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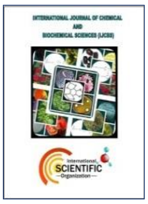

Nerve grafting versus nerve transfers for restoration of shoulder and elbow function after traumatic brachial plexus palsy

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Abstract

In treating patients with brachial plexus injury, there are no comparative data on the outcomes of nerve grafts or nerve transfers for isolated upper trunk or C5-C6-C7 root injuries. Overall nerve transfers have broadened our reconstructive options and delivered more reliable results for some patterns of injury to the brachial plexus. Nerve graft repair can give good results for elbow flexion when a viable proximal nerve is available. The purpose of our study was to compare, with review, the outcomes for modern nerve transfers for shoulder and elbow function with autogenous nerve grafting for upper brachial plexus traumatic injuries. Outcomes have improved for reconstruction of the paralysed shoulder using transfer of the accessory nerve to the suprascapular nerve. Fascicular transfer to musculocutaneous nerve has proved reliable for restoration of elbow flexion for patients with C5,6 and C5,6,7 injuries. Problems with nerve transfers include morbidity in the donor nerve territory, co-contraction, and pre-existing injury to the donor nerve. There is a balance of risks in these procedures which should be weighed up in individual cases.

Keywords: Brachial plexus, Injury, Nerve graft, Nerve transfer

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1. Introduction

The brachial plexus is a series of nerves formed by anterior roots of (C5–C8) + (T1). It functions to provide sensation and motor innervation to the skin and muscles of the shoulder girdle and upper extremity. It does so through different segments: roots, trunks, divisions, and cords [1]. Simple and practical classification scheme divides injury location into two groups: supraclavicular or infraclavicular lesions. Supraclavicular lesions imply injury at the spinal nerve and trunks levels. Infraclavicular lesions mostly occur at the cord and terminal branch levels [2]. The application of microsurgical techniques and the establishment of the principle of tension free repair in peripheral nerve surgery, brought several new techniques for brachial plexus reconstruction, especially in supraclavicular lesions with multiple avulsions [3]. In most of the brachial plexus injuries, it is necessary to recover the stability of the shoulder as well as its abduction and external rotation. Although there are many techniques to achieve this goal, one of the most used techniques is the nerve transfer of fascicles of the accessory nerve (XI) to the supra scapular nerve, which gives better results than using nerve grafts from a ruptured C5 root [4].

2. Brachial plexus injury

Brachial plexus injuries can cause functional and social disability related to loss of upper limb strength and hand function. When severe injury has occurred, surgical repair may offer the greatest chance of partial recovery [5].

2.1. Definition

Brachial plexus injuries are usually caused by trauma to the roots of the plexus as they exit the cervical spine. This most commonly occurs in road traffic accidents and falls from height. Inflammatory, neoplastic, and compressive causes are also possible.

2.2. Epidemiology

BPI is most common in younger males between the ages of 15 and 25. In Naraka's analysis of BPI in over 1000 patients, he described the law of 7 seventies [6].

2.3. Levels of injury

Various classifications of the level of BPI have been proposed. These frequent classifications have made the understanding of the anatomy of the brachial plexus complex and confusing. There are two types of characteristic lesions seen in BPI: avulsion and rupture. Avulsion refers to the nerve being torn from its origin, while rupture causes a complete division with irregular proximal and distal ends. In avulsion injury, only one disrupted end with a coiled spring-like appearance can be seen in the operative field in the acute stage or a fusiform pattern in the chronic stage [7].

Injury Type

Traumatic brachial plexus injuries can be classified into open injuries and closed injuries that result from stretching. The latter are much more frequent and generally caused by high-speed vehicle accidents, especially involving motorcycles [8]. Regarding location, brachial plexus lesions can be classified in two ways: pertaining to their position relative to the dorsal root ganglion and their position relative to the clavicle [9].

