Management of Missile Peripheral Nerve Injuries

Part 2: Surgical Management

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Learning Objectives: *After reading this article, the participant should be able to:*
1. *Recall the basic knowledge regarding the indications and timing for missile peripheral nerve injury (MPNI) repair.*
2. *Describe the types and techniques of MPNI repair.*
3. *Explain the basics of postoperative care and rehabilitation for MPNI.*

Surgical Management

The treatment of a missile peripheral nerve injury (MPNI) should begin immediately after the injury occurs. Immobilization of the extremity if a fracture is suspected can prevent further nerve injury. The importance of the primary surgical treatment of the wound cannot be overemphasized. Adequate excision of the devitalized tissue (debridement), hemostasis, evacuation of any hematoma, extraction of foreign bodies, and macroscopic inspection of the tissue, including the nerve trunk, are important. Surgical treatment of vascular, bone, or tendon injury, which can prevent the development of functional deficits, secondary nerve lesion, and pain, has priority. The use of wide-spectrum antibiotics may decrease the likelihood of complicating effects and expedite healing.

The microsurgical techniques may be the strongest tool in the management of MPNIs. The goals of surgical management are to achieve perfect alignment of nerve fascicles, to avoid tension at the suture site (longitudinal or circumferential), and to prepare the healthy tissue bed for the repaired nerve. Using microsurgical techniques and also adhering to appropriate timing and proper indications for nerve repair leads to a more successful outcome. Although certain factors that determine the outcome of the treatment (e.g., the type of lesion or nerve, the age of patient, the level and extent of the injury) are beyond the surgeon's control, certain other factors, such as choice of the type of repair (i.e., technique) and the perioperative management, are based on wise decision-making, provided the patient is referred to the surgeon on a timely basis.

Timing

The regeneration process begins almost immediately after a MPNI occurs. Axonal regeneration usually follows this sequence:

- Initial delay while the regenerating axon reaches the injury site or suture line at the repair site (2–4 weeks);
- Axonal penetration of the site of injury or repair (1–2 weeks);
- Axonal regeneration at a speed of 1 mm per day (1 inch per month); and
- Terminal delay (4–6 weeks) when the axons have reached the neuromuscular plate, and the new neuromuscular junction maturation process is occurring.

According to this scheme, most distal lesions (excluding neurapraxia) will show no signs of functional regeneration until about 7 weeks after injury or repair and no electrophysiological signs of recovery until about 4 weeks after injury or repair. No muscular regeneration occurs after 24

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Dr. Arnautovič and Dr. Krisht have disclosed that they have no significant relationships with or financial interests in any commercial organizations pertaining to this educational activity.

Dr. Ligon has declined to disclose to Lippincott Williams & Wilkins whether she has significant relationships with or financial interests in any commercial organizations pertaining to this educational activity.

Category: Peripheral nerves

Key Words: Peripheral nerves, Missile injuries, Pathophysiology, Electromyocardiography, Surgical technique

months following the injury, with the exception of some brachial plexus and sciatic nerve functions. Recovery of sensation is the only functional recovery that can be obtained by surgery performed 24 months after MPNI.

The timing of repair of MPNI is determined by evaluating all the clinical and electrodiagnostic data, as well as the length of time needed for recovery of neurapraxia (first-degree nerve injury), if suspected. It can be primary, early secondary, or late secondary. Primary nerve repair (within 24 hours) is reserved for "clean" nerve lacerations (e.g., caused by a cut with glass or a knife) or high nerve lesions. Because MPNIs are characteristically dirty wounds, early secondary nerve repair (within 3 months) and late secondary nerve repair (after 3 months) are considered. Early secondary nerve repair is undertaken within 12 weeks, when the nerve bed is clearly defined, the epineurium is thicker and "stronger," and the parent neurons are in optimal condition for regeneration. In our opinion, if early secondary nerve repair is indicated and if the patient is referred in optimal time, the repair should be performed earlier, between the 3rd and 8th weeks postinjury. This is the time of peak metabolic response after injury, when the proximal trunk effectively sends the "new axons" distally and when the distal trunk is most receptive, and also when the fibrous proliferation entrapping and tethering the nerve is less pronounced. Further delay in repair of the MPNI can make the surgery more difficult and augment nerve compression and stretching because of epineural and other fibrous tissue proliferation. In cases of infection or very difficult compound injuries, nerve repair should be postponed for at least 3 months.

