PAIN ON STIMULATING THE DISTAL SEGMENT OF DIVIDED PERIPHERAL NERVES

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During neurorrhaphy under local anesthesia it was observed that stimuli applied to the distal end of a severed peripheral nerve frequently caused pain. It was also found that the distribution of pain so induced could be shifted by blocking an adjacent intact nerve. The theoretical and practical implications of these observations led the authors to submit the following case reports.

CASE REPORTS


J.F.D., aged 36, sustained a gunshot wound of the lower third of the left arm in March 1945. During debridement it was noted that the median nerve was completely severed. There had been no recovery of median nerve function, either sensory or motor, since the injury.

On Sept. 5, 1945, approximately 6 months later, exploration revealed a gap between the two ends of the divided nerve which was too great to permit immediate repair. The proximal and distal segments were therefore dissected free of the surrounding tissues and thus mobilized so that a temporary end-to-end “bulb” suture could be done, in order to stretch the nerve sufficiently for subsequent anastomosis.

On Oct. 24, 1945, 7 weeks after the first-stage procedure, the median nerve was again exposed, under local infiltration of the skin and the proximal or central stump of the nerve. The proximal stump was then cleanly cut at the junction of the neuroma and normal-looking nerve. No pain was experienced during this part of the procedure.

The distal segment of the nerve was now cut in like fashion, no anesthetic agent having been applied to it. On making this distal cut, a sensation of pain was felt in the mid-palmar area. Faradic stimulation of the distal stump was then carried out, which elicited a burning type of pain in the mid-palm regardless of whether the bipolar electrodes were placed on the cut section of the nerve or on its surface. (A Hinsey-Geoghan stimulator was used at a current strength of 1.0 to 1.5 volts; 60 cycles; with the bipolar electrodes 3 mm. apart.)

Mechanical and electrical stimulation of the adjacent tissues did not elicit pain in this case. No motor response accompanied these tests. The distal segment of nerve was carefully walled off with dry gauze pads for a distance of 5 cm. to prevent “spread” of electrical current. (By mechanical stimuli is meant compression of the nerve with delicate bayonet forceps, which elicited responses similar to electrical stimulation.)

The ulnar nerve was now blocked with 2 per cent procain just above the olecranon groove, and the distal end of the median nerve again stimulated. This time the patient complained of pain over the dorsal surface of the 2nd and 3rd fingers instead of the palm.

Since the median nerve was completely severed, the only central connections were the ulnar and radial nerves. The ulnar nerve evidently participated in the relay of impulses responsible for a feeling of pain in the palm, for when it was blocked the pain was then referred to the dorsal aspect of the 2nd and 3rd fingers. The sensation of pain must then have been a function of the sole remaining nerve to the hand: the radial.

Microscopic examination of cross sections of the proximal and distal segments of the sev-
ered nerve (myelin and Bodian stains) in this and the following cases, taken from the site of the proposed suture, showed relatively normal nerve fibres in the proximal specimen, but no intact fibres in the distal section. There must, however, have been some functioning fibres in the distal segment capable of conducting impulses from the point of stimulation to the periphery.

**Case 2. Median Nerve. Forearm: lower third.**

P.F. was wounded on April 16, 1945 by an exploding grenade. Examination 7 months later revealed “complete paralysis of the sensory component of the median nerve from the wrist down.” At operation on Nov. 16, 1945, extensive scarring was found in the lower forearm and wrist. The proximal stump of the divided median nerve ended blindly in scar tissue 5 cm. above the wrist. The distal stump was found 2 cm. below the carpal ligament. It was necessary to do a first-stage “bulb” suture. To accomplish this, the defect of 7 cm. had to be made up by mobilizing the median nerve along the entire length of the forearm.

Examination on Mar. 25, 1945, approximately 4 months later, showed loss of pinprick, heat and pinch perception over the entire volar aspect of the 2nd and 3rd fingers and the distal half of the thumb. A healing cigarette burn was noted on the 3rd finger, but the patient had not been aware of any sensation at the time of burning. On stroking the skin with cotton, dysesthesias could be induced over the volar aspect of the thumb, index finger and thenar eminence, but none over the 3rd finger. All forms of sensation were readily appreciated over the dorsal aspect of these fingers within the radial nerve distribution.

On Mar. 26, 1945 the second-stage repair was carried out under local anesthesia only. The previous first-stage “bulb” suture and neuromata were resected following 2 per cent procain block of the proximal segment of the median nerve. When this had been done, bipolar electrodes were applied to the distal end of the median nerve for electrical stimulation, with the same technique described for Case 1. Pain was elicited over the dorsal aspect of the web space between the thumb and the index finger.