3. Diagnostic Approach

3.1. Imaging Studies

Radiographic imaging after a neck or shoulder girdle injury may reveal evidence of a concomitant neurological lesion. Radiographs of cervical spine, shoulder girdle, humerus, and chest should be obtained. Computed tomography (CT), along with computed tomographic myelography (CTM), contributes greatly to the evaluation of the level of nerve injury. In case of a cervical root avulsion a pseudomeningocele could be formed, in the process of dura mater healing. Immediately after the injury, blood clots appear at the avulsion point. These clots become apparent in myelography as overshadowing at the point of the lesion and around [10]. Myelographic studies in combination with magnetic resonance imaging are essentially a T2 sequence, which points out the contrast of spinal cord and roots to cerebrospinal fluid [11]. Compared to CT, MRI has certain advantages. It is a noninvasive method which can depict more lesions apart from root injuries and a formed pseudomeningocele. It can depict brachial plexus almost in total. It can reveal posttraumatic neuromas, along with the concomitant inflammatory response and edema of the surrounding tissues [12].

3.2. Histamine Test

Its purpose is to differentiate preganglionic and postganglionic lesions, but nowadays it is rarely performed. The intradermal injection of histamine causes triple response (red reaction due to capillary dilatation, wheal due to fluid extravasation from increased permeability, and flare due to arteriolar dilatation and to axon reflex in sensory nerve) [13].

3.3. Electrodiagnostic Tests

Electrodiagnostic tests are an integral part of both preoperative and intraoperative evaluation, providing that there is proper conduction and evaluation of their results. They are valuable tools, which must be used in conjunction with meticulous physical examination and adequate imaging evaluation, and not as their substitute [14]. Combined electrodiagnostic techniques like nerve action potentials (NAPs), somatosensory evoked potentials (SSEPs), and compound muscle action potentials (CMAPs) may give adequate additional information in order to help the surgeon in decision making [15].

4. Surgical intervention

4.1. Timing of Surgery

Deciding on the right time to operate on a traumatic brachial plexus injury must be done following a thorough analysis of each case. Patients with total palsy of the brachial plexus following the causal trauma have almost no chance of spontaneous recovery, so early surgery is usually indicated, even more so if root avulsions are diagnosed [16]. Conversely, with partial injuries some spontaneous improvement might occur. The best time to operate on such patients is after the third month, but before the sixth month after injury. Good results can be achieved after the seventh month, but the rate of good results decreases drastically, especially after 9 months [17]. One year since the trauma that caused the brachial plexus injury is the maximum time generally accepted to perform primary repair surgery expecting good results [9]. A variety of surgical procedures have been reported to improve the functional outcome. Which one is appropriate depends on the type of lesion. The types of surgical procedures are as follows [9].

5. Primary procedure

5.1. Neurolysis

When the nerve lesion is in continuity, neurolysis may help. It is of great importance to maintain the interfascicular structure and the nerve sheath. The clinical outcome of neurolysis is not easy to identify as any functional improvement may be the result of many factors other than neurolysis itself [9].

5.2. Nerve Grafting

Nerve grafting is the predominant technique for clear cut injuries with a healthy proximal stump and with no axial damage. The outcome is influenced by the length of the nerve graft, the presence of scar tissue at the wound site, the number of grafts used, the presence of a healthy proximal stump available for grafting and the nerve gap to be covered [19]. The use of free nerve grafting for peripheral functional recovery seems to provide poor results compared to the reconstruction of more proximal lesions.

Another choice is vascular nerve grafts when the ulnar nerve is often used . In such cases, the ulnar nerve is divided into smaller grafts, the size of the sural nerve, so as to increase the chance of success [20].

5.3. Nerve transfers

Nerve transfer (neurotization) is a method using the transfer of a functional but less important donor nerve to a nonfunctional, more important recipient nerve in cases of cervical root avulsions or intractable proximal brachial plexus injury. The choice of donor nerves for neurotization remains a controversial topic in peripheral nerve surgery mainly because of a lack of large randomized clinical trials of this specific surgical procedure [21]. The TDN is an ideal donor for motor nerve transfer because of its length and its large number of myelinated fibers. It has previously produced excellent results when transferred to several recipient nerves. The outcomes achieved in our case indicate that direct TDN transfer is a valid surgical procedure for the restoration of shoulder reanimation in patients with partial BPI in the setting of limited donor nerve availability [22].

