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Review Article

Cutting-Edge Approaches for Nerve Debridement Prior to Repair

Lilah Fones, MD, [*] Michael Rivlin, MD, [*] Rick Tosti, MD [*]

[*] Rothman Orthopaedic Institute, Thomas Jefferson University, Philadelphia, PA

A R T I C L E I N F O

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Peripheral nerve injuries can be devastating. Although neuropraxic and some axonotmesis injuries will recover spontaneously, nerve repair or reconstruction is required to restore function in high-grade axonotmesis or neurotmesis injuries. The first step of nerve repair or reconstruction is adequate nerve debridement with removal of necrotic and fibrous tissues. Debridement decreases neuroma formation at the repair site and produces an optimal surface for axonal regeneration. This article discusses nerve debridement, including the goals of debridement, debridement techniques, and signs of adequate nerve debridement before repair.

The success of recovery following peripheral nerve injury is related to the degree of neuronal injury. Seddon axonotmesis injuries and Sunderland Type 2 or greater injuries involve axonal discontinuity.[1,2] Following initial insult, the distal nerve stump undergoes Wallerian degeneration, and the proximal stump undergoes traumatic degeneration at the zone of injury to the next proximal node of Ranvier. Subsequently, nerve regeneration begins with axonal sprouting from the proximal stump, forming multiple filopodia branching outward toward the distal stump.[3–7] When only axonal damage occurs but the supporting connective tissue remains intact, axonal regeneration usually provides spontaneous functional recovery within 3 months.[5] When there is concomitant connective tissue disruption and interposed debris and fibrosis, axonal sprouting from the proximal stump will be inhibited and not reach the distal stump.[5,8] In this instance, nerve repair or reconstruction is indicated to achieve functional nerve recovery.

To achieve optimal outcomes, nerve repair can be thought of as consisting of several distinct steps. The first step is nerve debridement to create viable coaptation surfaces. Second, nerve ends are approximated by primary repair or using interposition materials such as conduits, allografts, or autografts. Interposition materials are indicated when the neurorrhaphy site cannot be directly opposed or if the coaptation has excessive tension. Finally, the nerve end coaptation is performed using microsurgical techniques. This article discusses nerve debridement, including the goals of debridement, debridement techniques, and signs of adequate nerve debridement.

Goal of Debridement

Overall, the goal of nerve debridement is to create two coaptation surfaces free of necrotic and fibrous tissues in an environment optimal for nerve repair and regeneration. Only healthy tissues can progress through the complex pathway of nerve regeneration.

External neurofibrosis or extrinsic nerve scarring results from the activation of the extraneural profibrotic cascade outside the epineurium and can impair normal nerve gliding, cause neural compression, tether the nerve in an undesirable position, and decrease nerve conduction velocity.[8] Particularly in the setting of subacute or chronic injuries, significant extraneural fibrosis can surround the injured nerve, as demonstrated in Figure 1. The initial goal of nerve debridement is to release extraneural fibrosis that can tether and compress the injured nerve. Subsequently, the nerve should be mobilized to a local environment appropriate for nerve gliding that is free of extrinsic compression and in an environment optimized for axonal regeneration. Ideally, the surrounding tissues should create an optimal nerve bed that minimizes scar formation (fat and muscle are ideal).

Second, endoneural fibrosis or intrinsic neural scarring occurs from fibrosis within the nerve, which interferes with neural vascular supply and axonal migration and impairs nerve

Corresponding author: Rick Tosti, MD, Rothman Orthopaedic Institute, Thomas Jefferson University, 925 Chestnut Street, Philadelphia, PA 19107.
E-mail address: rjtosti@gmail.com (R. Tosti).

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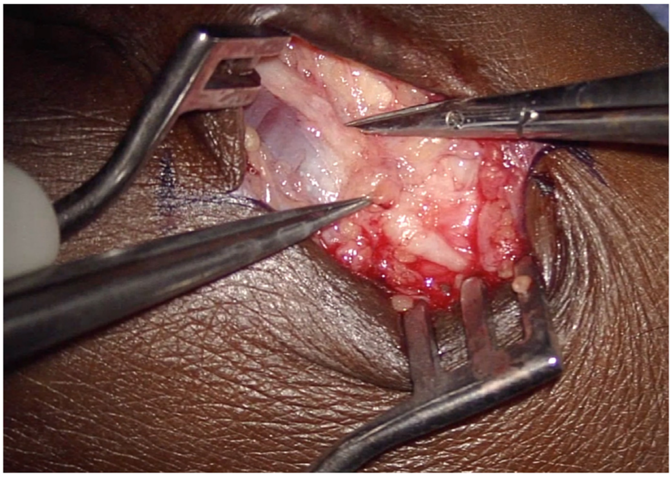

Figure 1. Injured radial sensory nerve entrapped with surrounding extraneural fibrosis requiring external neurolysis.