Type of Repair

Multiple MPNIs (combinations of various degrees and types of nerve injuries) often occur in one patient. In such cases, the optimal surgical management involves using two or more techniques to treat all of the injuries in one procedure.

Nerve Exploration. The skin incision should be as long as necessary, avoiding scar tissue or previously transplanted skin. Undermining the subcutaneous tissue releases adhesions and exposes subcutaneous nerves, which are potential sources of nerve grafts. The use of a tourniquet is not advised because it masks bleeding, compresses the nerve trunk, and can cause axonal swelling. A nerve dissection begins proximal to the injury, then distal, and then at the injury site itself. Almost all nerves have one side free of branches, and a pattern for the arterial perforating branches entering each nerve at the same side, which we call the "free edge" of the nerve. Knowledge of this anatomy is crucial for avoiding additional injury to the nerve by surgery. The fibrous tissue around the nerve and the epineurium should be used for indirect manipulation of the nerve. Careful and delicate tissue handling decreases the risk of epineural fibrous tissue proliferation and later scar tissue formation. Any scar tissue should be excised to allow the skin to stretch and to provide a healthy bed for the repaired nerve.

A nerve usually is accompanied by an artery and veins. Before the dissection is begun, the relationship among them should be established. Every attempt to preserve the artery is advised if a block of scar tissue involves both the major artery and the nerve. The severed nerve usually is swollen and purple-gray in color, in contrast to the ivory color of a normal nerve. A greater amount of fibrous proliferation and scar tissue forms along fibro-osseal or muscular canals and muscular septums, causing more pronounced damage of the nerves in these narrow passages. If a foreign body is present, the indications for its extirpation should be carefully weighed. Because it does not necessarily contribute to the complication, the clinical decision is made after evaluating the type, size, shape, and location of the foreign body and the clinical symptoms it is causing.

The epineural response to trauma is fibrous proliferation and production of collagen scar tissue. This "physiologic" response, which occurs in proportion to the extent of the injury, is exaggerated in MPNIs. The nerve can appear intact macroscopically, even while it contains a neuroma in continuity.

Neurolysis. Neurolysis may be either external or internal. External neurolysis begins with freeing the nerve trunk from adhesions. Internal neurolysis is indicated when an intact nerve is found during exploration of a nonfunctional

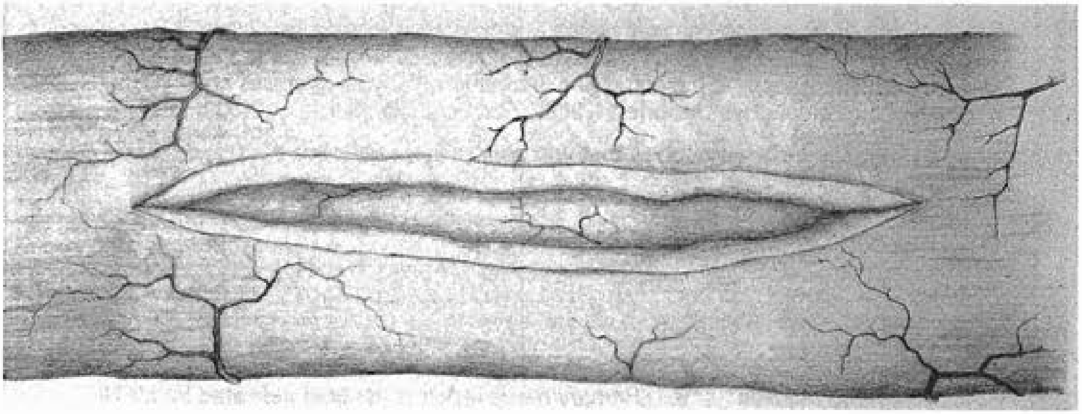

Figure 1. Internal neurolysis: epifascicular (external) epineurotomy.