5.4. Fascicular transfer

Recently, new promising ways of neurotization using only a part of the donor nerve have been published. Transfer of the triceps motor branches of the radial nerve to the axillary nerve was performed to restore deltoid muscle function and appears to be safe and effective. The functional loss relative to the triceps, with a single nerve transferred, is negligible because of compensation by the remaining heads [23].

6. Secondary Procedures

Different techniques are possible for secondary reconstruction of elbow flexion. A precise preoperative analysis of the lesion is enormously important, and the following clinical conditions should be differentiated: Complete paralysis of the upper extremity, partial paralysis after spontaneous regeneration or operative adjustment without any regeneration of the muscles for elbow flexion (M0), and partial paralysis after spontaneous regeneration or operative adjustment with insufficient regeneration of the muscles for elbow flexion (M1 or M2) [25].

6.1. Pedicled Muscle / Tendon Transfers

Pedicled muscle transfer is indicated in non-global BPI such as C5–6 root avulsion. Preoperative muscle strength examination is very important (at least M4). Joints must be freely mobile on passive motion. The gain in function must be greater than the functional loss at the donor site [7].

6.2. Bipolar transfer of latissimus dorsi

The LDM origin is approached through a longitudinal incision posterior to the midaxillary line, from the inferior axilla to a point between the ribs and iliac crest. Mobilizing the insertion of the LDM with the overlying thoracodorsal fascia, then neurovascular pedicle is located on the ventral surface of the muscle proximally near the lateral edge [26]. Alternatively, distal fixation can be performed to the radial tuberosity or proximal third of the ulnar diaphysis to increase the lever arm and improve strength, mimicking the ulnar insertion of the brachialis [27]. The resting tension of the repair should be about 100 degrees of flexion and maximum supination to optimize muscle strength along its Blix curve. Repair is reinforced with sutures across the tendon junction or hardware in the case of bony fixation [28].

6.3. Pectoralis Major Transfer

One of the commonly transferred shoulder muscles for elbow flexion is the pectoralis major muscle (PMM). The use of the PMM muscle can be generally categorized into distal muscle transposition techniques, proximal tendon transfer techniques and bipolar PMM transfer [29].

6.4. Bipolar Transfer

Under general anesthesia and in a supine position, the incision is made in the chest wall. After skin flap elevation the PMM is harvested with care to dissect the medial pectoral nerve. The harvested flap is then fixed in a similar way of the bipolar LDM transfer and the wound is closed [30].

6.5. Steindler flexorplasty

Incision is begun at the medial side of the arm, then curved around the medial epicondyle and ended at the proximal aspect of the flexor side of the forearm. After the forearm fascia and the belly of the pronator are exposed, the fascia overlying the ulnar nerve is divided, and the nerve lifted and retracted [29].

6.6. Triceps to Biceps Transfer

Triceps to biceps transfer has been used as a muscle replacement in patients with upper brachial plexus palsy (C5-6). If active elbow flexion is impeded by co-contraction of the triceps with the biceps, a triceps muscle transfer is likely to give a favorable result [32]. Two incisions are used; the first incision is along the centre of the back of the arm from the junction of upper and middle third down to the olecranon process. The second incision is on the lower anteromedial arm up to the cubital fossa to permit exposure of the biceps tendon [33]. The long head of the triceps is preferentially isolated proximally from the lateral head and the gap in the triceps tendon is sutured keeping the elbow in full extension. Since the long head arises from the infra-glenoid tubercle, this permits a more direct route of transfer to the distal biceps [33].

6.7. Free Functioning Muscle Transfer

Free functional muscle transfers (FFMT) are used primarily to reconstruct hand function or elbow flexion if no functioning regional muscles are available. The most commonly used donor muscles are the gracilis, the rectus femoris, the LDM, and the PMM. A second gracilis transfer can be performed, also using additional intercostal nerve motors, to restore opposing finger function, as in the "double Doi" procedure [34].

