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REVIEW ARTICLE

Basic Techniques of Peripheral Nerve Repair

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Abstract

Peripheral nerve injuries are commonly encountered in clinical practice. Early diagnosis of nerve injuries and application of basic concepts in their repair and management gives positive outcomes.

This article is a brief guide on the basic techniques of peripheral nerve repair.

The pre-op assessment, indications and timing of nerve surgery and techniques of nerve repair are discussed. In addition the approach to the management of nerve gaps is also discussed with due consideration to the various options available for management of nerve gaps.

Introduction

Peripheral nerve injuries are commonly seen, affecting about 2.8% patients presenting with trauma. These injuries are associated with considerable disability and loss of productivity, especially when associated with hand injuries[1,2]. A thorough knowledge and understanding of the anatomy and the pathophysiology of the nerve injury coupled with a high index of suspicion is essential for an early and correct diagnosis of any nerve injury. Management of peripheral nerve injuries still remains an enigma for the reconstructive surgeons despite the progress and ongoing research in molecular neurobiology of regeneration and microsurgical techniques. To achieve consistent and improving outcomes, the basic concept and principles of nerve repair should be complemented with the application of advances in microsurgical and molecular biological tools into clinical practice. The present article focuses on the basic techniques of peripheral nerve repairs.

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Classification Systems and Pathophysiology of Nerve Repair

Peripheral nerve injuries can be a part of medium to high energy trauma or present as a result of a low energy compressive forces or an ischemic lesion. The management options and prognosis of a nerve injury are dependent on the level and degree of the injury. Seddon, Sunderland and MacKinnon have proposed classifications of nerve injuries which serve as a guide for management and prognostication of these injuries[3,4,5].

Basic understanding of the pathophysiology of nerve degeneration and regeneration are essential for a reconstructive surgeon managing a nerve injury, so that the physiological process of regeneration can be supplemented and optimised by means of the surgical procedure performed. The process of reinnervation and functional recovery takes many months as the axonal regeneration needs to reach the distal end organs, which is occurring at the rate of around 1mm per day.[6] The misdirection and uncontrolled branching of the growing axons at the site of injury are some of the commonly seen errors in nerve regeneration [7] which can be avoided by practice of precise surgical technique.

Management of nerve Injury

Preoperative assessment

A thorough clinical examination is paramount to diagnose the degree and level of injury and to formulate the treatment plan. The surgeon should adopt a standardised stepwise approach for uniform evaluation of the central and the peripheral nervous system so that the subtle aberrations can be picked up and noted. It involves assessment of sensory deficit, motor losses, vasomotor changes and joint examination. Electrophysiological studies like Electromyography (EMG) and Nerve conduction velocity (NCV) allows to assess the pattern and the prognosis of functional recovery as well as guide for a surgical intervention[8].

Indications of surgery

Surgery can be guided by the classification of injury and the clinical judgement of the surgeon. Some of the scenarios which indicate an operative intervention for nerve injuries can be enlisted as:

1. Definitive nerve injuries or trauma along a major nerve trunk with neurological deficit, like open fractures, crush injuries, iatrogenic nerve injuries, cut wounds, post reduction injuries, etc.
2. Probable neuropraxia with failure to recover after 3 months of conservative management.
3. Associated vascular or orthopaedic injuries requiring intervention.
4. Persistent pain or chronic painful neuromas.
5. Arrest of improvement or worsening clinically and on electrodiagnostic studies.

Timing of surgery

Early nerve repair, whenever feasible, is advocated as delay in intervention leads to irreversible degenerative changes in the distal nerve end as well as the motor end plate, along with atrophy and the fibrosis in the innervated muscle which diminishes any chances of functional recovery[9,10,11]. Experimental animal model studies have proved the neuronal preservation and improved clinical outcome after early nerve repair[12]. Thus, whenever clinical evidence mandates a surgical nerve repair, like sharp nerve transections, the procedure is undertaken without any delay, and is labelled as '*Primary Nerve Repair*'. This has the advantage of minimal intraneural and peineural scarring.

