Clinical and electroneurographic evaluation of sensory/motor-differentiated nerve repair in the hand

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In 17 patients acetylcholinesterase activity was used to differentiate between sensory and motor fascicles in median and ulnar nerve repair of the hand. Eleven patients received follow-up evaluation 1 to 11 years after surgery, and at that time clinical and electroneurographic examinations were performed to evaluate the techniques. Clinical examination showed that four patients had regained on average 71.9% of hand function after median nerve repair, one patient had regained 83.6% of hand function after ulnar nerve repair, four patients had regained on average 53.3% of hand function after median and ulnar nerve repair, and two patients had regained on average 43.5% of hand function after median and partial ulnar nerve repair. The contribution of the ulnar nerve to reinnervation of the thenar muscles was 68.5%, whereas the median nerve did not contribute to reinnervation of the hypothenar muscles. Distal latencies for the median nerve showed a delay of 36% of the upper limit of normal value, and those for the ulnar nerve revealed a delay of 21.5%. This study demonstrated that sensory/motor-differentiated nerve repair of the median and ulnar nerves is possible and can be proven electroneurographically.

KEY WORDS • nerve injury • acetylcholinesterase • median nerve • ulnar nerve • sensory/motor differentiation

MATCHING the correct fascicles in peripheral nerve repair remains a great challenge. Various efforts have been made to achieve this, and currently there are four techniques available for fascicular sensory/motor differentiation: anatomical, \(^{26,27}\) electrophysiological, \(^{10,13,25}\) histochemical, \(^{8,9,11,15,23,28}\) and immunohistochemical (G Xiao-Song, et al., unpublished data). Histochemical identification of axonal acetylcholinesterase (AChE) activity, which is present in motor fibers, is a very useful and specific approach for differentiating motor from sensory fascicles. The demonstration of the distribution of the axonal carbonic anhydrase (CA) activity \(^{4,20,21,24}\) is a faster histochemical procedure; however, we have shown that CA activity can be observed not only in certain skin afferents but also in most of the muscle afferents in motor fascicles. Therefore, this method is less reliable than the determination of AChE activity.

The technique of staining for AChE was introduced in 1973 by Gruber and Zenker. \(^{14}\) Further clinical and experimental studies were made by Freilinger, et al., \(^{8,9,11}\) and, since 1979, the method has been applied in humans to nerve injuries of the wrist. Initially, a two-stage procedure was necessary because of the long incubation time required for the staining procedure. Recently, the time for incubation in the staining procedure has been reduced significantly, and results are available within 4 hours. \(^{23}\) A one-step procedure is possible if the biopsy is obtained under local or plexus anesthesia. To our knowledge, this is the first report of functional and electroneurographic results after sensory/motor-differentiated nerve repair at the wrist level. The aim of this study was to examine clinically as well as electroneurographically patients treated by this technique and to analyze the functional results.

Clinical Material and Methods

Case Material

Between 1979 and 1991, 17 patients (10 men and seven women) underwent median or ulnar nerve repair after sensory/motor differentiation. The technique was not used in every patient because the laboratory facilities were not always available. Eleven patients returned for follow-up evaluation; two were unreachable for follow-up study and four patients were excluded because of the short time since the operation.

The mean age of the 11 patients reviewed was 30 years (range 20 to 55 years) when the accident occurred. In seven patients the right hand was injured and in four
patients it was the left hand. The trauma was a cut injury in 10 patients and a crush injury in one. Only one patient had an isolated nerve injury; in the other 10, additional structures such as tendons, main arteries, and bones were injured. The median nerve alone was injured in four patients, the ulnar nerve alone in one patient, the median and the ulnar nerves were injured in four patients, and two patients sustained median and partial ulnar nerve injury. The patients were examined clinically and electroneurographically.

**Clinical Examination**

The clinical examination was based on an evaluation score designed by Millesi.\(^1^\) In this scoring system, the anatomical structures were assessed by the range of motion and the condition of the joints. For testing of sensibility a two-point discrimination (2-PD) test and a pick-up test were performed. Force measurements were performed as well. According to a system of multiplication of all values, a maximum score of 10,000 can be achieved.