7. Surgical Procedure

7.1. Recipient site preparation

Initial dissection is performed at the recipient site to make the bed and ensure that adequate donor vessels and nerves are present before any dissection of the donor muscle is carried out. The spinal accessory or intercostal motor nerves are both acceptable donor nerves, a graft may be needed in earlier stage. Alternatively, a portion of the ulnar nerve or median nerve can be used [35].

7.2. Gracilis muscle harvest

The anterior portion of the incision is first incised and the dissection is directed towards the adductor longus which is then retracted away from the gracilis muscle, and the vascular pedicle and motor nerve are identified in the interval. The resting muscle tension can be marked with 5-cm interval sutures. The distal tendon is then divided and gently pulled to the proximal thigh wound [35].

7.3. Gracilis muscle Transfer

To minimize muscle ischemic time (which should be less than 60 minutes) the recipient bed is fully prepared, and then the gracilis vascular pedicle is ligated proximally and divided. The proximal tendon is rapidly secured to the acromion and lateral clavicle with anchors. The vascular anastomoses are then performed. Once the circulation has been restored, the nerve transfer is performed. The repair is performed with the arm abducted (90 degree) and externally rotated (90 degrees) to ensure that post-operative shoulder motion will not affect the nerve repair site [36]. To obtain a good result, the final step is to restore an appropriate muscle tension. This can be achieved by restoring the original muscle resting length using superficially placed sutures [35].

8. Follow up and rehabilitation

The rehabilitation care of a patient with brachial plexus injury is too complex to be provided by a single person. Rehabilitation of an individual with a brachial plexus injury is a team effort that requires the close cooperation of many healthcare specialists. The rehabilitation effort is usually coordinated between the physiatrist and the surgeon [37].

9. Postoperative management

Immediate postoperative splinting for 3 weeks is required after nerve grafts or nerve transfer. Thereafter, re-education and rehabilitation should start, including physiotherapy (to avoid joint stiffness), muscle stimulation (to delay muscle atrophy), brain cognition and occupational therapy. Patients are encouraged to have electric muscle stimulation at home (twice a day). In cases of intercostal nerve transfer, passive shoulder elevation remains restricted to less than 90° for 6 months [7]. Regular follow-up in the rehabilitation center and outpatient clinic is extremely important and should be explained to patients before and stressed again after surgery. This explains why good results are commonly achieved by psychologically strong and ambitious patients who cooperate well in terms of their rehabilitation program, while poor results are often obtained by uncooperative patients [7].

11. Extremity Support

A functional arm orthosis usually formed of a shoulder saddle secured with a chest strap from which the arm orthosis is suspended. There is a plastic arm cuff suspended from the saddle by a Bowden cable to prevent subluxation of the glenohumeral joint. The functional arm orthosis can be further modified for patients with wrist weakness by adding a detachable wrist support [37].

12. Pain management

Brachial plexus injuries are followed by chronic pain in 30–90% of patients. Pain associated with plexopathy is often described as being neuropathic. It is important to identify neuropathic components of a patient's pain because different classes of analgesic drugs are usually required to manage this type of pain effectively [37]. Pain following brachial plexus injuries may be due to neuromas, denervation-reinnervation, avulsion, or musculoskeletal strain. Pain relief may occur with reinnervation following surgery in many patients with brachial plexus injuries [37].

13. Complications of surgery

Contractures related to certain types of incisions have been reported. In some exposures, the spinal accessory nerve is at risk and should be protected. More specific complications are variable and depend on the exact type of procedure performed [38]. Deafferentation pain can be one of the most difficult problems for the clinician to treat after brachial plexus injuries. This pain syndrome may occur after surgical repair or with conservative treatment of brachial plexus lesions [39]. Transcutaneous nerve stimulation (TNS) can be considered. TNS may work by preventing the cells in the dorsal column from sending abnormal signals proximally. TNS must be used for a prolonged period, and maximum benefit from the device may not occur for several months. For a total brachial plexus lesion (C5-T1), the stimulators are placed on the front of the chest (C3-C4 dermatome) and on the inner arm (T2 dermatome) [40]. Advances in surgical technique have renewed interest in surgical procedures to disrupt the signals generated in the dorsal reentry zone (DREZ) of the dorsal columns. Thomas and Sheehy documented good pain reduction (75% relief) in about half of the patients in their series. Most surgeons reserve such invasive procedures for long-standing severe pain that is refractory to conservative measures [41].

