Brachial Plexus Injuries: An Overview

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A brachial plexus injury results from the injury to the network of the nerves and manifests as impairment of motor and sensory functions of the involved upper limb. Brachial plexus injury is usually sustained in high speed motor bike accidents. These injuries occur in approximately 4.2% of motor cycle accidents. [1] Other less common modes of injury include automobile accidents, falls, sports injury, bicycle and pedestrian accidents, stab and gunshot wounds, inflammation (Brachial neuritis or Parsonage Turner syndrome) and compression by tumors. The magnitude of injury may vary in severity from a mild stretch to the nerve root tearing away from the spinal cord.

Brachial plexus injury leads to weakness or a partial or complete paralysis of the involved upper limb depending on the nerves injured. There may be an impairment or a total loss of sensation. Few patients experience burning or crushing kind of pain in the affected extremity.

Anatomy of brachial plexus

The **brachial plexus** is a network of nerves that originate from the spinal cord (5th to 8th cervical (C5C8), and 1st thoracic (T1) spinal nerves) and control the movement and sensation in the upper limb. The brachial plexus is formed by a union of anterior rami of the lower four cervical (C5 through C8) and the first thoracic (T1) spinal nerves between the anterior and middle scalene muscles. Some nerve fibers to the plexus may originate from the fourth cervical (C4, prefixed) or from the second thoracic (T2, post fixed) nerves. The sympathetic ganglion is in close relation to the T1 root. Three nerves receive contributions at the root levels; *dorsal scapular nerve* (C5,C6) supplying the levator scapulae and the rhomboid muscles, *long thoracic nerve*(C5,C6,C7) which supplies the serratus anterior muscle, and *phrenic nerve* (C3,C4,C5).

The anterior rami of C5 and C6 join to form the upper trunk. The suprascapular nerve arises from the superolateral aspect of the upper trunk. The C7 ramus continues as the middle trunk, and C8 and T1 combine to form the lower trunk. Each trunk divides retroclavicularly into anterior and posterior divisions. The anterior divisions of the upper and middle trunks unite to form the lateral cord. The anterior division of the lower trunk continues as the medial cord. The posterior divisions of all trunks join to form the posterior cord. The lateral pectoral nerve arises from the lateral cord. The medial cord gives off medial pectoral nerve, medial cutaneous nerve of arm and medial cutaneous nerve of forearm. Three nerves take origin from the posterior cord; the upper subscapular nerve, lower subscapular nerve, and the thoracodorsal nerve.

The cords eventually divide into terminal branches. The lateral cord divides in to the musculocutaneous nerve and lateral root of the median nerve. The medial cord gives off the medial root of the median nerve and continues as the ulnar nerve. The median nerve is formed by the union of medial and lateral cord contributions. The posterior cord terminates into the axillary and radial nerves.

Types of BPI

As per severity

1.Neuropraxia - It is caused by stretching of nerves and usually recovers spontaneously.
2.Rupture - The nerve is torn but maintains its attachment to the spinal cord.

Avulsion

The nerve is torn away from its attachment at the spinal cord. It is the severest form of injury and presents as partial drooping of upper eyelid, if roots involved are C8 and T1 (Horner's syndrome).

As per involvement of nerves

1.Upper brachial plexus injury - It involves the C5, C6 spinal nerves and presents with a weak shoulder and elbow. Functions of hand remain intact. In obstetric group it is called Erb's palsy. Involvement of C7 nerve is termed as an extended upper plexus injury.
2.Total brachial plexus lesion - It affects almost all the nerves of the plexus and presents with a flail limb without sensations.
3.Lower brachial plexus injury - This type of injury involves the infraclavicular part of plexus. Shoulder functions are intact but elbow and hand are paralysed.

Clinical examination

A patient with brachial plexus injury is likely to have sustained other concomitant injuries; head injury, fractures in the cervical spine, clavicle, scapula, and extremities, chest and abdominal trauma and vascular injuries. The neurological examination should determine the specific motor and sensory deficits. The British Medical Research Council grading system is used to measure the motor strength of each muscle.

A detailed neurological examination helps in identifying the site and severity of the injury and dictates the treatment algorithm. In partial injuries some of the functions in limb are intact. In upper brachial plexus palsy (C5, C6) shoulder and elbow functions are poor, however hand functions are preserved. Extended upper plexus palsy (C5,6,7) has additional weakness wrist and finger extension. Lower brachial plexus palsy (C8-T1) presents with poor hand functions with normal shoulder and elbow functions.

