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A STATE OF THE ART IN MINIMALY INVASIVE PERIPHERAL NERVE AND BRACHIAL PLEXUS SURGERY

Abstract: The injury of the peripheral nerves and brachial plexus are relatively frequent. Its significance lies in the fact that the majority of patients with this type of injury are part of working population. Since these injuries may create disability they present substantial socioeconomic problem nowadays.

This paper will present nowadays state of the art achievements of minimal invasive brachial plexus and peripheral nerve surgery.

It is considered that the age of the patient, the mechanism of the injury and the associated vascular and soft-tissue injuries are factors that primary influence the extent of recovery of the injured nerve.

The majority of patients are treated using open surgical approach. However, new minimally invasive and endoscopic approaches are being developed in the last years– endoscopic carpal and cubital tunnel release, targeted minimally invasive approaches in brachial plexus surgery, endoscopic single incision sural nerve harvesting, and there were even attempts to perform endoscopic brachial plexus surgery.

The use of the commercially available nerve conduits for bridging short nerve gaps has shown promising results.

Multidisciplinary approach individually shaped for every patient is of the outmost importance for successful treatment of these injuries. In the future, integration of biology and nanotechnology may fabricate a new generation of nerve conduits that will allow nerve regeneration over longer nerve gaps and start new chapter in peripheral nerve surgery.

INTRODUCTION

History of peripheral nerve surgery begins in the year 1608 when the first reconstruction of transected nerve was performed by Ferara. Modern peripheral nerve surgery starts in 1964 when Curtze started using operative microscope. Development of high-tech equipment and materials made possible for peripheral nerve surgery to grow, so that nowadays, its possibilities are exponentially improved. Precise

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diagnostics, state of the art microsurgical technique and minimally invasive approaches made huge improvement in treatment outcome. Cooperation of neurosurgeon, orthopedic, vascular and plastic surgeon, physiatrist, physiologist, neurologist and radiologist is essential in treatment of peripheral nerve injuries. The aim of this paper is to present current accomplishments and limitations of peripheral nerve and brachial plexus surgery, analyzing available literature.

Peripheral nerve injury is relatively common and occurs primarily from trauma or sometimes as a complication of surgery. Traumatic injuries can occur due to stretch, crush, laceration and ischemia and are more frequent in times of war. It is considered, that approximately 5% of all trauma patients have peripheral nerve and brachial plexus injury in the time of peace. (1)

Following a nerve injury, the axons undergo degenerative processes, and subsequently they attempt regeneration. Despite advancements in the precision of microsurgical techniques, full functional recovery following peripheral nerve repair cannot always be achieved. (2)

Primary tensionless end-to-end repair should be carried out whenever possible. For longer nerve gaps, the use of autologous nerve grafts is the current „gold standard". Over the past few years, the use of the commercially available nerve conduits for bridging short nerve gaps has increased. The evolution of tissue engineering, the use of biodegradable conduits for reconstruction of nerve gaps has shown promising results.

PATHOPHYSIOLOGY OF THE PERIPHERAL NERVE INJURY

The epineurium, perineurium and endoneurium are the connective tissue structures that protect and provide a framework for the nerve fibers. Blood supply to the peripheral nerves originates from the segmental extrinsic and longitudinal intrinsic blood vessels that originate from local and regional arteries. Although there are extensive connections between the extrinsic and intrinsic blood vessels (3) the peripheral nerves are primarily dependent on the intrinsic blood supply. Excessive tension along the nerve can significantly compromise the intrinsic blood supply. (4)

Almost immediately after injury, Wallerian degeneration begins, sealing the severed axon ends and initiating the regenerative phase. (5) After this, decreased production of neurotransmitters and increased production of materials necessary for regeneration begins. (6) Over the first few days following peripheral nerve injury, the axons in the distal nerve stump will degenerate. However, the myelin sheath and the basal lamina provided by the Schwann cells remain intact. (7) Presence of macrophages at the site of injury stimulates the proliferation of Schwann cells in the distal stump. (8,9) The proliferation of Schwann cells within their basal lamina leads to the formation of tube-like structures – Bands of Büngner, which provide a guide so that axons regenerating from the proximal stump can reach their targets. (10) Proliferating Schwann cells from the distal nerve stump provide the growth cones and guide the regenerating axons. Spontaneous functional recovery is dependent on the number of correctly matched motor and sensory neurons.

PATIENT EVALUATION

First step in the adequate evaluation of every patient is obtaining detailed patient history. Next, a thorough neurological and clinical examination must be performed. After these two essential segments of patient assessment, electrophysiological evaluation and sometimes neuroradiological examination (MRI, CT scan and high resolution ultrasonography) is done. EMNG (electromyoneurography) performed two or three weeks after injury shows fibrillations and later denervation potential. MR, CT and ultrasonography are adjuvant methods that can show partial or complete transection of the nerve or compression between bone fragments.

