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REVIEW ARTICLE

Recent Trends in Primary Brachial Plexus Surgery

Shweta Kedia[1], Anshit Goyal[2], Sumit Sinha[3]

Abstract The outcome of brachial plexus surgery depends on the timing of surgery and also the surgical techniques being used. There has been much recent advancement in the surgical management of these injuries. A lot of work has been directed towards improvising on the microsurgical technique like inter-fascicular neurolysis and use of tissue glue. Also newer adjuncts to surgery like the use of nerve conduits have eased the surgery. Distal nerve transfers have been shown to have shorter re-innervation recovery time and used at sites other than infra and supra-clavicular fossa. Spinal nerve root implantation has also come a long way in patients with cervical nerve root avulsion. Endoscopic exploration and the robotic surgery has brought in a revolution in the microsurgical field and brachial plexus surgery is not an exclusion. Several animal and human cadaveric studies have been performed to prove the feasibility of these techniques and proven with few case illustrations. And lately we are heading towards the use of robotic arm prosthesis in a case of missile induced nerve injuries. Neural machine interface is produced which supersedes the functional restoration provided by the conventional techniques.

Keywords: Peripheral nerve; Brachial plexus surgery; Recent techniques; Nerve conduits; Endoscopic; Robotic

Introduction

Brachial plexus injuries result primarily from a traction injury and are usually catastrophic to the individual. The "seven seventies"as described by Narakas attributes these injuries to motor vehicular accidents (70%)[1]. The commonest injury is supra-clavicular with at least one root avulsed. It results in loss of productive functioning of the upper extremity. However timely repair and reconstruction helps in restoration of useful function. In this article we intend to discuss the recent advances in the management of brachial plexus injuries and their impact on outcome.

It was in 1940s and 50s that Seddon and Bateman along with few others started planning surgical approaches towards brachial plexus treatment[2,3]. The aim was to identify the avulsion injury vs neuroma in continuity and the former lesions were planned for amputation surgeries and limb prostheses or arthrodesis. As for the neuroma in continuity, wait and watch policy was adopted for almost 2 years post injury. However, several technical advancements have led to a more proactive era contributing to a significant improvement in the outcome of these patients.

It has been rightly said that the brachial plexus surgery not only helps in reconstruction but also helps resolve any doubt pertaining to the need for surgical correction. The aim of the surgery in adult brachial plexus injuries is to achieve shoulder stability first and therefore, the reconstruction is always planned from proximal to distal. The outcome pertaining to C8 and T1 injuries is very unfavourable, which provides justification in some authors' opinion that these roots should not be reconstructed.

The earliest surgical technique consisted of coaptation of the injured stumps, at times achieved by clavicular shortening. The introduction of nerve grafts began in the late 60s and beginning of 70s[4,5].Since then, there have been several advances in the technique of nerve repair. Currently, nerve reconstruction is offered to patients as early as possible, as recovery thereafter depends on axonal growth[6].

The Brachial plexus surgery has rightly evolved through stages of neurolysis, direct nerve repair, nerve grafts and, neurotization each having their own significance and indications.

Neurolysis is performed to decompress the viable fascicles in cases of neuroma- in continuity. The advances in intra-operative electro-physiological

✉ Sumit Sinha
+91 9968292347
sumitneuro@gmail.com

1 Department of Neurosurgery and Gamma Knife
All India Institute of Medical Sciences, New Delhi, India

2 All India Institute of Medical Sciences, New Delhi, India

3 307, JPNA, Trauma Centre, AIIMS, New Delhi, India

studies have made it possible to have a quantitative assessment of the number of viable nerve fibers and help in choosing between neurolysis or resecting the neuroma and moving ahead with nerve grafts. The nerve action potentials (NAP) are measured intra-operatively and post-operatively, using one electrode proximal to the neuroma and one distally, and improvement in conduction is documented after the procedure[7]. Interfascicular neurolysis has a risk of vascular damage, and hence few authors instead prefer anterior epineurectomy by excising the fibrous tissue.

In patients with post-ganglionic injuries with a healthy proximal stump, nerve grafting is an option worthwhile considering. Seddon in 1963, propagated the use of nerve graft to reconstruct nerve losses[4]. Since then, the sural nerve, medial cutaneous nerve of the forearm, lateral cutaneous nerve of the forearm and ipsilateral ulnar nerve (as a pedicled vascularized nerve graft in lower root avulsions) have been used very commonly in post ganglionic injuries. Although free nerve grafting technique gives poor results for peripheral functional recovery, studies on vascularised ulnar nerve grafts also have not shown overall better recovery and functional improvement[8,9,10,11]. The surgical technique definitely has an impact on the outcome after nerve grafting and a lot of work has been dedicated towards this.

