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Review

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Review of current reconstructive approaches for pan-brachial plexus injuries

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Abstract

Pan-brachial plexus injuries present a challenging clinical problem, resulting in severe impairment of motor and sensory function in the upper extremity. Although current literature has outlined several promising methodologies for treatment, a consensus has yet to be reached. In this review, we present three general approaches for reconstructing the upper extremity in these complex cases.

Keywords: Pan-brachial plexus injuries, brachial plexus, reconstructive techniques

INTRODUCTION

Pan-brachial plexus injuries (PBPIs) are severe and life-altering conditions that result in a flail limb. These injuries cause long-lasting physical disability, psychological anguish, and chronic pain, and require a substantial financial investment for treatment. While brachial plexus injuries are overall quite rare, PBPIs constitute approximately 53% of all brachial plexus injuries[1]. These devastating injuries predominantly occur in young males following high-energy motorcycle or motor vehicle accidents[1]. Due to the complete loss of motor and sensory function of the upper extremity resulting from PBPI, the treatment continues to be challenging for surgeons.

Despite our understanding of the epidemiology and presentation of these injuries, the workup can vary significantly. This is seen primarily in the utilization of diagnostic imaging and electromyographic studies. 94% of surgeons surveyed obtained pre-operative advanced imaging. 80% routinely requested CT myelography, 55% a brachial plexus MRI, and 41% obtained both studies pre-operatively. Furthermore, electrodiagnostic studies were only acquired by approximately seven out of ten surgeons[2].

An MRI of the brachial plexus has the benefit of identifying signal changes both at the site of nerve injury as well as a possible lesion distally. A CT myelogram, on the other hand, has the specific benefit of delineating a nerve root avulsion *vs.* rupture. Plexus surgeons should be aware of this as a nerve rupture separates the distal trunk from a healthy nerve root that can be grafted. In contrast, an avulsion injury requires extra-plexal intervention.

Another inconsistency exists in the timing of surgical intervention. A survey completed by Belzberg *et al.* among experienced brachial plexus surgeons revealed an average recommended time for surgery of 2.4 months[2]. However, literature recommendations between 2 weeks up to 6 months have been reported[3-5]. Similarly, the time point after which surgeons recommend against nerve transfer/grafting ranges from six months up to one year, citing concerns over endplate viability, muscle atrophy and joint contractures[2-4,6,7].

One area of agreement is the priority of restoring elbow flexion and shoulder stability/abduction during the initial intervention. These two functions are imperative in restoring the ability to self-feed and in reestablishing rudimentary self-care. However, after this, there appear to be mixed preferences among surgeons for restoration of elbow extension, finger flexion, wrist motion, and hand sensation. Restoration techniques rely heavily on whether a C5 nerve root persists in a graftable state following acute PBPI. The frequency of a graftable C5 nerve root varies in the literature from 15% to 88%. With such a high incidence, most surgeons recommend brachial plexus exploration with a CT myelogram to ascertain C5 nerve root viability prior to finalizing the reconstructive plan[6,7]. Although less frequent, the same applies to the presence of a graftable C6 nerve root and below.

In the case of complete plexus injuries, practical nerve transfer options must come from outside of the plexus itself. This can include the spinal accessory nerve (SAN), the phrenic nerve (PN), the contralateral cervical seventh nerve root (CC7), intercostal nerves (ICN), and/or the hypoglossal nerve in a variety of donor-recipient combinations. Additional reconstructive options include tendon transfers, arthrodesis, and free functional muscle transfers (FFMT). Given the complexity of this clinical topic, the heterogeneity of PBPI, and the many permutations of treatment options that are available, multiple reasonable strategies may be employed in the treatment of PBPI. The following review is not meant to be exhaustive or prescriptive, but rather to describe three reasonable options that may provide a framework for surgeons who care for these challenging injuries.

TREATMENT METHODOLOGIES

Method 1: extra-plexal nerve transfers

The most referenced method for PBPI intervention involves nerve transfers from outside the injured brachial plexus, termed "extra-plexal transfers". According to recent polls of experienced brachial plexus surgeons, the SAN was the most utilized donor nerve, incorporated by 68% of surgeons during PBPI reconstruction, with the suprascapular nerve (SSN) being the most common recipient. The next most common donor was the intercostal nerves. Most often, these were transferred to the musculocutaneous nerve (MCN) and the median nerve. We will describe each of these techniques in further detail based on the function they aim to restore.