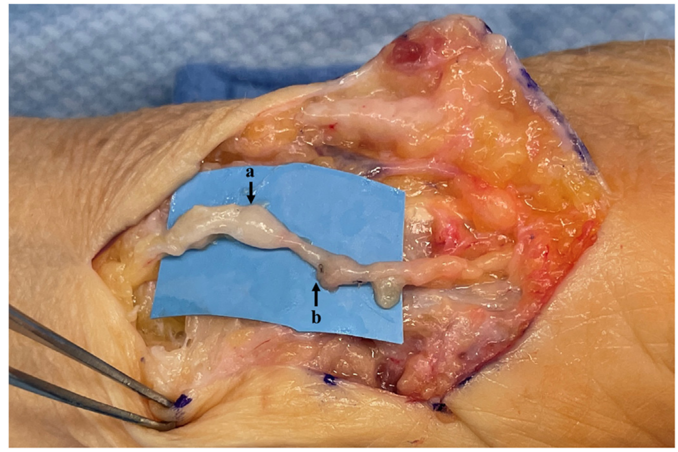

Figure 3. Intraoperative photograph demonstrating an example of improper debridement of the radial sensory nerve prior to repair demonstrating **A** neuroma-in-continuity adjacent to **B** previous suture line. Photo credit Kyle Eberlin, MD.

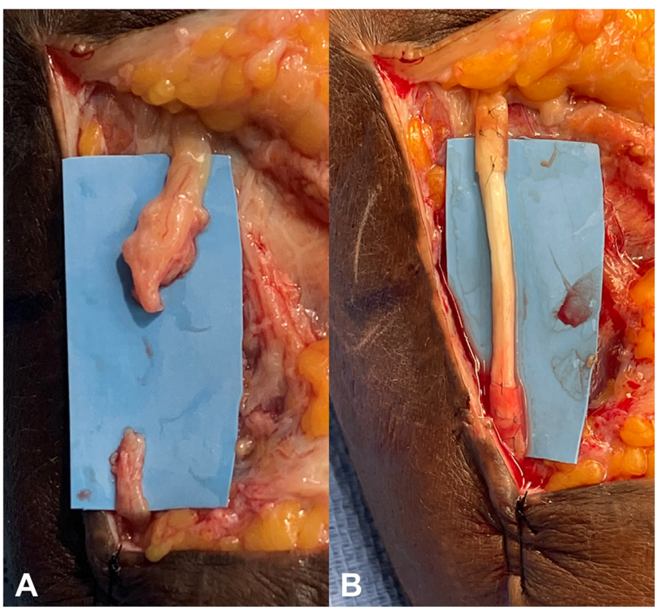

Figure 2. A Adequate nerve debridement is critical and should be performed even if it produces a larger nerve gap. **B** If a large nerve gap results from debridement, multiple repair techniques can be used, including conduits, allografts, or autograft nerves.

regeneration.[8] As axonal sprouting occurs from the proximal axon stump, interposed fibrosis will block axonal advancement, both preventing the axon from reaching its target end organ and causing neuroma formation.[3,5] Neuromas are a collection of disorganized axonal sprouting interposed with fibrous tissue that causes pain and decreased nerve function.[3,9,10] Scarring, infection, and ischemia contribute to neuroma formation.[9] Similarly, a neuroma-in-continuity represents a subset of neuromas that form with partial nerve transections in which the regenerating injured axon is entrapped in fibrous tissue while some nerve axons remain intact.[3,5] A neuroma-in-continuity represents a unique challenge to the treating surgeon. Treatment involves a full-thickness transection of the nerve to a viable level proximal and distal to the neuroma, which would sacrifice any remaining contiguous axons in the process. Alternatively, in the setting of a neuroma-in-continuity with preserved nerve conduction across the neuroma, one can consider intraneural neurolysis, where continuous nerve fascicles are carefully dissected from the surrounding thickened epineurium.[11] The decision is usually based on preoperative function. For fully transected nerves, an appropriate nerve debridement (Fig. 2) will excise all injured or compromised nerves to produce a healthy stump with protruding fascicles, even if this would result in a nerve gap. Failure to remove intraneural fibrosis may result in a neuroma-in-continuity after the repair. Figure 3 demonstrates the result of an attempted repair following inadequate nerve debridement in which a neuroma-in-continuity had formed and produced continued symptoms.