In total palsy entire limb is flail and insensate, superficial sensations being present only in the inner aspect of arm which receives innervation from the T2 dermatome. The limb hangs by the side of the body with arm and forearm being internally rotated. A positive Horner's sign indicates C8, T1 nerve root injuries with involvement of cervical sympathetics. Examination of individual muscle helps in indentifying the site of injury and forms a baseline to assess recovery. The neurological examination should determine the specific motor and sensory deficits. The British Medical Research Council (BMRC) grading system is used to measure the motor and sensory functions of the extremity (Table 1).

Table 1- British Medical Research Council grading system (Motor Power)

Muscle Grade	Description
5	Full range of movements against gravity with full resistance
4	Full range of movements against gravity with some resistance
3	Full range of movements against gravity
2	Full range of movements with gravity eliminated
1	Flicker of contraction
0	No contraction

Sensory examination is performed using two-point discrimination or Semmes Weinstein monofilament testing (Table 2).

Table 2- Assessment of sensory functions by the British Medical Research Council grading system

Grading	Description
S0	No sensation
S1	Recovery of deep cutaneous pain sensibility
S2	Recovery of superificial cutaneous pain sensibility
S2+	Same as S2, only with over response
S3	Pain and touch sensibility with a disappearance of over response. Two-point discrimination > 15 mm
S3+	Same as S3, only localization of the stimulus is good. Two point discrimination 7 to 15 mm
S4	Recovery of complete sensation. Two-point discrimination 2 to 6 mm

An examination of individual muscles helps in indentifying the site of injury and forms a baseline to assess recovery (Table 3).

Table 3 - Brachial plexus examination sheet

General Clinical Examination	
Sign	**Implications**
Horner Sign	Sympathetic ganglion injury (T1)
Diaphragmatic palsy	Phrenic nerve injury (C3-C5)
Tinel sign in neck	Root rupture (Proximal root stump may be present)
Deafferentation pain	Root avulsion
Winged scapula	Long thoracic nerve injury(C5-C7)

Fig 1 - Brachial plexus injury (Rt)