Tissue Glue

The two ends of the grafts were initially sutured individually, thereby making the procedure long and demanding. Moreover, the literature showed that nerve suturing might lead to inflammation and foreign body reaction impairing nerve regeneration[12]. Hence, the proponents of fibrin glue used glue to form a group of graft ends thereby constituting a single structure. Fewer stitches were needed in the proximal and distal sutures, which made the grafting procedure much simpler and much more secure.(Fig. 1) The utilization of tissue adhesives in the context of peripheral nerve repair is not a new practice, with literature dating back to the 1940s[13]. There is not a single controlled human trial comparing fibrin glue and micro sutures because its use for nerve repair is not approved by the FDA[14] Most researches done on rat models involving the sciatic nerve indicate that fibrin glue is equal, if not superior to micro-sutures in terms of functional recovery and histopathological results[15,16]. The repairs performed using fibrin glue showed less fibrosis and inflammation, better axonal alignment, and more axons across the repair site. Even when some variables were not clearly different in the two groups, fibrin glue remained an easier and quicker modality to use[17,18, 19]. However, bio-mechanical results have been a cause for concern since some studies show that it may not provide adequate tensile strength to the repair[20]. As an easier available option intra-operatively, it might also mitigate the learning curve of micro-neurosurgical repair[21]. To overcome these shortcomings, Isaacs et al examined 57 fresh frozen cadavers to assess resistance to gapping, peak load and stiffness between different nerve glues and a suture only group. The authors concluded that avoidance of gapping was critical to achieve successful nerve regeneration and fibrin glue in addition to two suture nerve repair helped avoid this initial gapping[22].

A preliminary clinical report of 56 cases by Narakas concluded that the main advantage of using fibrin glue was the gain in operative time and the ability to perform repairs in areas previously not possible such as at or within the bony foramen of a proximal nerve root.[23] Despite the increasing literature on the utility of fibrin glue, micro-suturing still remains the gold standard of nerve coaptation. More human trials are needed to establish the overall clinical superiority of nerve glue over micro-sutures.

Fig. 1 Use of glue along with tagging sutures helps in faster and safer anastomosis.

Nerve Conduits

There has been a lot of work on the graft to be used in repair. Repair with autografts has a number of disadvantages, such as the need for an extra incision, limited availability of donor tissue, nerve site mismatch, donor site morbidity and the chance of development of a painful neuroma[24] Because of these disadvantages, various alternatives have been developed such as nerve tubes, guides, or conduits. Most studies support use of conduits for short nerve gaps (<3 cm) in small diameter, non-critical sensory nerves[25,26,27]. Very few case reports exist about successful use of synthetic conduits in large diameter human nerves[28].

An ideal nerve tube should be easily fabricated with the desired dimensions and topography, sterilizable, non-immunogenic with relative ease of implantation[29]. It should cause minimal nerve compression and host tissue response[30]. A variety of biomaterials have been developed for use in nerve guidance conduits. They include naturally occurring materials like collagen and chitosan and synthetics such as silicone, polyglycolic acid (PGA) and polycaprolactone (PCL)[31].

The first experiments with silicone nerve tubes by Lundborg and colleagues demonstrated that axons can successfully regenerate across a 1 cm gap in the rat sciatic nerve model[32]. As animal models demonstrated promise, they transitioned to clinical research with silicon tubes. They presented 3 prospective studies with successful regeneration through silicon tubes. The 5-year follow up data showed that ulnar and median nerve repairs performed with silicon conduits were at least comparable to direct sutures[33].

Lohmeyer et al performed 55 digital nerve reconstructions in 45 patients using collagen conduits and reported consistent functional recovery for nerve gaps less than 15 mm long[34]. Polycaprolactone tubes (PCL) were investigated by Bertleff et al in a digital nerve repair model and were found to be comparable to sutures for gaps less than 20 mm[35]. In a prospective, multicenter, randomized study by Weber et al, 136 nerve transections in the hand were studied[36]. It was found that repair with PGA conduit produced superior results in short gaps of less than 4 mm when compared with end to end repair. They were also found to be superior to nerve autografts for defects upto 30 mm. Till now, PGA has been the most successful material implanted in humans, with a comprehensive evaluation of nine studies of 1990 to 2005 showing that 75% patients present with “good”or “very good”recovery[37].