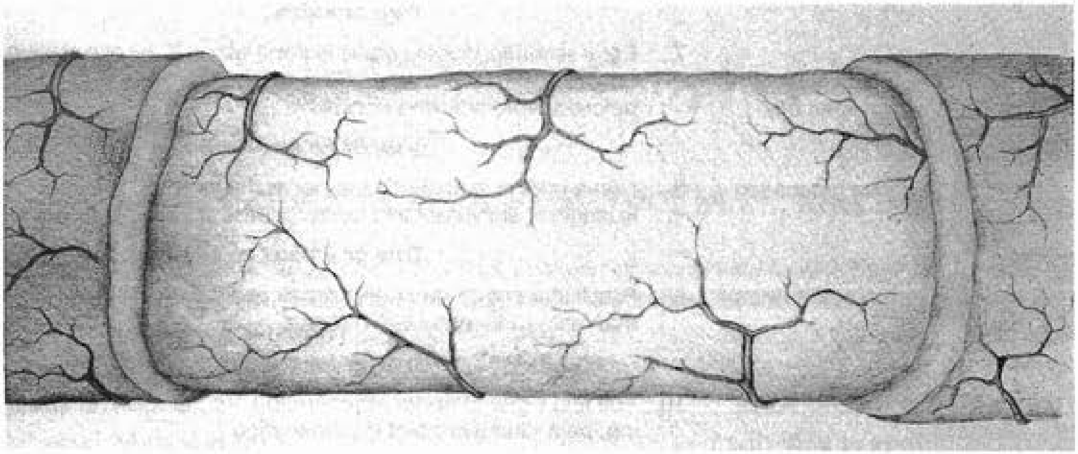

Figure 2. Internal neurolysis: epifascicular (external) epineurectomy.

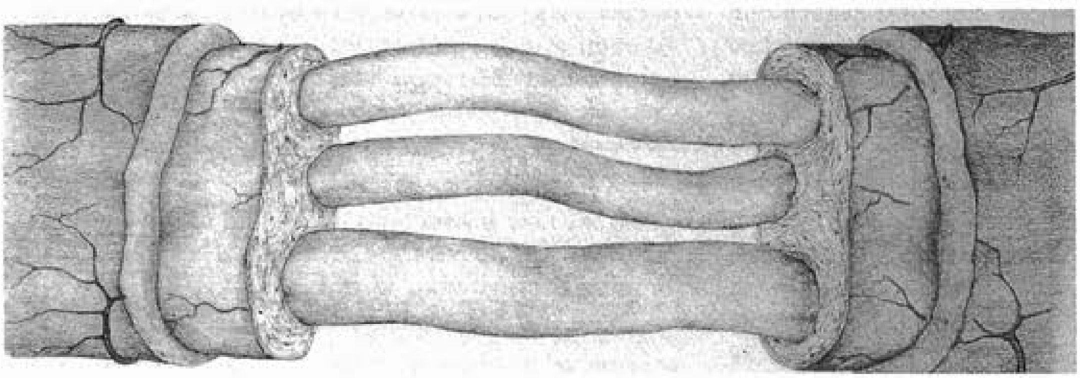

Figure 3. Internal neurolysis: interfascicular (internal) epineurectomy.

nerve or when incomplete loss distal to the lesion occurs, but the patient experiences pain of a neurogenic nature that does not respond to conservative management. Neurolysis, which reportedly improves the electrophysiological function of the nerve, involves three steps: (1) epifascicular epineurotomy (opening of the external epineurium) (Fig. 1); (2) epifascicular epineurectomy (resection of the external epineurium) (Fig. 2); and (3) interfascicular epineurectomy (resection of the internal epineurium) (Fig. 3).

Nerve Repair. The gap between the stumps of a severed nerve or fascicular group can be the result of traumatic loss of nerve tissue or elastic retraction of nerve stumps combined with intraneural scarring and retraction. Mobilizing the nerve from its bed, flexing the joints, and transposing the nerves can bridge nerve gaps smaller than 2 cm if there is no tension at the suture line. There are four patterns of internal neural topography: monofascicular, oligofascicular, polyfascicular with grouping, and polyfascicular without grouping. This pattern of internal fascicular organization has a certain didactic value, but is, according to our studies, an oversimplification. It would be most useful to know in advance of the surgery the internal fascicular and vascular organization of each nerve at each level as well as its vascularization at each segment.