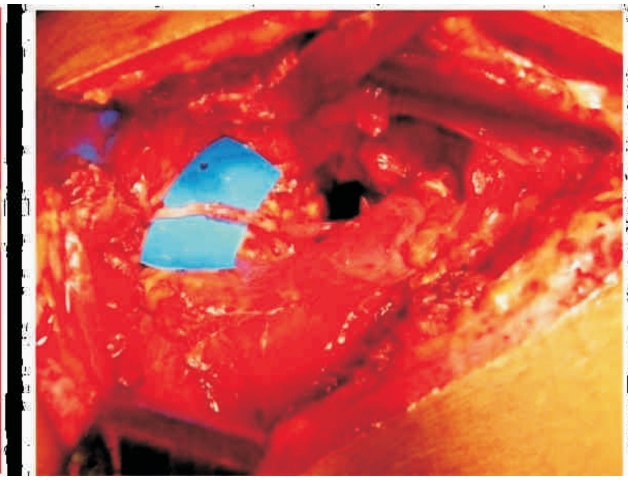

Fig 2- Spinal accessory nerve to Suprascapular nerve transfer

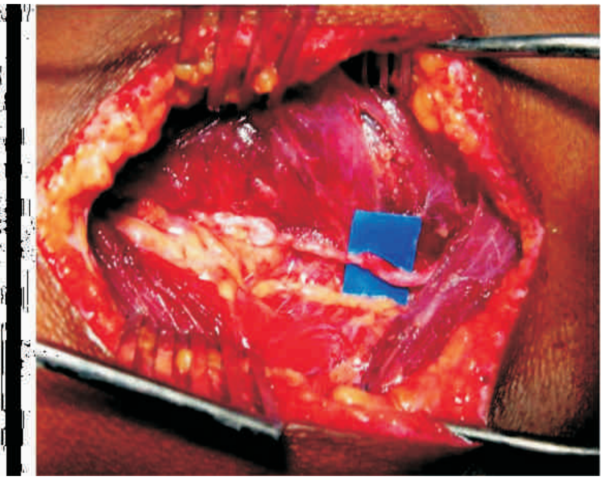

Fig 3- Transfer of triceps br to anterior br of Axillary nerve

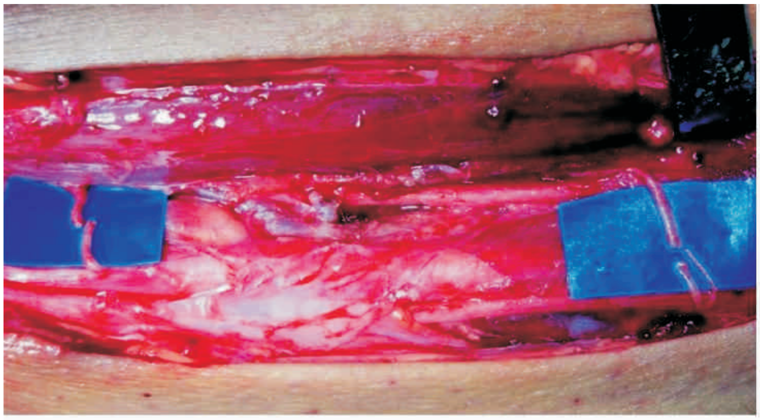

Fig 4- Bifascicular nerve transfers

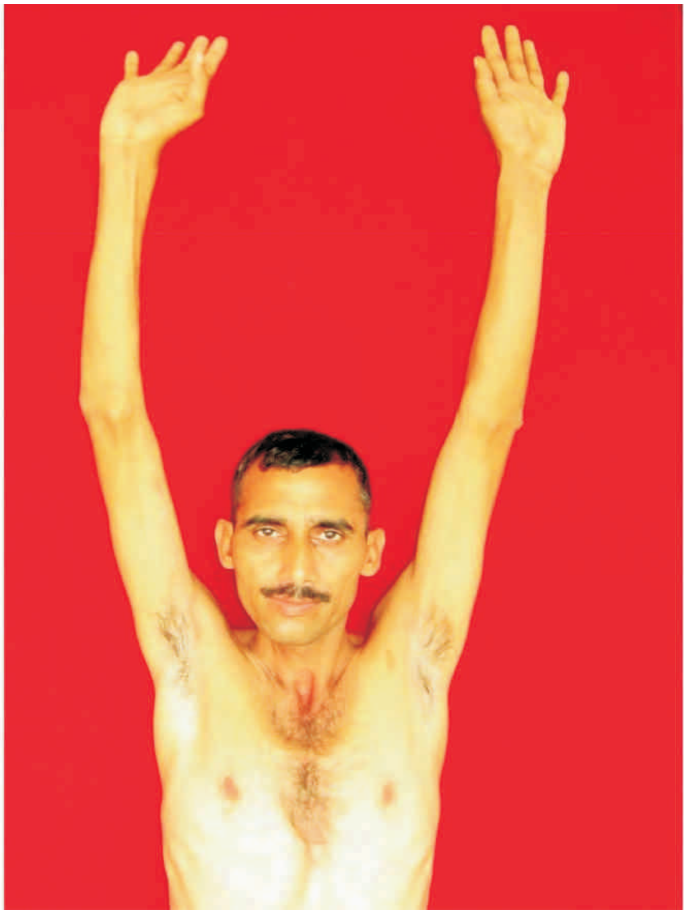

Fig 5- Restoration of full shoulder abduction

Fig 6- Restoration of full elbow flexion

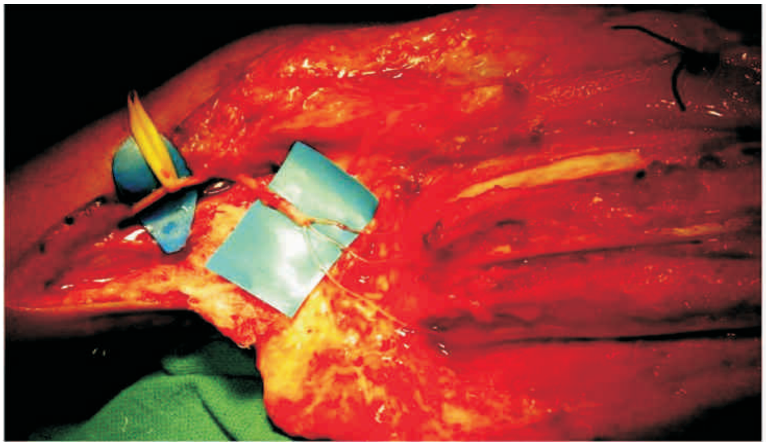

Fig 7- Intercostal nerve to Musculocutaneous nerve transfer

Fig 8- Contralateral C7 transfer

Muscle	Root value	Remarks (Bulk & Power)
Trapezius	C3,C4, Spinal accessory nerve	
Levator scapulae	C3,C4,C5	
Rhomboids	C4,C5	
Supraspinatus	C5,C6	
Infraspinatus	C5,C6	
Serratus anterior	C5,C6,C7	
Teres major	C5,C6	
Subscapularis	C5,C6,C7	
Pectoralis major clavicle	C5,C6,C7	
Pectoralis major sternocostal	C6,C7,C8 T1	
Latissimus dorsi	C6,C7,C8	
Biceps and brachialis	C5,C6	
Deltoid	C5,C6	
Teres minor	C5,C6	
Pronator quadratus	C7,C8,T1	
Pronator teres	C6,C7	
Flexor carpi radialis	C6,C7	
Flexor digitorum profundus II, III	C7,C8,T1	
Flexor digitorum superficialis	C7,C8,T1	
Flexor pollicis longus	C7,C8,T1	
Abductor pollicis brevis	C6,C7,C8,T1	
Opponens pollicis	C8,T1	
Lumbricals	C8,T1	
Triceps	C6,C7,C8	
Supinator	C5,C6	
Brachioradialis	C5,C6	
Extensor carpi radialis longus	C6,C7	
Extensor carpi radialis brevis	C6,C7,C8	
Extensor carpi ulnaris	C7,C8	
Extensor digitorum communis	C7,C8	
Extensor digiti minimi	C7,C8	
Extensor indicis	C7,C8	
Extensor pollicis longus	C7,C8	
Abductor pollicis longus	C6,C7	
Flexor carpi ulnaris	C7,C8,T1	
Abductor digiti minimi	C8,T1	
Flexor digitorum prof. IV, V	C7,C8,T1	
Abductor pollicis	C8,T1	
Opponens digiti	C8,T1	
Interossei	C8,T1	

Diagnosis