**Anatomical Functioning and Sensation Testing.** During the anatomical examination, individual function for all fingers is examined. Normal anatomical function of the hand is scored at 1250 (wrist 250, thumb 400, index finger 200, middle finger 200, ring finger 100, and small finger 100).

For sensation evaluation, static 2-PD testing of each hemipulp is evaluated. Lack of sensation is scored as 0, pain and touch sensation is scored as 0.1, protective sensation as 0.2, a 2-PD of 12 mm or more as 0.3, a 2-PD between 7 and 11 mm as 0.4, and a 2-PD of 6 mm or less as 0.5. Therefore, normal sensation of both hemipulps together is 1. The number 1 is added, which results in 2 for normal sensation for each finger (the addition of 1 is needed because a multiplication factor of 1 does not make sense). If equal values of 2-PD are achieved in each hemipulp, numbers like 0.2, 0.4, and 0.6 up to 1 are gained. The numbers between represent different values for each hemipulp.

The time needed to perform a standardized pick-up test in the blindfolded patient is registered for both hands. The values for the injured hand are divided by the values for the uninjured hand, and the number 1 is again added. This value for the pick-up test is multiplied by the anatomical scores of the wrist joint, and the anatomical scores for each finger are multiplied by the sensation factor for each finger. A hand with normal anatomical function and normal sensation is scored as 2500 ((wrist 250 × 2) + (thumb 400 × 2) + (index finger 200 × 2) + (middle finger 200 × 2) + (ring finger 100 × 2) + (small finger 100 × 2)).

**Strength Measurements.** For strength measurements, the power grip, pinch grip, and key grip are examined and both hands are compared. A strength factor of 4 can be achieved as a maximum. The total score of normal anatomical function and sensation (maximum score 2500) is then multiplied by the normal strength factor 4 and the result is a maximum score of 10,000 (equivalent to 100%). The values achieved in the injured hand may easily be converted in percentage values and compared with 100% of normal hand function. If this system is adapted for use in patients with complete ulnar nerve palsy, a score of 2300 or 23% of normal function is achieved. After complete median nerve loss, hand function is reduced to 3500 or 35%. After complete median and ulnar nerve loss, hand function is reduced to 1200 or 12%. The improvement rate was estimated as the difference between these complete nerve loss scores and scores of regained hand function.

**Electroneurographic Examination**

Electroneurographic examination of the median and ulnar nerves was performed based on normal values as described by Ludin.\(^1^\) The compound muscle action potentials of thenar and hypothenar muscles were assessed after stimulation of the median as well as the ulnar nerve. The two values obtained for each muscle group were added and defined as 100% of compound muscle action potential. Distal latencies and sensory antidromic conduction velocities were also measured.

**Surgical Technique**

The biopsy was usually obtained under local or plexus anesthesia, not in the main operating theater, but under sterile conditions in a small adjacent room in order to keep use of the operating room to a minimum. The main repair was begun depending on the additional injured structures.

Two marking sutures were placed subepineurally in the proximal stump for better orientation (Fig. 1). Then the biopsy specimen was taken and the histochemical staining performed. Under the microscope, motor fascicles were identified by deposits of AChE within the myelin sheath. A photomicrograph was obtained and the motor portion circled (Fig. 2). This picture was brought to the operating room. In the distal stump, the motor fascicle was identified by tracing it back from the muscle entry. Also, sensory fascicle groups were

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**Fig. 1.** Drawing of the proximal nerve stump, which is marked with two sutures of different color (A and B). The biopsy is obtained complete with markers, and attached to a coverglass for microscopic examination.
Sensory/motor-differentiated nerve repair in the hand

