices by using a vibratome. The slices were osmicated and embedded in plastic. Semithin (1-μm) sections were cut from the plastic blocks on an ultramicrotome (Reichert OM-2; Reichert–Jung, Heidelberg, Germany) and stained with toluidine blue.8 In osmicated tissue, toluidine blue stains myelin sheaths dark blue, whereas the axon remains nearly unstained. This provides appropriate conditions for (semi)automatic light microscopic analysis of myelinated fiber profiles as small as 1.2 μm in diameter.9

Morphometric Analysis

In a semithin section of each of the stumps, five sample areas of 9200 μm² were randomly selected for (semi)automatic measurement of all myelinated fiber profiles with an image analyzing system (VIDAS; Zeiss Kontron, Oberkochen, Germany).9 The total number, density, size (mean area), and size distribution of the myelinated fiber profiles were determined for each sample area. Also, the areas occupied by the fibers and the interspace were computed. The averaged data of five samples were considered representative of the stump.

For statistical comparison between the combined data of the different stumps, the Student t-test and Kolmogorov–Smirnow tests were used, the former for comparison of the area and density means, the latter for comparison of the size distributions. Samples were considered significantly different when the probability value was less than 0.05.

Results

Histological Analysis

An example of an osmium-hematoxylin–stained frozen section of spinal nerve C-5 is shown in Fig. 2 upper. The total quantity of myelin in donor stumps used for biceps muscle reinnervation was reduced from a score of 3 to a mean of 1.6 (SD 1.2) in C-5 stumps and 1.7 (SD 0.9) in C-6 stumps. The percentage of thick myelinated fibers (≥ 7.5 μm) in the total of myelinated fibers was clearly below the level of a normal spinal nerve (Fig. 2 lower). Nearly all proximal stumps contained at least some slight fibrosis and a few aberrant myelinated axons (Table 1)
Results of nerve grafting for brachial plexus traction injury

The mean MRC grade was 3.1 (SD 1.6). Five patients (26%) had Grade 3, and five (26%) had MRC grades of 4 or greater. Five patients (26%) had Grade 3, and five (26%) had Grade 2 or less. The mean MRC grade was 3.1 (SD 1.6).

Correlation Between Histopathological Findings and Muscle Strength

In the multivariate analysis, the relation between biceps muscle strength and percentage of myelinated axons was statistically significant (p = 0.02, Table 3). The histological parameters of thick fibers, fibrosis, and aberrant axons were not significantly associated with biceps muscle strength. In a similar statistical analysis of deltoid, supraspinatus, or infraspinatus muscle strength, again none of the histological parameters appeared to be significantly associated with strength.

Nerve grafting was aimed at recovery of biceps muscle function in 19 of the 25 patients. Nine (47%) of them attained biceps muscle strength MRC grades of 4 or greater, five patients (26%) had Grade 3, and five (26%) had Grade 2 or less. The mean MRC grade was 3.1 (SD 1.6).

The mean force exerted by the deltoid, supraspinatus, and infraspinatus muscles was less (Table 4).

Morphometric Analysis

Toluidine blue–stained myelinated fiber profiles of a C-5 donor and control stump are illustrated in Fig. 3. Parameters of myelinated fibers in donor and control stumps are presented in Table 5. These stumps did not differ with respect to the fiber density. However, with respect to all remaining parameters, including the mean size, the total area occupied by fiber profiles, and the percentage of profiles larger than 40 μm² (> 7.1 μm in diameter), significant differences were found (p < 0.0001; Fig. 4). Donor stumps contained more thin fibers compared with controls and, with the exception of Case 22, large fibers were rare (< 1%).

A statistical analysis of the correlation between the strength of the target muscle and the morphometric fiber parameters could not be performed. It turned out that nerve grafting to restore biceps muscle function was performed in only three of the five patients in the study.

Statistical comparison of donor and control stumps (Table 5) revealed that even in the same group differences existed. Control stumps only differed with respect to their fiber size distribution, but stumps obtained from patients also differed in fiber density and mean fiber size. Donor and control stumps differed with respect to both mean size and size distribution.