Principles of nerve repair

The surgeon should follow certain basic principles of peripheral nerve repair to achieve the best possible and consistent results. Careful attention to each surgical step, perseverance, practice and spending that extra time to achieve perfection is often rewarded with success and reduces the reexploratory procedures. The goal of any nerve repair surgery should be to provide for and facilitate the growth of the regenerating axons into the endoneurial tubes of the distal nerve stump with minimal loss of fascicles.

Salient operative principles that are common to all the nerve surgeries can be enlisted as:

1. Adequate illumination with magnification in the form of loupes or a microscope
2. Appropriate microsurgical instrumentation with suture materials and/or tissue glue
3. Use a tourniquet wherever possible
4. Use of short acting paralysing agent if intraoperative nerve stimulation is contemplated
5. Position of the patient and the operative field as per surgeon's comfort
6. Liberal and wide surgical exposures with sharp dissection preferred from virgin tissue to scarred or injured tissue and minimal disruption of local blood supply.
7. Blood free field with adequate hemostasis
8. Attempt to preserve the mesoneurium and the gliding planes of the nerve[13] with keeping the dissection and skeletonisation of the nerve ends to minimum
9. Careful handling of the nerve tissues and fascicles with either atraumatic microinstruments, using mesoneurium, or passing epineurial stay suture to facilitate manipulation as well as serve as a guide for gross fascicular matching
10. During nerve suturing, the fascicular pattern of the nerve must be taken into consideration

Primary neurorrhaphy

Direct nerve repair (primary neurorrhaphy) with epineurial microsutures is our preferred technique and considered as gold standard for the surgical repair of peripheral nerves.The procedure of primary neurorrhaphy can be divided into 4 major surgical steps:

1. Preparation

Before repair, the traumatised nerve ends need to be prepared and the necrotic and scarred tissue debrided with sharp microscissors or using a fine surgical blade. Healthy fascicles tend to pout out or herniate owing to the high endoneurial fluid pressure and tissue viability can also be judged from the pin point bleeding at the nerve ends. Also, the pouting out fascicles need to be trimmed appropriately a second time in relation to the epineurium to prevent bending or bunching up of the fascicles leading to misdirection of the regenerating axons after the repair.

Some important points to be considered are-

a. When handling a nerve, only the epineurium should be caught with forceps, and damage to follicles must be avoided.

b. While trimming the nerve to the non injured tissue, excess pull on the epineurium must be avoided to prevent proximal retraction of the epineurium after cutting the ends. This causes exposure of the fascicles, and makes suturing difficult afterwards.

2. Approximation

After adequate preparation, the nerve ends are approximated so as to judge the tension at the repair site by keeping the related joints in neutral or extended position. Length of the gap is assessed. Slight mobilisation of the nerve ends is almost always necessary so as to reduce the tension at the repair site. Due care is taken to prevent damage to the mesoneurium during mobilisation of the nerve[14]. Care is taken to avoid excessive intrafascicular dissection. Extensive dissection and mobilisation of the nerve affects the segmental blood supply which leads to ischemia and intraneural scarring at the repair site. Albeit, MacKinnon describes the robustness of the endoneurial blood supply allowing for mobilisation of the nerves over a long distance (bipedicle length to width ratio of 64:1)[8].

3. Coaptation

The nerve ends are then coapted with an aim to achieve gross fascicular matching. This is guided by the matching the longitudinal epineurial surface vessels or gross visual alignment of the internal nerve fascicles. The fibres to a specific target anatomical region are oriented together in groups of fascicles[15]. Hence a proper alignment of the cut ends of the nerve will aid in better functional recovery.Visual alignment can be supplemented by numerous techniques which are seldom used routinely such as topographical sketches, electrical stimulation and carbonic anhydrase and cholinesterase staining[16,17].