The superficial branch of the radial nerve was now blocked with 2 per cent procain above the level of the wrist, and the distal end of the median nerve stimulated again with the same current. No pain could be elicited on repeated trials. Evidently the radial nerve was responsible in this case for the central relay of impulses induced by stimulation of the median nerve stump.

**Case 3. Ulnar Nerve. Forearm: distal third.**

J.A., aged 27, had been wounded in action in February 1945. There had been complete paralysis of all ulnar nerve function below the level of the injury due to complete severance of the nerve in the lower third of the forearm. In August 1945 a first-stage attempt to repair the nerve was performed, which required extensive mobilization of both segments of the nerve before an end-to-end “bulb” suture could be accomplished, so great was the initial defect.

On Oct. 17, 1945, approximately 8 months after injury, and 2 months after the first-stage procedure, neurorrhaphy was carried out under local anesthesia. A large fusiform swelling marked the site of the “bulb” suture. The nerve above and below this was so badly scarred that an additional 10 cm. had to be resected. Satisfactory anastomosis was eventually achieved after full mobilization of the nerve and flexion of the forearm and wrist. The dorsal cutaneous branch of the ulnar nerve was dissected free as far as the dorsal aspect of the wrist, and one of its three subdivisions at this point sacrificed in order to release tension. As this branch was cut the patient cried out with pain, which he referred to the hypothenar area. Electrical stimulation of the distal end of the divided ulnar nerve itself was then carried out. This resulted in pain referred to the median nerve distribution of thumb, index and middle fingers. In this case, the effects of stimulating the isolated stump of the ulnar nerve were evidently relayed in a central direction by the median nerve.

J.J. received a severe gutter type wound in the medial aspect of the left forearm in February 1945, which resulted in a considerable loss of substance of the flexor carpi ulnaris muscle and overlying skin, and complete enduring paralysis of all ulnar nerve function below the level of injury.

On Dec. 3, 1945, under local cutaneous anesthesia supplemented by 2 per cent procain block of the proximal stump of the ulnar nerve, the latter was exposed from the middle third of the arm to the wrist. The nerve was found to be completely severed and embedded in dense scar tissue at the middle third of the forearm. The ulnar artery was thrombosed and was therefore resected at this point between ligatures. The distal end of the ulnar nerve was dissected down to the wrist and its dorsal cutaneous branch freed as far as the dorsal aspect of the hand.

Using bipolar electrodes, the isolated portion of the ulnar nerve was electrically stimulated with the technique described for Case 1. This caused pain over the median nerve distribution of the 3rd and 4th fingers, as did mechanical stimulation.

Stimulation of the isolated segment of the ulnar nerve was then repeated after blocking the median nerve in the mid-forearm with 2 per cent procain. Pain was now referred to the radial nerve distribution over the dorsum of the hand at the base of the 3rd and 4th fingers. Stimulation of the dorsal cutaneous branch of the ulnar nerve also elicited pain in this distribution.

As a check on the effectiveness of the median nerve block, the median nerve was now stimulated electrically above or central to the block; that is, at the level of the antecubital fossa. This resulted in contraction of the muscles supplied by the median nerve above the block, and pain referred to the entire median nerve distribution of the hand.

It appears, therefore, that prior to median nerve block, the effects of stimulating the distal stump of the divided ulnar nerve were relayed centrally by the median nerve; but that after the latter was blocked, by the radial nerve.

DISCUSSION

Observations similar to those just described were noted during the course of other operations (approximately one in five) carried out under local anesthesia for the repair of median and ulnar nerves that had been completely severed in the arm or the forearm. Other neurosurgeons have remarked upon similar findings. Unfortunately exact statistics cannot be supplied since no records of this phenomenon were kept until the latter months of the War. Nor was this type of observation possible during repair of nerves in the lower extremities, since spinal or general instead of local anesthesia was used.

Stimulation or dissection of scar tissue adjacent to severed nerves in some instances led to intensely sharp pain, localized to the operative site, and occurring almost immediately after stimulation was applied. In contradistinction to this, the pain evoked by stimulation or dissection of a distal nerve stump (1) was referred peripherally and not locally; (2) was burning in character rather than lancinating or shocking; and (3) occurred after an appreciable lag following stimulation.

It is noteworthy that in most cases no pain could be elicited by any form of stimulus applied directly to the fibromatous enlargement or "distal neuroma" of the isolated segment of nerve, although when the same stimulus was applied to the nerve itself immediately below or distal to this enlargement, the nerve proved to be exquisitely sensitive. In fact, there appeared to be a zone, usually 1 cm. in length, having a markedly decreased threshold as com-
pared with more distal portions of the nerve. This "trigger zone" was apparently similar to the local area of diminished threshold to stimuli applied at the boundary between scar and the distal stump of transected spinal cords in paraplegia. The explanation of this finding remains for the moment obscure.