The fascicular end-to-end nerve repair consists of performing—on each side—an external epineurectomy of approximately 0.5 cm, followed by an internal epineurectomy, and division and dissection of the nerve into fascicles or fascicular groups. Resection of the entire extent of the pathologic tissue should be performed (i.e., until healthy tissue is reached). Two interfascicular or perineural stitches (for example, 10-0 sutures, 5–7 cm long thread) are placed for each fascicle or fascicular group. Adequate alignment of the fascicles or fascicular groups is achieved by orienting them according to the "picture in the mirror," the position of the blood vessels, the remnants of mesoneurium on

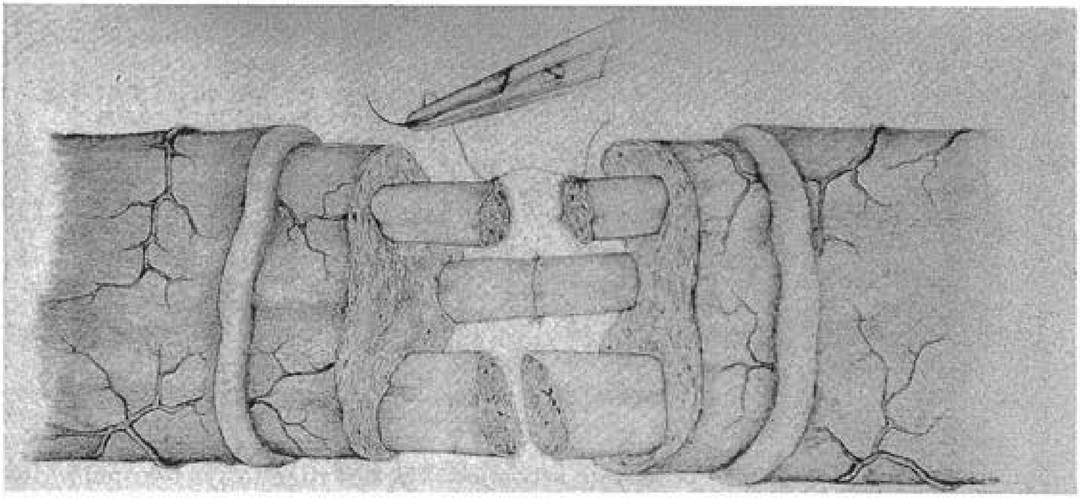

Figure 4. Fascicular end-to-end nerve repair.

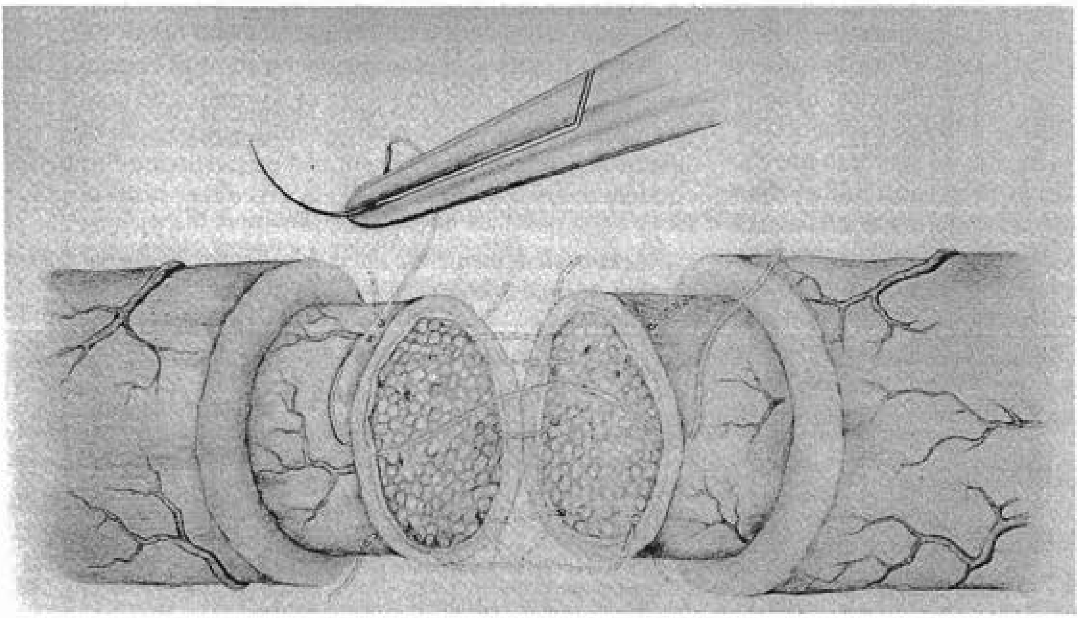

Figure 5. Epineurial end-to-end nerve repair.

the lower side of the nerve, and the small groove or particularities in the contour on either side (Fig. 4). This type of nerve repair is recommended for oligofascicular patterns and polyfascicular patterns with grouping.