Generally, in case of tendon and nerve injuries in the wrist, the tendons are repaired first, and nerves are coapted later. This minimises the tension over the nerve repairs. But in cases of nerve and tendon injuries in the palm, it is preferable to suture the nerves first, before the tendon, because the finger flexion after tendon suturing makes the nerve repair difficult.

4. Maintenance

The nerve coaptation is then maintained or secured with epineurial sutures with monofilament 9-0 or 10-0 suture, or a thicker suture depending on the diameter of the nerve taking care to avoid malalignment (Fig 1,2). Monofilament nylon is the suture material of choice as it leads to minimal foreign body reaction and scarring[18]. Two lateral sutures at 180 degrees apart followed by 2 to 4 epineural sutures, depending on the diameter of the nerve to be repaired, are usually adequate. We must resist the temptation of overzealous or tight suturing, keeping in mind that every suture leads to fibrosis. Fibrin glue can be used to supplement and seal the repair in addition to sutures (Fig 3), but when used alone, it lacks the necessary tensile strength[19].

It is also very import to coapt the nerves with the proper alignment of sensory and motor fascicles, especially in cases of ulnar nerve at the wrist level which consists of 40% motor and 60% sensory fascicles.Improper realignment can result in excellent regeneration, put poor functional outcomes if sensory and motor fascicles are not properly aligned[20].