14. Reimplantation of Brachial Plexus—the Role of Neurotrophic Factors

Since the 1980s, many scientists have achieved axonal regeneration in central nervous system transplants through the use of peripheral nerve autografts [42].

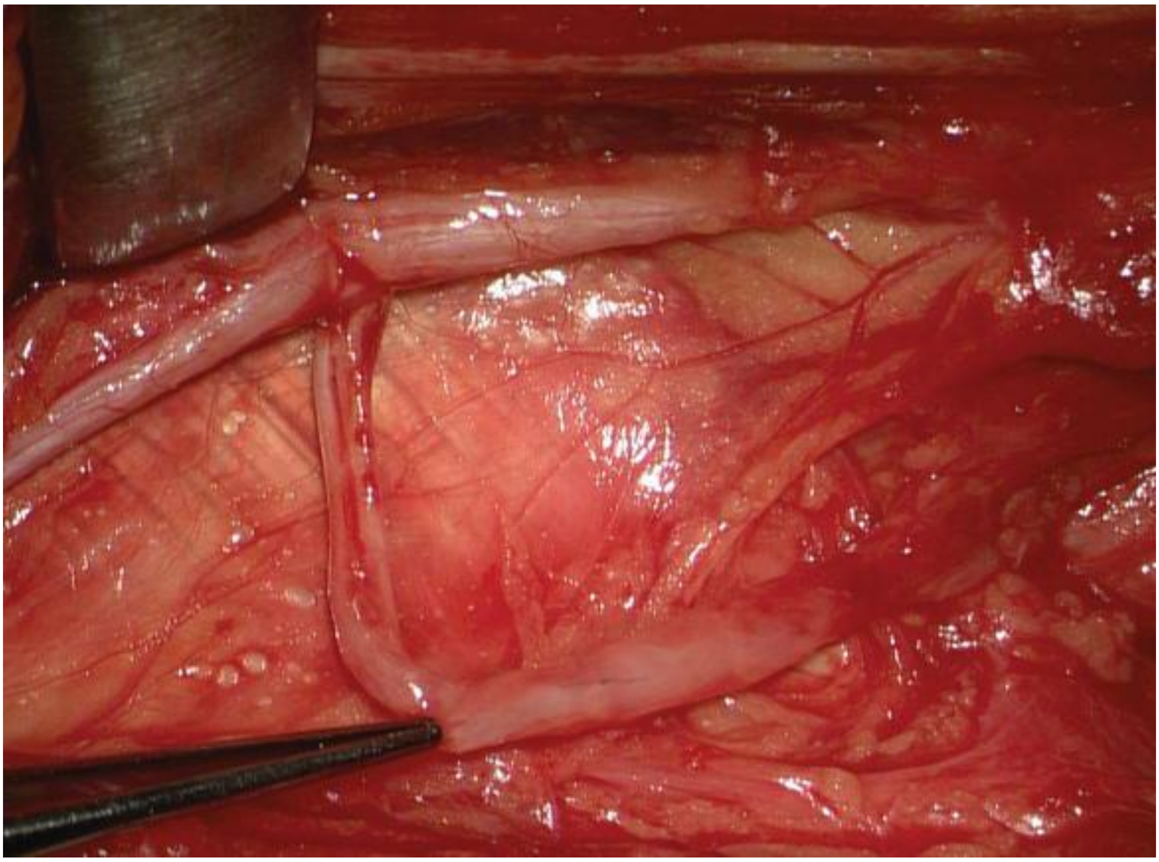

Figure 1. Transfer of the triceps motor branches of the radial nerve to the axillary nerve. [24]