TABLE 1
Functional outcome after median and ulnar nerve repair at the wrist*

<table>
<thead>
<tr>
<th>Source of Data</th>
<th>Anatomical Examination†</th>
<th>Pick-Up Test</th>
<th>Sensation Factor</th>
<th>Strength Factor</th>
<th>Achieved Hand Function (%)</th>
<th>Improvement Rate (%)</th>
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<tr>
<td>normal value</td>
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<td>2</td>
<td>4</td>
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<td>1.6</td>
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<td>1.8</td>
<td>1.6</td>
<td>1.6</td>
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<tr>
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</tr>
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</table>

* Evaluation based on the system of Millesi. Normal value: maximum = 10,000 points (100% of hand function). After complete dissection of median nerve, hand function is reduced to 35%; after complete dissection of ulnar nerve, hand function is reduced to 23%; after complete dissection of median and ulnar nerves, hand function is reduced to 12%. Improvement rate is the difference between 35%, 23%, or 12% and % value of achieved hand function. Cases 1-4: lesion of the median nerve alone; Case 5: lesion of the ulnar nerve alone; Cases 6-9: lesion of the median and ulnar nerves; Cases 10 and 11: lesion of the median nerve and partial lesion of the ulnar nerve.
† Range of motion and condition of the joints.

Results

Clinical Examination

In all 11 patients, the follow-up evaluation was performed a mean of 1.5 years (range 1 to 11 years) after the operation. Ten patients remained right-handed after the accident and one patient became ambidextrous. None of the patients had to give up their profession because of the accident; they returned to work after an average of 5 months (range 1 to 12 months). The results of the functional examination are shown in Table 1.

Cases 1 to 4 had lesions of the median nerve. In these patients, median nerve repair resulted in an average hand function value of 71.9 ± 16.1% (± standard deviation) of normal, denoting an average improvement of 36.9 ± 15.7%. Ulnar nerve repair in Case 5 resulted in 83.6% of normal hand function, which is an improvement of 60.6%. Four patients (Cases 6 to 9) had lesions of the median and ulnar nerves. They regained an average hand function 53.3 ± 11.5% of normal, with an average improvement of 41.3% ± 11.5%. The last two patients (Cases 10 and 11) underwent median nerve repair and partial ulnar nerve repair, and achieved a hand function 72% and 15% of normal, respectively. In these patients we did not compare the obtained values of hand function with the basic values of median and ulnar nerve injury because the ulnar nerve was only partially injured. One patient (Case 11), who sustained a severe crush injury, did not improve at all.

Anatomical recovery (motion of fingers) is expressed in Table 1 according to the results of anatomical examinations and strength factor. Sensory recovery is expressed by the "sensation factor" for each finger and the pick-up test (Table 1). The sensation factor of 1.6 means a 2-PD of at least 12 mm. This was taken as the cut-off level. In Cases 1 to 4 with lesioning of the median nerve, a sensation factor of 1.6 could be achieved in 14 of 16 fingers. In two fingers the sensation factor was 1.8 and in three fingers it was 2.0. One patient (Case 5), who sustained an ulnar nerve injury achieved excellent sensation factors of 1.7 and 1.9. After lesions of the median and ulnar nerves in four patients (Cases 6 to 9), a sensation factor of 1.6 was achieved in 15 of 20 fingers. In four fingers the sensation factor was more than 1.6. Case 10 achieved values of 1.6 and 1.8.

![Fig. 2. Photomicrograph of the proximal stump of a human median nerve. The motor fascicles are circled (white arrow). The suture marks (black arrows on the radial and dorsal surfaces of the nerve) facilitate exact positioning of the fascicles.](image-url)
Case 11 achieved reasonable values only for the fingers innervated by the ulnar nerve.

Electroneurographic Examination

After the coapted median and ulnar nerves were stimulated, compound muscle action potentials could be obtained from thenar as well as from hypothenar muscles in all patients (Table 2). In median nerve injuries, compound muscle action potentials of the thenar muscles could also be obtained after stimulation of the ulnar nerve. This indicates a mixed innervation pattern, which influences reinnervation. After stimulation of the median nerve, compound muscle action potentials of hypothenar muscles could be obtained in only one patient. The mean value of compound muscle action potentials for thenar muscles was 8750 μV, and for hypothenar muscles it was 11,250 μV. The ulnar nerve contributed a mean of 68.5% to reinnervation of the thenar muscles. Measurement of distal latencies showed a delay of 36% of the upper limit of normal value for the median nerve and a delay of 21.5% for the ulnar nerve. Sensory antidromic conduction velocities were only measurable if the 2-PD was below 20 mm. One patient (Case 5) refused the electroneurographic examination since he had regained an excellent clinical result.