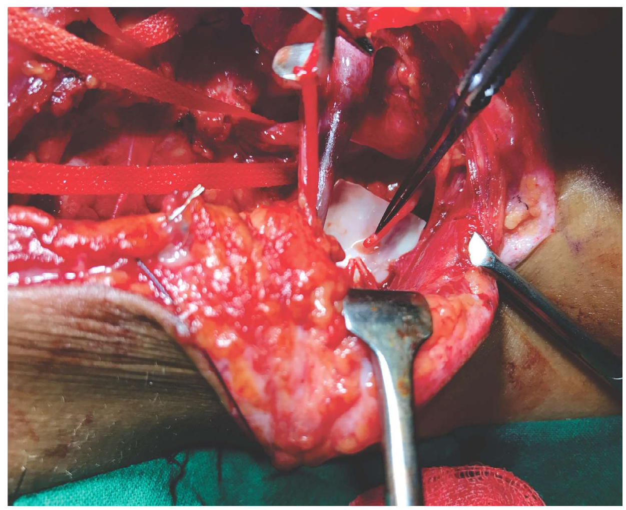

Fig. 1 Preparation of nerve ends - Intercostal to musculocutaneous nerve repair

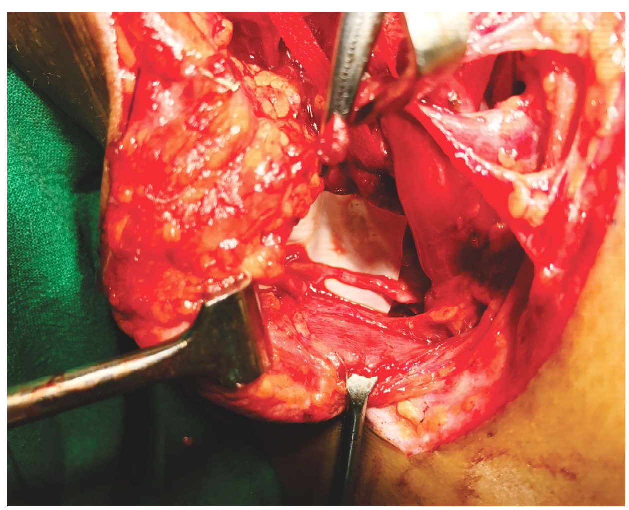

Fig. 2 Nerve repair with microsutures

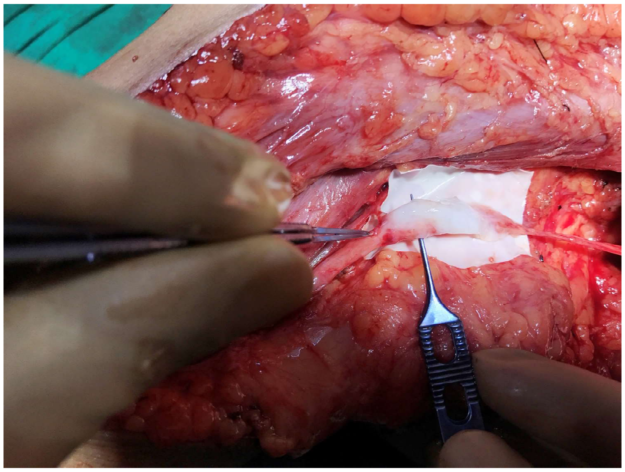

Fig. 3 Use of fibrin glue in nerve repair

Grouped fascicular repair versus Epineurial repair

Another anatomically attractive technique practised in primary neurorrhaphy is the grouped fascicular repair.[21] This entails intraneural fascicular dissection and direct matching of the corresponding fascicular groups with perineural sutures. Advocates of this technique promote this method as it leads to accurate alignment for the growing axons due to fascicular matching, but it has the disadvantage of increased trauma and scarring due to permanent sutures intraneurally as well as ischemia due to extensive fascicular dissection.

Many clinical as well as experimental studies have found little superiority and no better functional outcome than the simpler epineural repair.[22,23] However, this method is employed in certain situations like ulnar nerve injury at wrist where the topography is well defined to contain 2 sensory and a motor fascicle bundle.

Nerve cuffs

To prevent the connective tissue ingrowth at the repair site and misdirectional axonal sprouting, numerous biological as well as synthetic materials have been employed as an ensheathing cuff. Examples include venous patch, muscle cuffs, plasma clots, collagen, Millipore, Silastic, Surgicel and so on. Though theoretically sound, some studies have found increased incidence of nerve compression due to improper sizing[24].

Laing et al[25] have used vascularised fascia to wrap nerves. They have used it in neuromas after neurolysis. We too prefer to use local vascularised fascial flaps based on the perforators of the radial or ulnar artery as a wrap around the repairs of forearm nerves, especially in case of scarred bed for smother gliding and to augment the vascularity of the nerve repair.

Management of nerve gap

Many times we are faced with a situation that after preparation of the nerve ends we are left with a relatively tight primary repair due to nerve gap, especially in chronic lesions, with a dilemma of proceeding with primary neurorrhaphy or going for nerve grafting. Following can serve as rough guidelines to aid decision-making intraoperatively.

1. Mobilisation

Though some amount of nerve mobilisation is allowed to facilitate primary neurorrhaphy, experimental studies have shown about 50% reduction in blood supply when a nerve is stretched to about 8-10% of its in vivo length[26]. Elasticity of the nerve ends is further reduced in chronic cases with established Wallerian degeneration when being explored for a non-conducting neuroma, so mobilisation will not be much helpful in these cases. The anchoring funicular suture, first described by Tsuge[27] is a very convenient method for nerve injuries with gap or chronic nerve injuries. This affects the microcirculation at nerve ends very minimally. A 6-0 suture loop can be used to give gradual traction, and bring the cut ends together, keeping an eye on the microcirculation at the nerve ends. Jabaley describes such epineural splint sutures[28] to be placed at around 1.5 to 2 times the nerve diameter from the defect to distribute the tension equally and symmetrically. This louped suture is taken first, and then the epineurial repair is performed in conventional manner.

2. Joint positioning

Immobilising the joint in a favourable position should be viewed as an added insurance forsafety of nerve repair and never as a means to achieve primary neurorrhaphy in case of large nerve gaps, as they are uniformly associated with poor results due to extensive scarring from ischemia and neuroma formation. Under no circumstances, flexion of the wrist and elbow beyond 40 degrees and 90 degrees respectively should be performed for and post primary neurorrhaphy.[14]

3. Nerve transposition

Some nerves are amenable to alteration of their anatomical course, like ulnar nerve at elbow joint, thereby reducing the nerve gap and achieving a tension free primary repair.