These patients are routinely checked by X-rays of the cervical spine, shoulder, humerus and chest. An increased incidence of skeletal injury is observed in blunt trauma with concomitant stretch injury of the brachial plexus. Fracture of transverse process of cervical vertebra indicates injury close to the cord level and may be associated with root injury. Fracture of first rib and clavicle may be associated with brachial plexus and subclavian vessel injury. Chest radiograph with an elevated dome of diaphragm may indicate phrenic nerve injury. In addition fracture of ribs may caution the surgeon against the use of intercostal nerves in neurotization. CT myelogram is a very sensitive imaging technique to define the root avulsion. A typical root avulsion is seen as pseudomeningocoele on CT myelogram following healing of dural sheath surrounding the root. Therefore myelographic study should be performed 3 to 4 weeks after the injury. However due to the invasive nature of CT myelography and its inability to demonstrate the lesions beyond neural foramina it is gradually being replaced by Magnetic Resonance Imaging (MRI).[2] The use of MRI has gained popularity as an imaging tool in brachial plexus injury.[3] It is non-invasive and provides details of brachial plexus anatomy. MR myelography (MRM) is a T2 weighted sequence that enhances the contrast between the spinal roots and cerebro spinal fluid. [4] It therefore achieves myelogram like images. Few studies indicate MRM as good as CT myelogram in localizing root avulsions. MR neurography is a new technique which can localize the site of injury, any disruption in nerve continuity and neuroma formation The most common technique of MR imaging uses T2 weighted fat suppressed images and T1 weighted images to provide an anatomical localization. However these techniques fail to produce three dimensional images. Vascular structures like veins adjacent to the nerve are difficult to differentiate because of similar signal intensity. Three dimensional diffusion weighted MR sequence provides a contrast between nerves and surrounding structures and brachial plexus anatomy is more clearly defined. Further refinements in 3T MR neurography with three dimensional imaging has further helped clinicians to detect postganglionic brachial plexus lesions.