Primary factors that influence the extent of recovery of the injured nerve are the age of the patient, the mechanism of the injury and the associated vascular and soft-tissue injuries.

In a first-degree injury according to Sunderland classification, patient history usually includes a blunt injury (stretch or compression). In this situation, the nerve continuity is intact and all the layers of connective tissue as well. As a result, there is no presence of Tinel's sign at the site of injury. With this degree of injury, management is conservative and full recovery is expected.

Second- and third-degree injuries according to Sunderland classification are clinically differentiated from first-degree injuries because Tinel's sign will develop and then advance as the axons regenerate. These injuries are also managed conservatively. Full recovery is expected after a second-degree injury.

Surgical intervention is indicated with fourth-, fifth- and sixth-degree injuries. In practice, any open wounds in which nerve injury is suspected should be explored, while closed injuries are usually followed up expectantly with investigative techniques such as electromyography or nerve-conduction studies. If nerve function does not recover after the initial 3-month period after the injury surgical exploration is performed.

Electrophysiological assessment with nerve conduction studies and needle electromyography are useful in evaluation of closed injuries that have not recovered within the first 3 months following the injury. The electrophysiological parameters such as conduction slowing, block or failure evaluates the gross dysfunction of the peripheral nerve.

However, electrophysiological assessments can falsely localize focal lesions because the proximal parts of the peripheral nerve are typically not amenable to electrophysiological evaluation. In these situations, magnetic resonance imaging is increasingly used as it has high specificity and sensitivity when evaluating focal injuries such as cervical nerve root avulsions or other brachial plexus injuries. (11)

Considering all the above, clear indications for surgical treatment are:

- Open injuries with apparent transection of the nerve continuity
- Closed injuries that show no signs of recovery three months after injury
- Progressive neurological deficit because of the scaring or vascular compression
- Pharmacoresistant chronic neurogenic pain, even if neurological recovery after surgery is not to be expected

OPEN SURGICAL TREATMENT

Over the past years, surgical techniques have improved tremendously. For any nerve repair, an understanding of the nerve topography will enable the surgeon to align the motor and/or sensory fascicles in the correctly. This will ensure good nerve regeneration and also, optimize functional recovery. During nerve repair, it is important to appreciate the longitudinal extent of the injury. The nerve ends should be resected sufficiently to reveal the normal fascicular pattern.

There are four main types of surgical treatment of peripheral nerve injury: (1) neurolysis; (2) end-to-end suture; (3) nerve grafting; and (4) nerve transfer.

Neurolysis can be done as the only surgical procedure with lesions in continuity, or it can be done during preparation of the nerve stumps for suture.

Primary end-to-end neurorrhaphy is the most desirable approach for reparation of peripheral nerve injuries when the gap between the two ends of the nerve is relatively short. (12) Following complete transection of a nerve, the nerve ends will retract, due to their elasticity. When this occurs it is impossible to perform direct end-to-end suture.

In contaminated wounds, primary repair should not be undertaken; however, nerve ends should be approximated and marked using colored stitches during initial debridement to prevent the retraction and to ease dissection of the nerve stumps in the course of second surgery.

In the case of greater defects or longer gaps between the cut ends, neurorrhaphy will cause excessive tension at the repair site that will impair microvascular flow in the nerve tissue and lead to excessive scarring at the repair site. (14) In these situations, primary neurorrhaphy should not be performed,(15) and a suitable alternative should be considered.

Nerve grafting is usually performed when nerve tissue defect is longer than 2 cm, after all the additional procedures for approximation of the nerve stumps without tension. There are several types of grafting:

1. Cable grafting
2. Interfascicular grafting
3. Fascicular grafting
4. Vascularized grafting

Advantages of interfascicular nerve grafting are better approximation of nerve and graft diameter, better orientation of the fascicles, thin graft gets nutrients by diffusion from its bed, better graft revascularization and less scaring. However, there are also imperfections of nerve grafting – two suture margins that are potential obstacle to axon growth, harder identification of the appropriate fascicular groups in longer defects, scaring of the distal suture margin or graft itself in longer defects.