4. Bone shortening

Bone shortening for tension free nerve repair is never practised in absence of fracture. Few applications of this technique are in cases of mutilating extremity trauma with near complete amputation and replantation surgeries for hand and fingers.

5. Autologous nerve grafting

Interfascicular nerve grafting was first described by Seddon[29] then popularised by Millesi[30] in cases not suitable for primary nerve repair.When compared with nerve conduits, nerve grafts remain more reliable[20] as they provide a larger number of basal lamina tubes which act as a scaffold for the growing axons, whereas nerve conduits have to rely on fibrin clot stability.

Autografts are the gold standard for nerve grafting material and can be classified in 3 major types as cable grafts, trunk grafts and vascularised nerve grafts[31]. Cable grafting is the preferred option wherever feasible, as they allow for better individual fascicular matching, better revascularisation, and a proper size match.Fascicular matching becomes difficult in case of large nerve gaps as the internal topography changes along the course of the nerve.It is recommended to harvest maximum nerve graft and use 10-20% larger graft to avoid any tension. Sural nerve (Fig 4) remains the most commonly employed donor nerve and provides about 30-40 cm of nerve graft.To channel the maximum number of growing axons towards the distal end organs, it is advisable to reverse the orientation of the nerve grafts especially when a longer defect is bridged.The suturing techniques and principles remain the same as that of primary neurorrhaphy. Trunk grafts are rarely used due to poor fascicular alignment and inadequate central revascularisation leading to more scarring. Free or pedicled autologous nerve grafts are described only for vascularised ulnar nerve grafting to contralateral C7 root in cases of complex pan brachial plexopathies.

Grafting versus primary repair

In acute sharp cut nerve injuries subjected to primary surgical repair, the nerve gap evident between the nerve ends, is due to the elastic retraction and amenable to direct repair by some mobilisation. However, when the injury is chronic or due to severe contusion or crush injury, the nerve ends become fibrotic and difficult to approximate as well as much of the fibrotic tissue is transected during preparation of the nerve ends. Such nerve gaps are should not be repaired directly and nerve grafting is indicated as they show superior results.

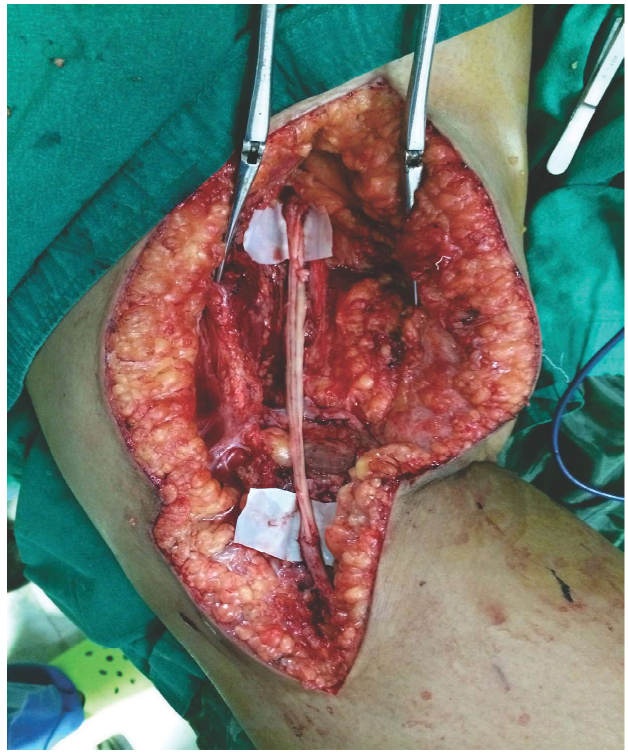

Fig. 4 Sural cable nerve graft

Primary neurorrhaphy gives superior results to nerve grafting as the axons have to traverse two coaptations in nerve grafting, giving more chances of misdirection, loss of fibres and neuroma formation. But if a direct repair is under tension, the results are superior with interposition nerve grafts. Variable guidelines are found in literature and it is generally recommend that a nerve gap of 2.5 cm or those requiring an elongation of nerve trunks by more than 10 % should be repaired with cable grafting rather than primary repair under tension[30].