The electrodiagnostic studies (EDS) help in clinical diagnosis and provide useful information about peripheral nerves and muscles innervated by them. The EDS can diagnose re-innervation before the clinical recovery is evident and can be used as a follow up tool following surgery. EDS essentially record the action potential in the nerves and electrical activities in the muscle. Hence nerve functions both sensory and motor can be assessed by nerve conduction studies (NCS) and muscle electrical activity can be assessed by electromyography (EMG). In closed brachial plexus injuries EDS should be performed 3 to 4 weeks after the injury when Wallerian degeneration has taken place.

Treatment

Timing of Repair

The commonly seen closed injuries are initially managed conservatively. Some of them are neuropraxic injuries and recover in few weeks time. Other injuries should be observed up to 10 to 12 weeks for spontaneous recovery. During this period passive range of joints is maintained. After one month of injury an electromyography and CT myelography / MR myelography is performed. Patients with clinical (flail and anaesthetic limb, Horner's sign, severe deafferentation pain) and radiological evidence of root avulsions(pseudomeningoceles) can be operated at this time. Other patients should be followed for another 6 to 8 weeks for neurological recovery. If there is no recovery, surgery should not be delayed further as results of surgery deteriorate with passage of time. If partial recovery has occurred, exploration and reconstruction of the nerves that are not recovering is indicated. Management of missile injury of the brachial plexus differs considerably from the traction injuries. [5] The tissues are crushed and burnt from a direct contact with the missile and stretched via temporary cavitation. Wounds are heavily contaminated with virulent organisms.These injuries are better treated as delayed repair if there is little or no recovery.

Surgical Techniques: Exposure of Brachial Plexus

Exploration of plexus is done under general anesthesia through a reverse C shaped incision with its horizontal limb about 1 cm above and parallel to the clavicle and the vertical extension along the posterior border of the sternocleidomastoid muscle. The supraclavicular pad of fat is reflected downwards and laterally from the posterior border of sternocleidomastoid muscle. The inferior belly of omohyoid muscle is divided and plexal elements are identified in the space between the anterior and middle scalene muscles. Their absence suggested root avulsions.

The suprascapular nerve is located along the lateral aspect of the upper trunk. Often its proximal end is involved in the upper trunk neuroma. In severe traction injuries suprascapular nerve is retracted distally and might be located in the retro- or infraclavicular region. The spinal accessory nerve is located, once the deep fascia is incised along the anterior border of the trapezius muscle. The phrenic nerve is located on the anterior surface of scalenus anterior muscle and identified by its vertical course and contractions of diaphragm on electrical stimulation. It is dissected distally and then divided and moved laterally for transfer. Infraclavicular plexus is explored through an incision in the deltopecteral groove with its distal extension in the inner aspect of the arm. Exposure of the cords and their terminal branches usually need the division of pectoralis major and minor muscles.

Surgical techniques: Nerve related procedures

1.Direct nerve repair - A direct nerve repair without nerve grafts is possible in only sharply transected injuries (stab and iatrogenic injuries) provided the proximal and distal ends can be approximated without the tension. In more common traction injuries nerve ends are retracted apart and a direct coaptation is not feasible.

2.Nerve grafting - Nerve grafting is the predominant technique employed in brachial plexus repair. **Nerve grafts** are required in traction injuries to bridge the nerve defects once the neuromas are resected. The commonly used donor nerves are 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.

The nerve graft should be 20% longer than the length of the nerve defect. Vascuarized nerve grafts[6,7,8] may be more suitable in a scarred bed and at reconstructing large nerve defects. In global brachial plexus with C8 and T1 root avulsions, pedicled vascularized ulnar nerve has been used for a contralateral C7 root transfer to the median nerve.

3. Nerve transfers- Nerve transfer or nerve bypass procedure involves transfer of a functional but less important nerve to the distal injured nerve usually within a period of 6 to 9 months after the injury. Nerve transfers are performed for repair of severe brachial plexus injury in which the proximal spinal nerve roots have been avulsed from the spinal cord. The use of nerve transfers has been a major advance in the field of brachial plexus reconstruction with many different donor nerves being used to restore the desired function.

In partial brachial plexus injuries, both extraplexal and intraplexal nerve transfers, result in good functional outcomes. An important aspect in nerve transfer is to reinnervate the target muscle close to its motor end plates. This reduces the denervation period and functional gains are superior when compared to proximal nerve transfer.