Discussion

Severe brachial plexus traction injuries result in root avulsions and/or rupture of spinal nerves. The first priority in brachial plexus reconstructive surgery is restoration of elbow flexion. In the case of rupture, shortening of proximal stumps is obligatory to obtain healthy nerve tissue suitable for grafting. However, even at the lev-
el of the intervertebral foramen, the transected stump may reveal traumatized or degenerated tissue and a disturbed fascicular architecture. The intraoperative decision whether to include a particular spinal stump in the repair plan so far lacks a solid basis. Information on the presence of myelin and fibrosis in spinal nerve stumps can be acquired intraoperatively by frozen-section examination. Myelin formation is triggered by the axon, and myelin disappears when the axon degenerates. The presence of myelin in the proximal stump, therefore, indicates viable axons. In this retrospective study—the association of four histopathological parameters, 1) myelin quantity; 2) thick myelinated fibers; 3) fibrosis; and 4) aberrant axons—with the attained muscle strength following nerve grafting was assessed. The major finding is a significant correlation between the quantity of myelin in the entire cross-sectional area of the proximal stump and the strength of the biceps muscle. The mean quantity of myelin in the histopathological assessment of C-5 and C-6 stumps used as donor sites for grafts to restore biceps muscle reinnervation was reduced from a score of 3 to scores of 1.6 and 1.7, respectively. In the morphometric analysis, a significant reduction (p < 0.0001) of the area occupied by myelinated fiber profiles was found when compared with stumps of healthy controls (Fig. 4 left). From the 95% CI we concluded that a myelin quantity increase of 1 U on a scale of 0 to 3 (which represents a mean increase of 25% myelin) results in an average increase in biceps muscle strength of at least 0.13 and at most 1.65 on the MRC scale. The estimated effect of a mean increase of 25% myelin is an increase of 0.9 biceps muscle strength (Table 3). This is almost one point on the MRC scale and thus can be considered to be of clinical importance.

The minimum quantity of myelin that has to be present to “guarantee” the recovery of biceps muscle strength of at least MRC Grade 3 is not yet known. The overall recovery rate of the biceps muscle to MRC Grade 3 or greater in this study was 74%. Because anterior root filaments are shorter than the posterior ones, they rupture first. In the case of single ventral rootlet avulsion or preganglionic rupture of the entire root, all stained fibers must be sensory. In these instances, the resulting myelin quantity is theoretically reduced to approximately 50%. It is unknown, however, whether the quantity of myelin in the cross-sectional area of a healthy proximal stump is equally representative of sensory and motor axons. Probably, however, a reduction by more than 50% is indicative of a degraded regenerative motor capacity.

The lack of a correlation between the quantity of myelin and deltoid, supraspinatus, and infraspinatus muscle strength is a result of the surgical strategy. Without exception the transsectional area of the distal stump toward the biceps muscle was fully covered by nerve grafts. This contrasts with the grafting procedure toward the shoulder muscles, in which distal coverage was not complete in several instances.

The histopathological examination of donor stumps showed a mean of ± 9% of thick myelinated fibers. Normal peripheral nerves contain approximately 40% of fibers with a diameter of 7 μm or more and, therefore, the number of thick fibers in donor stumps appears to be reduced. This histopathological observation is supported by the morphometric analysis of the five sampled donor stumps, which showed that the mean computed fiber size was significantly reduced (p < 0.0001) from 7.4 μm in controls to 3.7 μm in patients (that is, from 43 to 11 μm²). Less than 2% of the fibers were larger than 7.1 μm (40 μm²), as compared with 31% in controls (Table 5). Apparently, the relative number of thick fibers in the donor stumps is reduced, indicating a change in fiber composition. This may be associated with a decreased regenerative potential, implicating poorer results of nerve grafting. A reduction of thick fibers has been described following nerve lesion and frustrated regeneration. In this study, the correlation between the percentage of thick myelinated fibers and restored biceps muscle function was not signif-
significant. Therefore, we concluded that a proximal stump may be sufficient for grafting regardless of the fact that the relative number of thick fibers is reduced.