Elbow flexion

The favored technique for elbow flexion restoration, while using the SAN to SSN transfer for shoulder motion, is a direct nerve transfer of ICN to the MCN. A 2018 meta-analysis has shown improved function and decreased comorbidity of transferring two ICN over three or four[8]. To accomplish this, a curved incision along the sixth intercostal space from sternum to axilla is completed. Soft tissue is retracted superiorly, and the 5th and 6th ribs are exposed. ICN 5-6 are dissected from the inferior border of their corresponding rib and sectioned at the level of the costochondral junction. Next, a longitudinal incision is made along the proximal medial arm, posterior to the biceps muscle belly. The overlying fascia at the interval between the biceps and the coracobrachialis is incised, and the MCN, along with biceps motor branch, is identified. The MCN is transected at least 1 cm proximal to its insertion into the biceps allowing room for coaptation. The ICN is then reflected into the axilla to the MCN [Figure 1]. The shoulder is abducted to 90 degrees and externally rotated during repair to ensure a tensionless neurorrhaphy. This technique negates the need for an interposition nerve autograft along with donor morbidity and worse associated outcomes[9,10].

Functional results for this transfer have seen improvement over time, with 42%-90% of patients regaining elbow flexion to a British Medical Research Council (MRC) grading system, strength grade 3 or greater. One study showed nearly 40% of patients improved to grade 4[11-13]. In comparison, a meta-analysis from 2001 suggested that the SAN to MCN transfer produced a significantly lower likelihood of obtaining functional elbow flexion[12]. Furthermore, compared to the phrenic nerve transfer, there were no statistical differences in the final MRC grade or EMG results[14]. This is important to note as the ICN transfer does not require a nerve graft and eliminates the possibility of diaphragm paralysis/pulmonary complications with the sacrifice of the phrenic nerve.

Shoulder stabilization/abduction

When addressing shoulder stabilization and abduction, extra-plexal nerve transfers from the SAN to the SSN are preferred. For this procedure, a supraclavicular approach is used, and the proximal brachial plexus is explored. The target SSN is identified as branching from the upper trunk and traversing through the suprascapular notch. The SAN is isolated on the deep surface of the trapezius muscle. The SAN is dissected as distally as possible prior to transecting it to maximize length for coaptation[15-17]. Similarly, the SSN is transected as it branches from the upper trunk, preserving as much length as possible. A tension-free coaptation is then performed between the two nerves [Figure 2].

Previous studies have demonstrated encouraging outcomes, with 70%-90% returning good/excellent abduction results through the supraspinatus. Additionally, SAN to SSN fared significantly better than SAN to axillary nerve transfers in regaining functional shoulder abduction in 92% of patients compared to 69%[12,18].

Elbow extension

To restore elbow extension, ICN 3-4 to the triceps motor nerve is the procedure of choice in this reconstruction methodology. Meticulous dissection along the inferior border of the corresponding ribs from the costochondral junction to the axilla is required to isolate the longest ICN for transfer. The radial nerve motor branch to the long head of the triceps is identified as the radial nerve proper crosses distal to the teres major. Once isolated, this motor branch can undergo direct coaptation to ICN 3-4. Again, this is done with the arm abducted to 90 degrees and externally rotated to ensure tensionless coaptation[9,19].

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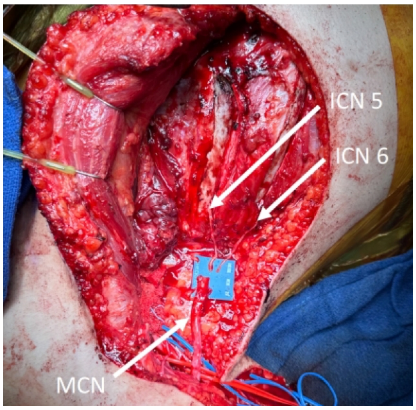

Figure 1. Submammary exposure for intercostal nerve (ICN) five and six transfer to the musculocutaneous nerve (MCN).