In extraplexal neurotization a non brachial plexus component nerve is transferred to an injured nerve. One of the most commonly performed extraplexal nerve transfer is between the spinal accessory nerve and the suprascapular nerve [9,10,11]. This restores useful degree of shoulder abduction and external rotation by reinnervating the supraspinatous and infraspinatous muscles. A simultaneous transfer to the axillary nerve yields much better results in shoulder abduction and is best achieved following a nerve transfer between the triceps branch of radial nerve and the axillary nerve.

Donor nerves in restoration of elbow flexion include ulnar and or median nerve fascicles , medial pectoral nerve , intercostal nerves [12,13] , phrenic nerve [14] , thoracodorsal nerve, and spinal accessory nerve . An intercostal nerve contains no more than 500 motor fibers , hence at least two or three intercostals nerves (T3, T4 and T5) are transferred to the musculocutaneous nerve. Chuang et al[12] and Gu et al have popularized the transfer of phrenic nerve to musculocutaneous nerve (either directly or with a sural nerve graft).Phrenic nerve to spinal accessory nerve transfer has the disadvantage of requiring a long nerve graft to reach the musculocutaneous nerve . In the exposure of intercostals nerves a semicircular incision is extended from axilla to the chest along the infraareolar region. In restoration of elbow flexion, the deep central branches of the third, fourth and fifth intercostals nerves are dissected up to the costochondral junction and transferred laterally to the musculocutaneous nerve.

Fascicular nerve transfers (ulnar and median)-

A longitudinal incision is made along the anteromedial aspect of upper arm. The musculocutaneous nerve is identified after it has traversed the coracobrachialis muscle. In its distal course the musculocutaneous nerve gives off its motor branches to the biceps and brachialis muscles. A longitudinal epineurotomy is made in the ulnar nerve at the level of the biceps motor branch and an isolated fascicle of the ulnar nerve is sutured end to end to the biceps motor branch. In a similar fashion a fascicle of the median nerve is coapted with the motor branch to the brachialis muscle. 13,14,15

Management Strategy

C5 - C6 and upper truncal injury-

An upper truncal injury with intact nerve roots is amenable to nerve graft repair. In C5-C6 root avulsion injury nerve transfers offer far superior results over tendon/ muscle transfers or shoulder arthrodesis . Nerve transfer between the distal spinal accessory nerve and the suprascapular nerve through the posterior approach restores useful range of shoulder abduction and external rotation. A simultaneous axillary nerve neurotization in the quadrilateral space further improves the range of shoulder abduction by reinnervating the deltoid muscle.[16]

Elbow flexion is best achieved either by biceps reinnervation, or both biceps and brachialis reinnervation. In C5-C6 injuries intraplexal donor nerves provide better functional results than the extraplexal nerves (spinal accessory, phrenic, or intercostal nerves).The bifascicular nerve transfer between the ulnar and median nerves and the biceps and brachialis branches of the musculocutaneous nerve, has become a standard procedure in restoration of elbow flexion in C5- C6 root avulsion injuries (Fig 1 to 6). Sparing of single fascicle from the ulnar or median nerve does not result in any subjective deficit in hand function. Preoperative and postoperative evaluation of pinch strength, grip strength and

two point discrimination at the pulp of little and index fingers usually remain unaltered .There is no added advantage in fascicular selection using a nerve stimulator while performing the fascicular nerve transfers.

C5 - C7 injury-

In addition to the deficits observed in C5-C6 injuries these patients find difficulty in extension of elbow and wrist. Therefore triceps branch of radial nerve cannot be used for neurotization of axillary nerve. The lack of elbow extension leads to difficulty in putting the hand in space and reaching out on objects which affects prehensile functions. In these injuries reconstruction is similar to C5-C6 injuries, however long head triceps branch can be neurotized by 3rd & 4th intercostals nerves (Fig 7). When C6 root is available, it can be used to reconstruct the radial nerve. However it is important to note that delicate balance is required between elbow flexion and extension. If triceps becomes too powerful, it may adversely affect elbow flexion.