In comparison with fascicular end-to-end repair, epineural end-to-end repair requires less time and is simpler. The disadvantages are that this repair achieves less precise alignment of the fascicles and the possibility of leaving a gap between the two nerve stumps, which could fill with fibrous scar tissue. In an epineural repair, the external epineurectomy is performed for up to 0.5 cm on each side. Thus, by the time the epineurium proliferates and reaches the suture line, that line has already healed, precluding any interposition of the epineurium between the stumps. Again, resection should continue until healthy tissue is reached. Two guide stitches are placed in the inner epineurium, for example, using 8-0 sutures, followed by four to six stitches on both sides (Fig. 5). This type of repair is recommended for the monofascicular patterns and polyfascicular patterns without grouping.

Nerve Grafting. If the gap between the two stumps is more than 2 cm or there is tension across the suture line, a nerve graft is indicated. Success of the graft depends on, among other factors, the surgeon having a thorough understanding of the neural fascicular anatomy. The different types of nerve grafts are trunk, cable, and interfascicular. The preferred repair is the interfascicular nerve graft, which eliminates tension, has the suture line in a well-vascularized bed, and allows for a more precise coaptation of the fascicles. The disadvantages of this type of graft include a longer time needed to perform it; the regenerating axon has to penetrate two suture lines (versus one); the donor and recipient nerves have different fascicular patterns; and there is some resulting sensory loss in donor skin distribution.

In interfascicular nerve grafting, an external epineurectomy of approximately 0.5 cm is performed on each side, followed by (on each side) an internal epineurectomy, a dissection into the fascicles or fascicular groups, and then a resection until healthy tissue is reached. The resulting gaps between the stumps of fascicles or fascicular groups vary in length. The length of the gaps, the number of fascicles needed for repair, and the lengths of the needed nerve grafts must be determined. Grafts should be 10% to 20% longer than the gap. The next step is identifying corresponding fascicles or fascicular groups. Each nerve requires an average of three to five interfascicular nerve grafts. Matching

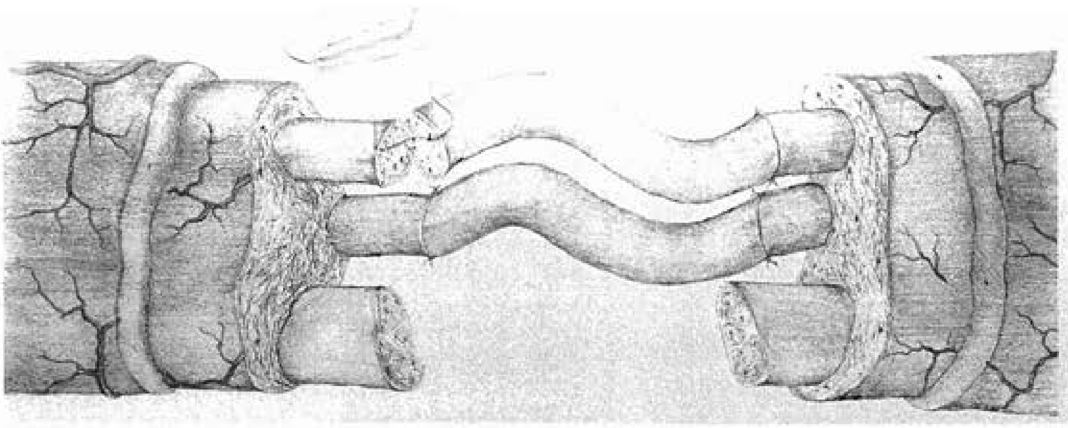

Figure 6. Interfascicular nerve grafting.

the grafts with the corresponding fascicles should be attempted. The nerve ends of grafts should be placed inverse (proximal-distal, distal-proximal) to those of the nerves to preclude a misdirectional regrowth of the axons. The nerve grafts are sutured to the corresponding fascicles, usually with two stitches placed intraepineurially or perineurially (Fig. 6). For an upper extremity injury, we prefer to use the cutaneous nerve of the medial arm or forearm, rather than the sural nerve, for nerve grafts. The cutaneous nerves can be harvested from the same exposure without requiring an additional skin incision in the leg. The sural nerve, on the other hand, has the advantage of being long (35–40 cm) and having more fascicles. Once the grafting is complete, the graft bed is debrided to achieve a healthy environment. Successful nerve grafts up to 25 cm long have been reported.