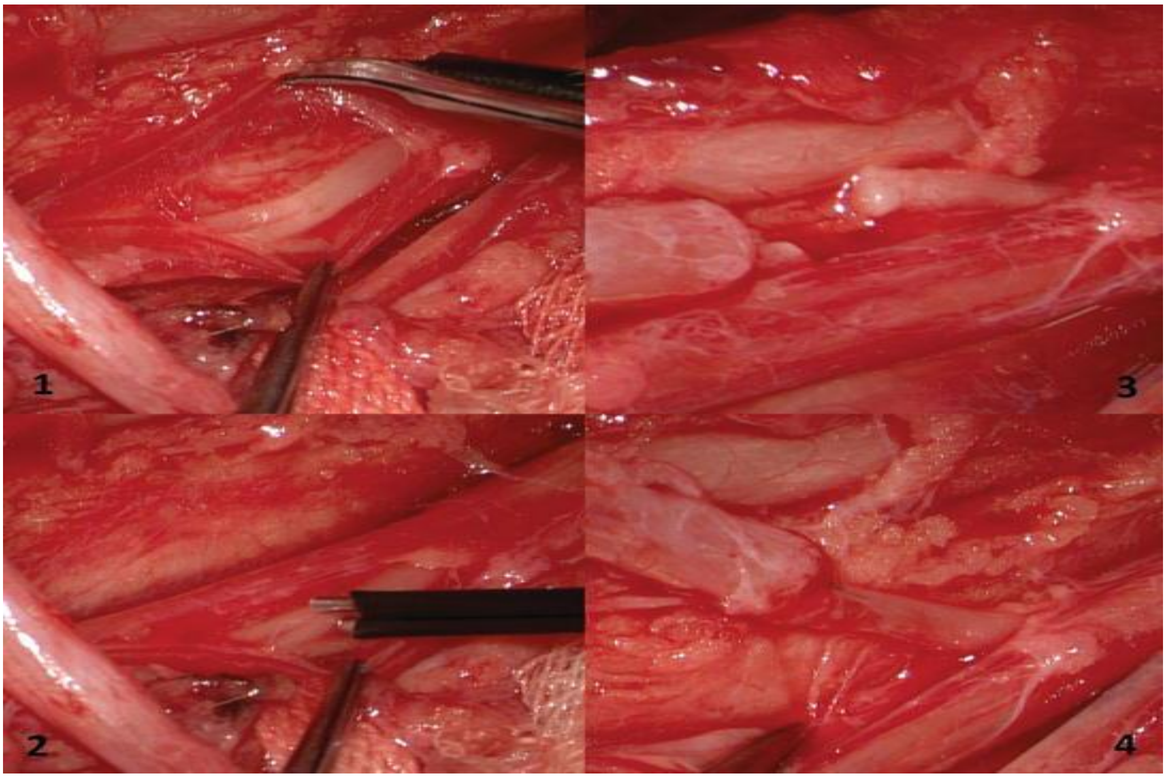

Figure 2. Fascicular transfer to the musculocutaneous nerve. (1) Epineurotomy of ulnar nerve; (2) detection of fascicle with direct bipolar electrical stimulation; (3) preparation; (4) direct coaptation [24]

Figure 3. The PMM elevated on its neurovascular pedicle **[31]**

Figure 4. The separation of heads of triceps and the reach of transferred head of triceps [33]

Figure 5. Gracilis muscle harvesting [35]

Figure 6. Gracilis muscle in-setting [36]

Many questions remain about this type of procedure. It also has limitations. In particular, the delay between injury and the surgical procedure plays a critical role in neurological restoration. The very early results are rather promising so that future action should take place. The question remains as to whether 3 mm and 5 mm diameter grafts may be responsible for further injury to the spinal cord. Further research should focus on the bioengineering, characterization, and experimental application of this type of implant [43].

15. Conclusions

In patients with demonstrated complete traumatic upper brachial plexus injuries of C5-C6, the pooled international data strongly favors dual nerve transfer over traditional nerve grafting for restoration of improved shoulder and elbow function. These data may be helpful to surgeons considering intraoperative options, particularly in cases in which the native nerve root or trunk may appear less than optimal, or when long nerve grafts are contemplated.

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