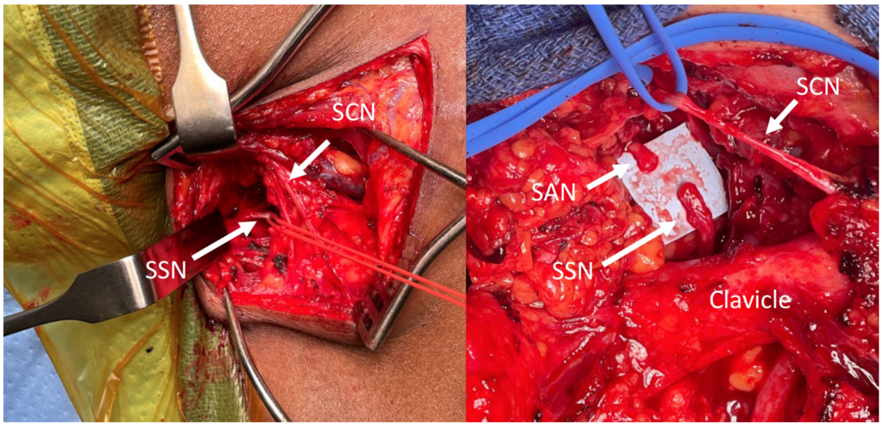

Figure 2. Supraclavicular approach for a direct end-to-end transfer of the spinal accessory nerve (SAN) and the suprascapular nerve (SSN). Supraclavicular nerve (SCN) and clavicle utilized as landmarks.

ICN 3-4 to the triceps motor branch has shown good results, with studies showing 47%-82% of PBPI patients regaining functional elbow extension of M3 or greater[9,19-21]. This suggested method incorporates two ICN branches for the triceps motor transfer. A study by Gao *et al.* demonstrated there was no added benefit, including a third ICN to this specific transfer[21]. An important caveat is that while this ICN transfer for elbow extension and the aforementioned ICN transfer for elbow flexion have demonstrated good clinical outcomes, both procedures cannot be performed on the same extremity. Intercostal motor nerves cannot be utilized to reinnervate opposing functions as simultaneous action of antagonistic muscle contraction will lead to poorer outcomes.

Hand function

Restoration of hand function remains a difficult obstacle for surgeons during the reconstruction of pan-plexus injuries. Many remain unconvinced that nerve transfers can reliably provide a more functional, stable hand than focal arthrodesis. In this method, arthrodesis of the wrist, first carpometacarpal joint and thumb interphalangeal joint is completed as a secondary surgery to create a stable platform for self-care.

Traditional wrist fusion techniques utilize a dorsal locking wrist fusion plate spanning the second or third metacarpal to the distal radius, placing the wrist in neutral to a slightly extended position. This may be augmented with bone autograft, which has been shown to achieve excellent fusion rates[22,23]. The first carpometacarpal joint should be fused in approximately 35 of palmar abduction, 30 of radial abduction and 15 of pronation. The bone graft can be utilized to aid in fusion which can be achieved by a variety of methods including plates, compression screws, staples or wires[24-26]. Similarly, the thumb interphalangeal joint can be fused with several techniques, including tension bands, staples or compression screws across the decorticated articular surfaces. To optimize function, the thumb should be flexed between 15 and 35.

Several studies have shown exceptional fusion rates at each joint. Furthermore, following a patient self-assessment, 97% of polled PBPI patients were satisfied with wrist stability following fusion and 89% stated the fusion enhanced upper extremity function[27]. A similar study demonstrated subjective patient assessments of disability of the arm, shoulder, and hand (DASH) scores improved from 51 to 23, which was a statistically significant improvement. Additionally, following fusions, patients reported improved appearance, function, hygiene, and satisfaction[26].

Hand sensation

The intercostobrachial nerve (ICBN) is a stout sensory nerve providing cutaneous innervation to the axilla and proximal medial arm. This nerve can be utilized as a nerve transfer to the lateral cord contribution to median nerve (LCMN) to restore hand sensation. To accomplish this, the same submammary incision used to harvest ICN nerves is extended posteriorly along the lateral border of the pectoralis major. In this region within the second intercostal space, piercing superficially through the serratus anterior, the ICBN can be found traveling within subcutaneous fat into the axillary region. The dissection is carried through its terminal axillary branches, where the ICBN is released. The axillary incision is extended until it is in continuity with upper medial arm dissection. The pectoralis major is retracted superiorly, and the pectoralis minor is released off the coracoid as necessary to expose the infraclavicular plexus. The LCMN is identified at its origin and transected. The ICBN is then mobilized with as much length as possible and redirected into the infraclavicular space for direct coaptation[28].