The morphometric analysis showed that the size distribution of fibers in donor and control stumps was significantly different (Fig. 4 right). The bimodal distribution of fiber diameters with peaks at 4 μm and 11 μm in controls, which is in concordance with that of normal peripheral nerves, could not be found in donor stumps. Instead, the relative number of fibers with a diameter smaller than 7.1 μm was increased in patients. Fibers of donor stumps together occupy only approximately one quarter of the area of those found in controls (Fig. 4 left). Thick and thin fibers can be sensory or motor. In view of the relatively low percentage of thick fibers and, therefore, relatively high percentage of thin fibers, it is likely that thin fibers account at least partly for the restoration of biceps muscle function. A considerable proportion of the thin fibers must, therefore, actually be successfully regenerating motor fibers.

In studying the microscopic sections of the proximal stumps we noted the presence of aberrant axons. A comparable histological phenomenon has been described in graft sections obtained in monkeys following tibial nerve repair. Fibrosis in the pathway of regenerating axons may misdirect these axons to aberrant sites outside the endoneurium, which should decrease the chance that these outgrowing axons reach a proper place in the distal acceptor stump. Surprisingly, we found no significance between the varying amount of fibrosis and aberrant axons and attained biceps muscle function. Apparently, the quality and vitality of the remaining myelinated axons in the definitive proximal stump are of more importance for recovery of biceps muscle function than both the presence of fibrosis and aberrant axons. It should be taken into account that stumps with a substantial amount of fibrosis were not used. Quite often, more proximal resection to potentially more viable tissue is not possible in brachial plexus traction lesions even after removing the bone boundary of the intervertebral foramen.

Technically it is not yet possible to provide the surgeon with data from computerized morphometric analysis of nerve stump histopathological studies during the surgical procedure. At present, this technique is still far too time consuming and labor intensive, but technical progress and computer developments will no doubt solve these problems in the near future. Until then, the only method for acquiring information on the quality of the donor site is gross estimation of myelin content on frozen sections.

The assessment of the quantity of myelin requires some technical experience. Care should be taken not to underestimate the actual amount of myelin, especially when the proximal stump is swollen due to edema. There may be interobserver variation, but current techniques enable any neuropathologist to judge whether a stump is suitable for transplantation.

Until now, histological characteristics of the donor site have not been taken into account in published studies on the results of brachial plexus grafting. Biceps muscle recovery to MRC Grade 3 or greater has been achieved in 58 to 64% of C-5/C-6 musculocutaneous nerve grafting procedures. Patient groups seem similar as far as interval between trauma and operation and mean graft length are concerned. It is likely that the relatively good biceps muscle recovery in the present series (74%) is due to selection. Intercostal–musculocutaneous nerve transfer results in biceps muscle strength of Grade 3 or greater in 50 to 74% of cases and offers a reasonable alternative whenever the quality of the donor nerve is poor.

Intraoperative recordings of somatosensory evoked potentials may have an additive value in the assessment of (preganglionic) root avulsions, but the efficacy of this measuring method has not yet been proven. The same holds for intraoperative nerve action potentials for the assessment of the status of the roots and transcranial electrical motor evoked potential recordings.

Use of CT myelography enables an accurate assessment of the integrity of the nerve roots in 85% of cases. At least in the remaining 15% of cases, perioperative frozen-section examination is helpful, because a largely viable nerve excludes root avulsion or intradural rupture. The use of an endoscope to visualize the root filaments is still experimental.

Conclusions

The myelin quantity in the C-5/C-6 spinal nerve stump in traction lesions is clearly related to biceps muscle function recovery. Because it is possible to assess the myelin quantity by intraoperative frozen-section examination, this technique is of potential value in decision making. If less than 50% myelin is present, the use of C-5/C-6 stumps in a transplantation procedure aiming at biceps muscle reinnervation should be abandoned in favor of a nerve transfer procedure.

References


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