There has been a significant aount of research dedicated to the development of synthetic nerve conduits for short nerve gaps that are not amenable to primary tensionless end-to-end neurorrhaphy. Using nerve conduits donor-site morbidity, such as pain, scarring, neuroma formation and permanent loss of sensation of the area supplied by the donor nerve, are prevented. (16) At present, several commercially available synthetic nerve conduits have been approved by the U. S. FDA for peripheral nerve repair and include collagen, degradable biological material derived from bovine Achilles tendon or a combination of polyglycolic acid (PGA) and polylactideecaprolactone (PLCL), both of which are degradable synthetic aliphatic polyesters. The majority of published papers is showing that outcome of recovery is similar as when using autograft. (17,18,19)

Nerve transfer (neurotization) involves repair of a distal denervated nerve element using different proximal nerve as the donor of neurons and their axons to reinnervate the distal targets. The concept is to sacrifice the function of a lesser-valued donor muscle to revive function in the recipient nerve and muscle that will undergo reinnervation. Nerve transfer procedures are increasingly performed for repair of severe brachial plexus injury (BPI), in which the proximal spinal nerve roots have been avulsed from the spinal cord. Functional priorities in nerve transfer of brachial plexus injuries are (in following order):

1. Forearm flexion
2. Shoulder stabilization
3. Abduction and external rotation of the shoulder
4. Sensory function of the thumb and index finger
5. Hand function

Table 1. Classification of nerve transfers

Extraplexal nerve transfer	Intraplexal nerve transfer
A. Nerves from the cervical cord – Spinal accessory nerve – Phrenic nerve – Anterior nerves of the cervical plexus – C3 and C4 spinal nerves – Contralateral C7 spinal nerve	– Spinal nerve stumps – Collateral branches of the brachial plexus – Combined nerve transfer
B. Nerves from the thoracic cord Intercostal nerves (usually III to VI)	

MINIMALLY INVASIVE PERIPHERAL NERVE AND BRACHIAL PLEXUS SURGERY

During last few years technological development lead to creation of new, minimally invasive surgical techniques, growing in every part of surgery, and it found its place in peripheral nerve and brachial plexus surgery.

Endoscopic carpal tunnel release (ECTR) has been performed since the late 1980s, using two operating techniques. Advantages of endoscopic carpal tunnel release are shorter recovery time, less postoperative pain, reduced postoperative wound sensitivity and less scaring. Disadvantages are steep learning curve, less visibility, which may result in incomplete sectioning of the TCL and increased neurovascular injury and increased cost associated with endoscopic instruments. Several published papers showed excellent results using this technique. Hankins et al. showed 82.6% of complete recovery using Brown's biportal technique, while Chen et al. had 91% of complete recovery using Menon's uniportal technique. (20,21)

There were also attempts of treating cubital tunnel syndrome using endoscopy. Tsai et al. report 64% success in their series of 85 cubital tunnel releases. (22) Ahcan and Zorman show even better results – in their series good or excellent result was achieved in 91% of patients. (23) While in these series only „in situ" decompression was performed, Krishnan et al. published data of 11 treated patients, where decompression was followed by subcutaneous transposition, with excellent results in 63.7%, good in 27.3% and satisfactory in 9.1% patients. (24)

Tarsal tunnel syndrome surgery can also be performed using minimally invasive endoscopic approach with promising results – 82% had excellent recovery in Mulick and Dellon's series of 87 treated patients. (25)

Endoscopic surgery of brachial plexus is still in development. Even though the technology has made huge leap in the last years, sometimes exact localization and type of lesion cannot be established, so open surgical exploration is necessary. A few cadaver trials using surgical robotic systems were conducted in attempt to find a minimally invasive technique for exploration of the brachial plexus, during which would also be possible to make surgical reparation of the injured nerve. (26)

Another interesting application of endoscope in peripheral nerve surgery is in sural nerve harvesting. As we know, sural nerve is probably the most frequently used donor for nerve grafting. Usual open approach for sural nerve harvesting is done by making series of small incisions in the path of this nerve. In the last few years a new method was developed – endoscopic sural nerve harvesting. Duration of the procedure is about 25 minutes and requires only one skin incision in length of 12 mm. (27)

CONCLUSION

Together with technological progress, peripheral nerve and brachial plexus surgery made its improvements. Use of microsurgical technique, operative microscope and modern materials made huge difference in treatment outcome in peripheral nerve and brachial plexus surgery nowadays. Open surgical treatment is still the most used treatment modality, but endoscopic surgery is being used more and more for selected cases. Using minimally invasive treatment, trauma of the tissue is less, the incision is smaller, there is less scaring; however chances for iatrogenic lesion of nerve and vascular elements is higher.

Improvements in presurgical evaluation leads to more precise determination of type and location of the injury, decreasing the need for complete exploration of the peripheral nerve and brachial plexus and enabling usage of smaller incisions – specific approaches for specific types of lesions. Multidisciplinary approach individually designed for every patient is of the outmost importance for successful treatment of peripheral nerve and brachial plexus injuries. In the future, integration of biology and nanotechnology may fabricate a new generation of nerve conduits that will allow nerve regeneration over longer nerve gaps and start new chapter in peripheral nerve surgery.

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