Postoperative Care, Rehabilitation, and Nerve Regeneration

Physical therapy and rehabilitation should begin almost immediately after the wound heals and should continue for months. Certain factors favor successful regeneration (Table 1). A vigorous regenerative process, induced by injury to the peripheral nerve, will, under optimal conditions, lead to the repair and eventual recovery of function. The first signs of regeneration are the return of sweating, pain, and vibration sensation. The last to return is two-point discrimination. The phases of nerve regeneration are (1) axonal regeneration and connection with the end organ (less than 1 year); (2) return of elementary motor and sensory function (1–3 years); and (3) return of complex and compound movements (> 2 years). A clinical follow-up evaluation and electromyocardiography should be performed approximately every 3 months until good recovery is observed.

Table 1. Factors That Influence Favorable Functional Outcome After Nerve Injury

Younger age of patient
Distal level of lesion
Absence of complicating factors (e.g., infection)
Shorter time after injury (e. g., < 6 months)
Absence of combined injuries of neighboring tissues, especially blood vessels
Use of microsurgical technique and timing of surgery
Use of pre- and postoperative physiotherapy and rehabilitation
Single nerve injury or just pure motor or pure sensory nerve involvement
Injury to lower extremity: has better prognosis than upper extremity lesions (no need to regain complex and compound movements and dexterity)

Acknowledgment: We thank Ms. Grace Domagala-Zobkov for her original artwork.

Readings

Cooper CJ, Ryan JM: Interaction of penetrating missiles with tissues: some common misapprehensions and implications for wound management. *Br J Surg* 77:606, 1990

Daniel RK, Terzis JK: *Reconstructive Microsurgery*. Boston: Little Brown, 1977, pp 406-424.

Ehni BL: Treatment of traumatic peripheral nerve injury. *Am Fam Physician* 43:897, 1991

Hems TEJ, Glasby MA: Comparison of different methods of repair of long peripheral nerve defects: an experimental study. *Br J Plast Surg* 45:497, 1992

Kempe LG: *Operative Neurosurgery: Volume 2—Posterior Fossa, Spinal Cord and Peripheral Nerve Disease*. New York: Springer-Verlag, 1970

Kline DG, Hudson AR: Selected recent advances in peripheral nerve injury research. *Surg Neurol* 24:371, 1985

Kline DG, Hudson AR: Acute injuries to peripheral nerves, in Youmans JR (ed): *Neurological Surgery*. Philadelphia: WB Saunders, 1990, pp 2423-2510

Kline DG, Hudson AR, Zager E: Selection and preoperative work-up for peripheral nerve surgery. *Clin Neurosurg* 39:8, 1992

Mackinnon SE: New directions in peripheral nerve surgery. *Ann Plast Surg* 22:257, 1989

Millesi H: Peripheral nerve surgery today: turning point or continuous development? *J Hand Surg* 15B: 281, 1990

Millesi H: Forty-two years of peripheral nerve surgery. *Microsurgery* 14:228, 1993

O'Brien B McC, Morrison WA: *Reconstructive Microsurgery*. New York: Churchill Livingstone, 1987

Omer GE: Nerve injuries associated with gunshot wounds of the extremities, in Gelberman RH (ed): *Operative Nerve Repair And Reconstruction*. Philadelphia: Lippincott, 1991, pp 655–670

Samii M: Modern aspects of peripheral and cranial nerve surgery, in Krayenbuhl H (ed): *Advances and Technical Standards in Neurosurgery*. New York: Springer-Verlag, 1975, pp 33–85

Seddon H: *Surgical Disorders of the Peripheral Nerves*. Baltimore: Williams & Wilkins, 1972