While nerve guidance conduits have shown promise in short gap, digital nerve repair, data in brachial plexus repair has been limited. Ashley et al showed good results with collagen conduits in patients with obstetric brachial plexus palsy with 4 out of 5 patients regaining function 2 years post operatively[38]. Wolfe et al studied bioabsorbable nerve conduits as an adjunct to brachial plexus neurorraphy and found evidence of clinical and electromyographic recovery[39]. However, further evaluation is required to establish their clinical efficacy in brachial plexus injuries. Future research should focus on their enrichment with neurotrophic factors and/or schwann cells to aid nerve regeneration.

Distal Nerve Transfers

Closed target nerve transfer is a procedure outside the supra and infra clavicular fossa at a site closer to the neuro-muscular junction, also called as distal nerve transfers. The most glaring example of such procedure is modified Oberlin method. (Fig. 2) First performed by Prof. Oberlin in mid-1990s ,Oberlin procedure is the Copernican revolution for brachial plexus surgery, which has changed the philosophy of treatment of these devastating injuries[40]. The original Oberlin procedure has been fortified by another nerve transfer to brachialis branch of MCN using a motor fascicle from the median nerve (double fascicular transfer). The ideal median nerve donor fascicle contains nerves to the flexor digitorum superficialis (FDS) and flexor carpi radialis, without the anterior interosseous nerve (AIN) supply. Such distal nerve transfer has been observed to be a better alternative than conventional methods. Several studies have affirmed that expendable fascicles of the ulnar, thoraco-dorsal and radial nerves are viable options for distal nerve transfer[41]. Bertelli J et al , in his clinico-anatomical study has shown the superiority of selective distal ulnar motor fascicle (FCU motor branch) harvest and connection to a triceps branch to restore elbow extension over non selective ulnar nerve transfers[42]. This transfer keeps the option of later transfer of the still functional FCU tendon to the digital extensors. Flores LP reported radio-radial nerve transfer for the elbow extension. He described distal nerve transfer as a novel tecnique to be used in patients with C5-C7 nerve root injury and preserved finger extension motion[43,44]. Fascicle innervating the extensor digitorum communis muscle was sectioned, derouted and connected to a motor branch to the lateral head of the triceps and it showed improvement in elbow extension to MRC Grade 4. Studies have shown that distal nerve transfer in high ulnar injuries have led to shorter re-innervation period and better ulnar intrinsic recovery[45]. Anatomical feasibility of preserving the motor branch of ulnar nerve (MBUN) after the contralateral C7 transfer procedure has been proven useful for a later stage repair using the recovered pronator quadratus motor branch (PQMB)[46]. Transfer of the supinator motor branch of the radial nerve (SMB) to the posterior interosseous nerve (PIN) and the pronator teres motor branch of median (PTMB) to the anterior interosseous nerve (AIN) in patients with lower brachial plexus injuries for successful recovery of digital extrinsic flexion and extension in lower brachial plexus injuries is another such example[47]. Distal nerve transfer was also found to be a superior method of managing isolated MCN injury compared with conventional nerve grafting[48].