Debridement Technique

The degree of nerve debridement is proportional to the degree of injury.[5] Sharp, clean nerve lacerations should be thoroughly inspected to ensure no neural injury extends outside of the presumed zone of injury. In these cases, minimal nerve debridement may be required. In contrast, subacute or chronic injuries and acute stretch or avulsion injuries are associated with a larger zone of injury. This has been shown in a rat model of sciatic nerve injury in which avulsion-type injury resulted in a significantly larger zone of injury relative to sharp laceration.[12] These injuries necessitate more aggressive debridement.[5]

In the case of subacute and chronic peripheral nerve injuries, external neurolysis and nerve mobilization are often required and should be undertaken first. Microsurgical instruments are used to carefully free the injured nerve from surrounding scar tissue adherent to the epineurium without violating the epineurium (Fig. 4A).[13–15] Once adequately mobilized, a contrasting background can be used to visualize the proximal and distal nerve ends. Care should be taken to prevent iatrogenic extension of the zone of injury through rough nerve handling, extensive tension while mobilizing the nerve, or extensive mobilization that puts the neural vascular supply at risk.[3,5]

All damaged nerve sections or fascicles must be excised; however, resecting healthy nerves and needlessly increasing

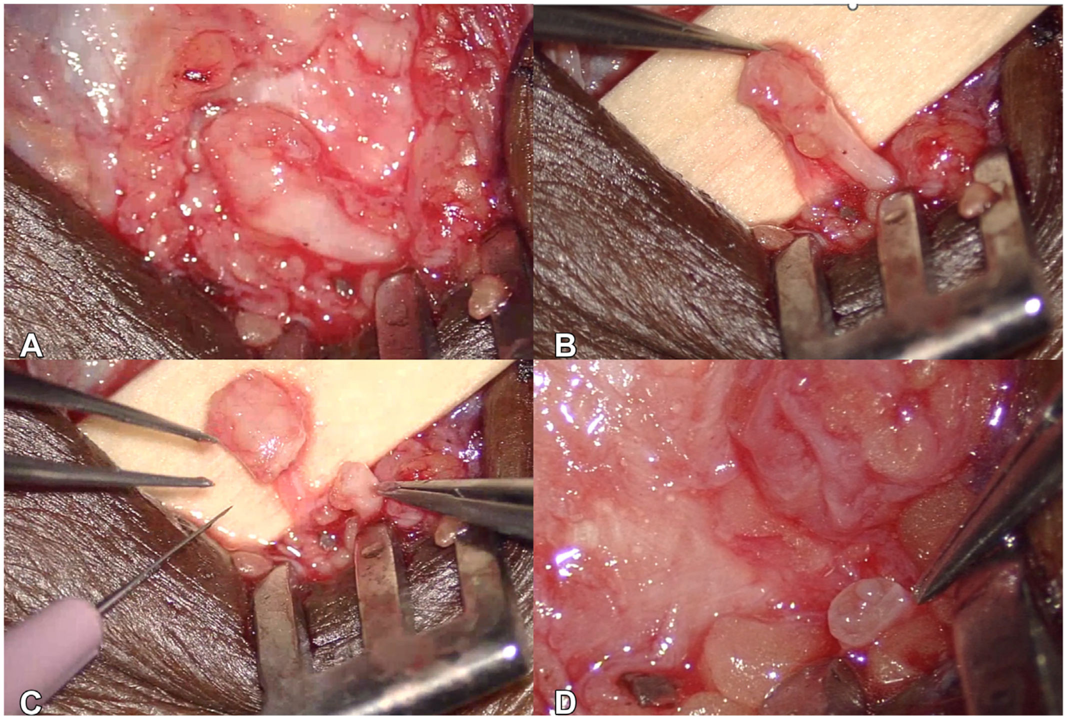

Figure 4. Intraoperative photographs on nerve repair. **A** Transected nerve following external neurolysis in a well vascularized wound bed. **B** Nerve positioned on tongue depressor and with tension applied for sharp transection with scalpel for excision of injured nerve end. **C** Sharp debridement of fibrotic intraneural fibrosis from healthy nerve. **D** Healthy nerve end following debridement allowing for visualization of individual nerve fascicles.