In Case 4, after median nerve block in the mid-forearm, the brachial artery was stimulated electrically in the antecubital fossa, with consequent pain of considerable severity referred to the entire median nerve distribution. It is therefore concluded that, in this case at least, there were neural communications between the artery and the median nerve above the level of the forearm. Corroborating this view is the fact that in several cases explored by us and others at the same hospital, distinct nerve branches were demonstrable coursing between the median nerve in the mid-portion of the arm and the adjacent brachial artery. Thus, while the main autonomic supply of the arteries of the upper extremity may be derived from the median nerve in the forearm, there also appear to be significant connections in the upper portion of the arm as well.

Stimulation of the divided ulnar artery in two patients, each having long-standing severance of the adjacent ulnar nerve, resulted in pain referred to the volar carpal region and hypothenar eminence, upon stimulation of the distal end of the artery, but no sensation upon stimulation of the proximal end. (No tests with intra-arterial injections were carried out.)

At this point it should be emphasized: (1) that every precaution was taken so that no spread of electrical current should occur; (2) that no motor response followed stimulation of the distal nerve segments described; and (3) that the area supplied by each severed nerve described was totally insensitive to all forms of cutaneous stimulation as tested clinically prior to neurorrhaphy, with the possible exception of Case 2.

From these and similar cases it is clear therefore that stimulation of the distal, chronically isolated segment of a completely divided nerve "A," may result in pain referred to the area innervated by an adjacent intact nerve "B." It is also evident that after blocking nerve "B," the pain may then be referred to a zone supplied by another intact nerve "C," which in turn apparently serves as the central relay for sensory impulses induced by stimulation of nerve stump "A."

Sensory impulses induced by stimulation of an isolated nerve segment may reach an intact nerve by direct anastomosing branches similar to those motor branches described in the illuminating communication by Murphey et al. Stimulation may also induce changes in the chemical mediator within peripheral sensory units where terminal twigs of adjacent nerves overlap and arborize. It is also possible that the painful sensations described may be due to impulses induced in the peripheral network of the autonomic system, thus evoking a local sympathetic reflex, the effects of which in turn are relayed centrally by an intact peripheral nerve subserving that area. The pain elicited by stimulation of long-divided distal nerve stumps (prior to their
operative section) can hardly be attributed to an “axonal reflex” effect since the latter depends upon freshly cut nerve.

The nature of the fibres presumed to be functioning in the distal segment of chronically divided nerves must remain for the moment a matter of speculation. Several possibilities, however, come to mind: (1) Some fibres may have preserved their viability without undergoing degeneration, by virtue of continuity with viable fibres in adjacent intact nerves. This is in keeping with the fact that anastomotic branches frequently exist between the ulnar and median nerve. (2) Regeneration of fibres across the gap of scar tissue separating the two ends of a long-divided nerve is possible but unlikely, since nerve fibres could not be demonstrated in specimens of the scar, and since there was no clinical evidence that any such regeneration had occurred. Moreover, if regenerating nerve elements had bridged the gap, they would presumably have entered the distal nerve segment by way of its severed end, marked by fibroma formation. However, stimulation of the distal fibroma did not result in pain, while stimulation of the nerve below it did. It seems unlikely therefore that nerve fibres responsible for pain in the distal segments of these divided nerves had traversed the gap between nerve ends. The only alternative is retrograde regeneration of fibres from the anastomotic branches described by Murphey et al. after careful studies of motor function of these same nerves, or retrograde regeneration of fibres of the autonomic nervous system, in accordance with their well recognized proclivity for regeneration.

The immediate practical significance of these observations to the neurosurgeon has been illustrated by several cases we have had to re-explore in order to resect a neuroma-in-continuity and carry out neurorrhaphy. This procedure had not been done at the initial operation because pain had been elicited on stimulating the distal segment of the nerve. Accordingly the neuroma was not resected initially as it should have been. Pain on stimulation distal to a neuroma cannot be relied upon as an index of functional continuity of that nerve, even though there is no visible break or gap in continuity at the site of injury.

CONCLUSIONS

1. Stimulation of the distal stump of certain long-divided peripheral nerves elicits pain.

2. The pain may be referred either to the sensory distribution of the divided nerve or of an adjacent intact nerve and can be abolished, or its distribution shifted, by blocking an adjacent intact nerve.

3. Central relay of the effects of distal stump stimulation is evidently mediated by one or more intact peripheral nerves closely related to the injured one.

4. The pain described above may be the result of, (a) impulses reaching intact nerves via direct anastomotic branches between the divided and intact nerves; (b) changes induced by stimulation in the chemical mediator of
sensory units at the zone of overlap between closely related peripheral nerves; or (c) stimuli affecting peripheral fibres of the autonomic nervous system.

5. The practical significance of these observations is discussed.

REFERENCES


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