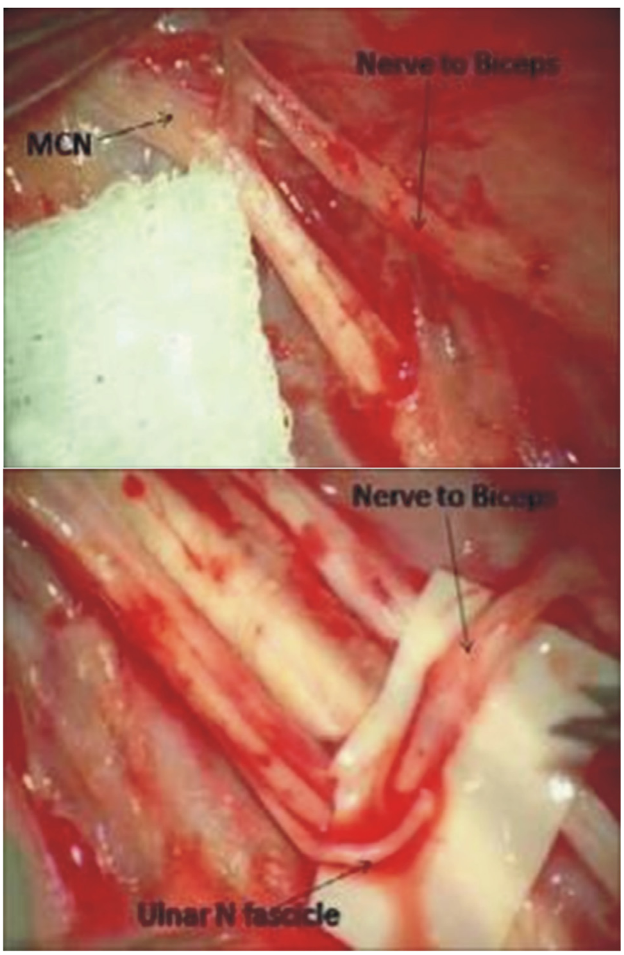

Fig. 2 Nerve to biceps is identified from its origin from musculocutaneous nerve and then anastomosed with ulnar nerve fascicle. The transfer is done as close to the neuromuscular junction as possible.

Root Reimplantation

Almost 70% of the brachial plexus lesions involves avulsion of at least one spinal nerve root of the brachial plexus and associated with poor outcome[49]. Such patients undergo neurotization. Four types of neurotization procedure has been described 1) extra-plexus, 2) intra-plexus, 3) close-target, and 4) end to-side neuro-rrhaphy[50] and differs basically in the choice of donor nerves[51-60].

A number of animal studies also have recognized spinal nerve root implantation as a feasible repair technique for cervical root avulsion[61]. The interest in direct root implantation was rekindled clinically in 1995, when Carlstedt et al described the implantation of a ventral nerve root and nerve grafts into the spinal cord in a patient with brachial plexus avulsion injury[62]. The results of surgery were reported in several other studies in literature[63,64]. Currently, limited data on spinal root replantation exists in the literature and no controlled human trial has been reported comparing its clinical efficacy with other surgical modalities for brachial plexus avulsion. Htut et al reported a case series of 44 patients with severe brachial plexus avulsion injuries, who were studied following surgical repairs[65]. In 8 patients, who underwent reimplantation of spinal nerve roots directly into the spinal cord in conjunction with other repairs, motor recovery in the proximal limb was similar to that achieved by conventional nerve grafts and transfers. Carlstedt et al reported a case series of 10 patients of which 3 achieved meaningful (MRC Grade 4) functional recovery of proximal muscle function after spinal nerve root repair and replantation of avulsed ventral roots into the spinal cord[66]. Another case report by Carlstedt et al about a preadolescent boy who underwent replantation of all motor roots for complete brachial plexus avulsion injury showed recovery in the proximal part of the arm 8 to 10 months later and also in the intrinsic muscles of the hand by 2 years post operatively. Interestingly, motor recovery was accompanied by complete relief of pain. A subsequent follow up fMRI study on the same patient detected activity in the primary and non-primary sensory cortex during movements without visual control[67]. A few other studies have also suggested that ventral root replantation may lead to a relief in neuropathic pain that typically follows an avulsion injury[68,69]. Amr et al in 2009, described 5 patients with traumatic brachial plexus palsy out of which 3 suffered complete avulsion[70]. Cord replantation in complete avulsions led to grade 4 improvement in shoulder abduction/flexion and elbow flexion.

With better understanding of neuronal regeneration in the spinal cord, re-implantation of nerve roots will almost certainly become a routine part of surgical management of brachial plexus injuries in the next decade.