C5 T1 injury-

This is a severe injury characterized by flail upper limb. The first priority of reconstruction is elbow flexion followed by shoulder abduction. The hand reanimation is aimed at achieving protective sensation and some finger flexion. In these patients regaining some useful function for their daily activities is aimed at. In case of preganglionic injuries where no graftable root is available, nerve transfers is undertaken to achieve above reconstruction. A single stage reconstruction can be performed in 3 to 5 months post injury. The spinal accessory is used to neurotize suprascapular nerve and 3 rd,4th,& 5th Intercostal nerves are used to neurotize musculocutaneous nerve. To regain protective sensation in hand and achieve finger flexion contralateral C7 (CC7) is used (Fig 8) to neurotize median nerve using vascularised ulnar nerve graft.[17] Later to achieve hand stability wrist arthrodesis and thumb fusion can be performed. Due to long graft and prolonged regeneration time the results of vascularised ulnar graft are unpredictable. Wang et al reported the use of direct cooptation of contralateral C7 root to injured lower trunk by a modified prespinal route. Out of 75 patients 35 also required humerus shortening by 3 to 4.5cms. In 47 patients they also used CC7 to neurotize musculocutanaous nerve through bridging antebrachial cutanous nerve arising from lower trunk. They reported successful outcomes in more than 50% of patients with greater than M3+ power in target muscles. Doi et al have described double free functioning muscle transfer using gracilis for achieving hand prehension, elbow flexion in total palsy. The details of this procedure are described in the succeeding paragraphs. They have reported that most of the patients were able to hold a can and could lift heavy objects. In post ganglionic injuries where graft-able roots are available, cable nerve grafts are used to reconstruct shoulder and elbow functions. Bertelli et al in their cohort of patients with total palsy 87% had graft-able roots. When C5 root is available, this root is used for neurotization of distal muscles. To achieve shoulder functions we transfer spinal accessory to suprascapular nerve and if C5 root is found graftable then it is neurotized to lateral cord using long cable grafts from sural nerve. When C6 is also found to be graftable it is used to neurotize the posterior cord using cable grafts. Our preference is therefore for shorter cable grafts.

C8 T1 injury -

These are uncommon injuries accounting for about 3% of all brachial plexus injuries.Hand functions are poor with preserved shoulder and elbow functions. The reconstruction aims to achieve prehension with protective sensation. Nerve transfers in form brachialis branch of musculocutaneous nerve to anterior interosseous nerve can be done to achieve grasp functions of hand. [18] This however requires an interposition nerve graft. Alternatively brachialis branch can be transferred to posterior fascicular group of median nerve(Fig 1. The posterior fascicular group at brachialis group is composed of anterior interosseous nerve responsible for finger flexion. To restore finger flexion, motor branch to the brachioradialis muscle has been transferred to the anterior interosseous nerve in the management of lower plexus lesions.[19]

13Prespinal route in contralateral C7-

To reduce the distance to the target nerves, grafts connected with the contralateral nerve root, have been placed underneath the anterior scalene and longus colli muscles, and then passed through the retro-esophageal space to neurotize the recipient nerve.[20] **Infraclavicular injury-** These are stretch injuries of brachial plexus and involve the peripheral nerves like axillary,musculocutaneous or radial nerves. Cord injuries may also occur in presence of severe trauma. They account for about 15% of all brachial plexus injuries. They are often associated with shoulder dislocation, or fractures of scapula and humerus and vascular injuries. Hence these injuries are challenging to deal with. Surgical exposure is by infraclavicular incision along the deltopectoral groove and pectoralis major is required to be detached from its insertion. The dissection is often tedious due to extensive scarring, previous surgeries and major vessels of upper limb in closed vicinity entrapped in dense fibrosis. Surgical options in their management include neurolysis, direct nerve repair and nerve grafting.

Secondary Procedures in Brachial Plexus Injury

A sizable number of patients fail to recover following primary nerve reconstruction. Also there is a group of patients who report more than a year after injury when nerve repair is not feasible. Such cases can be rehabilitated by secondary procedures such as tendon or muscle transfers, free functioning muscle transfers, osteotomies and arthrodesis.

Conclusion

In the management of brachial plexus injuries, an incorporation of micro surgical techniques in neurolysis, nerve repair, nerve grafting and nerve transfer has made possible to restore a functioning limb in many of the patients with brachial plexus injuries, which was considered a difficult or an impossible task just two decades back. An early repair within 6 months of injury is important for a successful outcome. Patients reporting late may be benefited with secondary muscle and skeletal procedures.

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