Discussion

Complete restoration after peripheral nerve repair is rarely accomplished in adults. The new neurites must pass through different stages of myelination in order to become a functional mature fiber, and the newly formed fibers must make contact with the appropriate motor and sensory targets. Our patient was 11 years old. The mean value for the compound muscle action potentials was 7450 μV, and the ulnar nerve contributed a mean of 68.5% to reinnervation of the thenar muscles. Measurement of distal latencies showed a delay of 36% of the upper limit of normal value for the median nerve and a delay of 21.5% for the ulnar nerve. Sensory antidromic conduction velocities were only measurable if the 2-PD was below 20 mm. One patient (Case 5) refused the electroneurographic examination since he had regained an excellent clinical result.

Electroneurographic Examination

Many factors, including surgical technique, age of the patient, and end-organ survival, influence the functional result following nerve repair. Of these factors, we can influence only the surgical procedure in order to achieve accurate alignment in mixed peripheral nerve repair. We consider identification of AChE activity a good means to reach this aim. Although demonstration of CA activity is a more rapid method, it is not specific for motor axons, and therefore not suitable for sensory/motor differentiation. A more rapid method for AChE staining has been reported in the literature, but that technique is less reliable because the classification is based on “irregular masses.” In our experience, a longer incubation period is necessary to demonstrate AChE activity in myelinated fibers. To overcome the time period required for staining, the biopsy is taken under local or plexus anesthesia prior to the main repair.

Clinical Examination

Most reports concerning sensory/motor-differentiated nerve repair present experimental but not clinical results. Only Van der Put, et al., and Hakstian were able to show an improvement by their technique of sensory/motor differentiation in comparison to nerve repair without that method. We could find no previous reports on results of the method we used. In our functional examination, we found an average regained hand function of 71.9% after isolated median nerve repair, and of 53.3% after median and ulnar nerve repair. This is a satisfactory result compared to hand function of 35% after isolated median nerve loss and of 12% after median and ulnar nerve loss. Only one patient who sustained a severe crush injury with median and partial ulnar nerve loss did not improve at all. Crush injuries usually have a poor functional outcome.

Electroneurographic Examination

Our measurements showed high values of compound muscle action potentials in all patients for thenar and hypothenar muscles. Although the ulnar nerve plays an important role in reinnervation of the thenar muscles, compound muscle action potentials values after stimulating the median nerve indicate that selective coaptation had taken place. Compound muscle action potentials values after stimulation of the ulnar nerve are higher than those after stimulation of the median nerve. This may be due to a larger motor portion in the ulnar nerve at the wrist level compared to the median nerve. The values of distal latencies also showed reasonable results. In our patients, sensory antidromic conduction velocities could be measured only if 2-PD was less than 20 mm. It is interesting to note that Almquist, et al., did not find a correlation between sensory antidromic conduction velocities and 2-PD.

A mixed innervation pattern of thenar muscles is common and advantageous for the functional outcome. At the time of injury, however, the contribution to reinnervation by the ulnar nerve is not known and therefore not reliable; thus, the effort of matching appropriate fascicles is highly relevant.

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Surgical Technique

The biopsy is easy to perform. Initially, the time-consuming staining procedure was a disadvantage. Now we are able to obtain a result within 4 hours. Further improvements are currently being introduced and will lead to an additional reduction of time in the near future.

Our technique of sensory/motor differentiation by means of AChE staining allows accurate alignment of fascicles, so they can reach the appropriate target. Clinical examination showed good sensory and motor recovery. The electrophysiological evaluation revealed a mixed innervation pattern of thenar muscles.

References


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