Endoscopic Exploration of the Brachial Plexus

Another step towards advancement in techniques for brachial plexus surgeries is the use of endoscopy. To avoid the time consuming conventional approach for determining the need of surgery, few authors suggested the minimally invasive approach. It may be used as a tool to analyse the morphology before embarking into a tedious process. Monsivais et al was one of the first few to document the use of endoscopy to visualise the dorsal and the ventral rootlets in ten goats[71]. Krishnan et al performed a cadaveric study on 11 fresh human cadavers at the supra - and infra-clavicular levels[72]. The endoscopic observations were tallied with the findings in open surgery performed thereafter in the same cadavers. The omohyoid muscle provides a reliable landmark at supraclavicular level and infra-clavicular landmark is the axillary artery. They recommended the use of endoscopic technique along with intra-operative nerve stimulation as a useful step forward. Gustavo et al performed an endoscopic approach using three supraclavicular portals in two fresh human cadavers with the aid of da Vinci tele-manipulation system[73]. CO2 at 4 mm Hg was used to inflate the area. They succeeded to reconstruct an artificial lesion created at the upper trunk with the use of epineural microsurgical suture technique. They concluded that the use of robot in the tele manipulation and minimally invasive is a feasible option. Garcia et al also have suggested endoscopy as a next logical step in refining the diagnostic and treatment procedures[74]. It may be used as an ancillary option for assisting open surgery. Technique involves introducing the five ports at well defined landmarks. In an another cadaveric study, Morgan et al evaluated the use of Video assisted thoracoscopic surgeries (VATS) as an alternative surgical corridor for the exposure of C8-T1 nerve root as well as lower trunk lesions[75]. This trans thoracoscopic endoscopic surgery avoids the morbidity associated with supraclavicular and posterior sub scapular dissections and is very useful when there is severe scarring anterior to the lesion. Despite all these cadaveric studies , there is still a long way to go and explore the use of endoscopy on live patients. There is also a long learning curve .

Robotic Assisted Neurolysis

Like in other microsurgeries, robotic surgery has been a recent addition in the surgeon's armamentarium for performing nerve surgeries. Several animal studies have now been directed towards showing the efficacy of robotic surgery in brachial plexus lesions[76]. Peripheral nerve surgery assisted by Da Vinci robotic system eliminates physiological tremors and three-dimensional high-resolution vision. Both the traditional brachial plexus approach or the mini-invasive approach has been shown to be possible with robot assisted nerve surgery. Feasibility of robotic intercostal and phrenic nerve grafts in pigs have been a success[77,78]. A surgical da Vinci Model S system robot, was used to isolate the posterior edges of the fourth, fifth, and sixth intercostal nerves at the level of the anterior axillary line. The anterior edges of the nerves were transected at the rib cartilage zone. Author successfully harvested three intercostal nerves in an average of 33 minutes in 3 pigs without major complications. Robot-assisted neurolysis may be clinically useful for harvesting the extra -plexal nerves for brachial plexus reconstruction.

Robotic Arm Prosthesis in Brachial Plexus Surgery

The most recent addition has been the use of prosthetic devices, especially in the missile induced nerve injuries[79]. Here, a new program develops advanced prosthetic devices that can interface with neural tissue to obtain direct neural control. With time it is expected to supersede the functional restoration that can be obtained by standard nerve repair techniques. Artificial arm function is limited due to inadequate control method. Various techniques like nerve transfers to muscle (targeted muscle innervation) and or skin are being tried to provide alternate pathway for cutaneo-sensory feedback to missing hand. (neural machine interface). Kuiken et al developed a technique that used nerve transfers to muscle to develop new electromyogram control signals and nerve transfers to skin, to provide a pathway for cutaneous sensory feedback to the missing hand[80]. They observed that targeted sensory re-innervation may provide a pathway for meaningful sensory feedback. The re-innervated muscle acts as a biological amplifier of motor commands in amputated nerves and used to enhance control over robotic arm. However, the degree of freedom of the robotic arm is limited due to the number of re-innervated muscle sites.

Bionic Limbs

The industrial and clinical advances for interfacing robotic limbs with the human body have not been very significant. For the first time bionic reconstruction; a combined technique of selective nerve and muscle transfers, elective amputation, and prosthetic rehabilitation to regain hand function, was demonstrated by Oskar et al in three patients of global plexus injury[81]. Treatment was performed in two stages; first, useful electromyographic signals for prosthetic control identified and created, and then hand was amputated and replaced with a mechatronic prosthesis. Author recommends this procedure for patients with global plexus injury along with lower root avulsions. However, this concept of prosthetic replacement of an electively amputated limbs after mutilating injuries is difficult to execute because of the limited availability of muscle tissue left under voluntary muscle control.

Conclusion

From the times when a wait and watch policy was being adopted to the times of minimally invasive surgeries, we have come a long way in managing brachial plexus lesions. With the wider options available in the form of tissue glue and nerve conduits, there has been a definite improvement in the surgical outcome. The endoscopic surgery along with the tele robotics may help in overcoming the associated morbidity with the conventional techniques. Randomised trials are needed to prove the therapeutic benefits of the emerging techniques. Nevertheless, the secondary surgeries being performed, complements the available surgical options. For the best of results, a multidisciplinary approach is needed.

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