the nerve gap is undesirable. We recommend starting by resecting only a few millimeters and making an assessment. If the nerve still does not appear adequately debrided, then the process can be repeated. Multiple tools have been advocated to cut nerves with the goal of minimizing crush forces to limit the zone of injury and surrounding perineural fibrosis. Options for nerve transection include the use of microscissors, a scalpel or a razor blade against a tongue depressor (Fig. 4B, C), and specialized nerve holding clamps combined with a disposable razor blade (Fig. 5).[5,16] Sharma et al evaluated the use of microscissors versus razor blade on subjective grading of microscopic imaging of nerve ends and found better fascicular and epineural integrity with the razor blade. They postulated this resulted from scissors cutting tissue via shearing force between two sharp blades that would create more trauma than razor blades or scalpels, which divide by a compressive force.[17] In contrast, Rummings et al[10] found no difference in cut peripheral nerve ends microscopic appearance in an animal model between microserrated scissors, commercial nerve cutting guide, or scalpel blades on a tongue depressor. Rose et al[18] demonstrated a smoother cut surface with the use of an 11 blade or scissors compared with a razor blade in a cadaver model. The different outcomes may reflect different study models (animal versus cadaver model), but overall, limited evidence exists on the best technique to perform nerve transection. We believe that any of the above methods are acceptable, but we most often choose to use a fresh ophthalmic knife and a hard tongue depressor as a cutting board. Tension is placed along the edge of the nerve with microforceps, and the knife moved in a slicing motion to create a single clean cut. We believe that excessive pressure or a firm chopping motion may unnecessarily impose a less desirable crushing force.

Signs of Adequate Debridement

Assessment of nerve debridement is critical but can be achieved by considering a few points. First, the surgeon must assess the tactile feedback while transecting the nerve. If the nerve feels hard or fibrotic, this represents retained intraneural fibrosis, and more nerve tissues should be excised. Healthy nerves should be soft and pliable. Next, the nerve end should be evaluated end-on as demonstrated in Figure 4D. Individual nerve fascicles should be visible pooching out from the surrounding epineurium.[5,19] Furthermore, nerves have excellent blood supply, and after adequate debridement, bleeding should be visualized around the fascicles.[5] At this point, the nerve gap (if any) is measured, and the proper technique to restore the nerve is executed.

In complex and difficult-to-evaluate damaged nerves (such as those with crush injury, ballistic injury, revision nerve repairs, and radiated nerves in tumor beds), frozen sections can be obtained and analyzed microscopically for the presence of healthy myelin and degree of neurofibrosis. Direct microscopic visualization or collagen staining can also be beneficial. One study of traction brachial plexus injuries found that increased myelin quantity visualized on an osmium-hematoxylin-stained frozen section was associated with improved outcomes.[20] This technique is limited by time and carcinogenic properties of the osmium-hematoxylin stain and has prompted the development of alternative microscopic analysis techniques, including Stimulated Raman Histology microscopy, which is a label-free method that relies on the intrinsic different vibrational spectroscopies of nerve contents, but this microscopic technique is being developed and is not widely used.[21] Although these methods may be time-consuming and intraoperatively cumbersome, sometimes, these are necessary to make proper surgical decisions.

Figure 5. Example of specialized nerve cutting clamp, the Checkpoint Edge Nerve Cutting Kit (Checkpoint Surgical Inc).

In conclusion, successful nerve repair requires proper identification of the neural zone of injury, meticulous nerve handling, and fine microsurgical repair. To minimize intraneural fibrosis, clean and atraumatic resection is needed through the healthy uninjured nerve. To minimize extraneural fibrosis, the nerve should be in an optimal tension-free position on a native noninjured tissue bed.

Conflicts of Interest

No benefits in any form have been received or will be received related directly to this article.

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