6. Allografts

Despite the potential advantages of using allografts for nerve grafting, like ample availability, no donor nerve morbidity, reduced operative time and amenable to storage, allografts do poorly as compared to the autografts primarily due to host immune response and associated complications of immunosuppression[32]. Processed acellular allografts are available which are not immunogenic and show better functional recovery in longer nerve gaps when compared to empty conduits but are still inferior to autografts[33].

7. Nerve conduits

Peripheral nerves are characterised by regeneration potential in optimum microenvironment. After the realisation that the nerve grafts act only as the guiding tubes for the growing axons with maintenance of the favourable milieu in a closed environment, the concept of nerve conduits or 'Entubulation' was put forth. Numerous materials have been attempted as conduits to bridge small nerve gaps which are enlisted in the section on nerve cuffs with varying results. The ideal conduit should have low antigenicity, biodegradability and easy availability.

Consensus from current research and trials suggests comparable results in functional recovery with nerve autografting and nerve conduits for peripheral nerve injuries with nerve gaps of up to 3 cm[34]. More recently nerve conduits are being used as a mode of local delivery of neurotrophic agents and Schwann cells to enhance nerve regeneration.

8. Nerve transfers

Nerve transfer implies coaptation of a part of or whole of a healthy expendable donor nerve to the distal end of a damaged and denervated nerve. This is generally employed in motor nerve injuries where a donor nerve to expendable muscle or some of its fascicles are reassigned to a prioritised motor nerve[35]. Thus, effectively, a proximal injury is transformed into a distal one with shorter regeneration distance as well as preservation of the motor end plates and muscle integrity. End to side nerve repair[36] and direct muscle neurotisation[37] are other techniques which can be utilised in cases with paucity of donor fascicles.

Postoperative management and evaluation

Some form of splintage and immobilisation is advised in cases of nerve repairs, grafts or nerve transfers for a period ranging from 2-3 weeks or even till 6 weeks, depending on the level of injury and the tension at the repair site. After this period, gradual passive mobilisation and stretching is started under supervision with a goal of full range of passive motion by around 3 weeks after the mobilisation is started[38,39].

Outcome evaluation is equally important as patient rehabilitation. Evaluation of recovery and the progress of outgrowing axonal ends can be monitored by means of advancing Tinel's sign, serial electrodiagnostic studies and clinical examinations. Stimulation of the peripheral repaired nerves and recording the evidence of cortical recognition is termed as somatosensory evoked cortical potentials and is employed in uncooperative, pediatric patients and in experimental animal studies to monitor nerve recovery[40]. Postoperative rehabilitation and training of the patients for the relearning process is to be started before the clinical evidence of reinnervation and is largely dependent on the motivation and the compliance of the patient[41]. Sensory re-education is very important, and must be focussed upon.

Secondary procedures

Various secondary rebalancing procedures in the event of failure of nerve recovery leading to functional debilitation are tendon transfers, free functioning muscle transfers, arthrodesis, tenodesis and amputations in selected patients. A detailed description of these procedures is beyond the scope of this paper.

Future directives

With increasing understanding of the neurobiology of regeneration and the factors affecting this complex process, numerous advances have been made with regards to therapeutic targets and intervention modalities.Nanotechnology has been used to repair the axons at a cellular level[42] axonal growth has been stimulated and coordinated by use of pulsed electromagnetic fields[43] and bioengineered grafts have been made available with microspheres containing the neurotrophic factors as well as tubules lined with schwann cells and embryonic stem cells[44] to promote robust, early, and precisely directed nerve regeneration.

In conclusion, the field of peripheral nerve injury is complex and needs an interdisciplinary team approach for successful management and rehabilitation of an individual with peripheral nerve injuries. Ongoing research in the molecular biology of the nerve injury has provided new potential targets for novel therapeutic options which are targeting the accelerated nerve regeneration and recovery of nerve function.

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