Initial data for this technique has demonstrated impressive results, as 91% of patients registered the return of hand sensation[28]. This is a notable improvement to sensory rami of ICN or supraclavicular nerve reconstruction techniques that afford limited sensation recovery[29-33]. Anatomic data shows that at only 1,000 nerve fibers, and a diameter of 2.7 mm, the ICBN is much smaller than the average 5,300 nerve fibers and 3.7 mm diameter of its target LCMN. However, with more than double the average axon count of the sensory rami of ICN, the ICBN is considered by many to be a superior choice to ICN, even when incorporating two donor ICN[29].

Graftable C5

With an available C5 nerve root, sural nerve grafting to the anterior division of the brachial plexus upper trunk is recommended. This will provide innervation to the MCN and median nerve, aiming to restore elbow flexion, rudimentary grasp, and hand sensation. As above, restoration of shoulder stability will require a SAN to SSN transfer and elbow extension will require ICN 3-4 to triceps transfer[7].

Method 2: double free functional muscle transfer

Initially described by Doi out of Yamaguchi, Japan in the late 1990s, the use of the gracilis FFMT has slowly gained popularity[34,35]. Some authors have demonstrated greater improvements in elbow function over extra-plexal nerve transfers and this reconstructive technique has the benefit of providing secondary improvements to hand function[36-38].

Elbow flexion

The main function of the first FFMT is to maximize elbow flexion. The most common free muscle transfers involve the gracilis. This superficial muscle lies in the medial aspect of the thigh and is supplied by a branch from the profunda femoris, the medial femoral circumflex, and innervated by the obturator nerve. To harvest, the muscle must be released from its origin on the pubic symphysis and its insertion at the pes anserine. The medial femoral circumflex vessels and the obturator nerve can both be harvested at a length of up to 10 cm, which will facilitate easy anastomosis and coaptation at the transfer site. A skin paddle is often taken with the FFMT for postoperative monitoring [Figure 3]. Following the harvest of the gracilis muscle from the medial thigh, the proximal attachment to the clavicle is secured with suture anchors. This first FFMT is routed beneath the mobile wad proximal to the elbow joint and sutured to the extensor digitorum communis (EDC) tendon, allowing for elbow flexion and digit extension. The innervation of the gracilis muscle is accomplished by direct coaptation of the gracilis obturator nerve to the SAN. In addition, vascular microsurgical anastomoses complete a reliable artery and vein. These can include the thoracodorsal, transverse cervical, or thoracoacromial pedicles based on ease of reach and surgeon preference [Figure 4].

In the context of double FFMT, Doi showed good to excellent restoration of elbow flexion in 96% of patients[35]. Furthermore, the work by Maldonado *et al.* further demonstrated FFMT was able to restore M3/M4 elbow function in a greater percentage of patients than ICN to MCN transfers (68% *vs.* 42%)[37]. It is important to inform patients that similar to extra-plexal nerve transfers, reinnervation and initial functional return can be expected within six to nine months postoperatively[39].

Shoulder stabilization/abduction

Restoration of shoulder stability is once again prioritized in this reconstructive method. In the context of double FFMTs, traditional extra-plexal donors to the SSN and axillary nerve (i.e., the SAN and ICN) are being utilized for innervation of the free muscle flaps. With no other good donors for the SSN and axillary, tendon transfers have been historically performed. However, poorly reported outcomes have led to shoulder arthrodesis becoming a more universally accepted and implemented procedure[7,40]. When prepared with a subacromial corticocancellous graft, one study reported successful glenohumeral fusion rates as high as 94%. Following fusion, scapulothoracic abduction and arc of rotation averaged 57 and 50 degrees[41].

Elbow extension

To restore elbow extension, the ICN 3-4 to triceps motor transfer is again selected as in the previously described purely extra-plexal nerve transfer reconstructive method. While recent results for this transfer are promising, it is also important to note that results for these transfers are highly contingent on patient BMI. Several analyses have demonstrated that elevated BMI is inversely related to obtaining functional results[42,43].

Hand function

In the second stage of the technique, an additional FFMT from the contralateral gracilis is attached to the second and third ribs through a series of drill holes. This tendon is tunneled along the medial arm, beneath the lacertus fibrosus, and deep to the pronator teres creating a pulley during muscle contraction. A second forearm incision is made, and the terminal tendon is woven into the flexor digitorum profundus and flexor pollicis longus muscle belly, providing rudimentary grasp capabilities. Options for vascular anastomosis similarly include the regional vessels listed for the first FFMT, while innervation may be provided by ICN 5-6. Utilizing this approach, Doi published results where 65% of his patients achieved > 30 degrees of active finger arc of motion through this second FFMT technique[44].

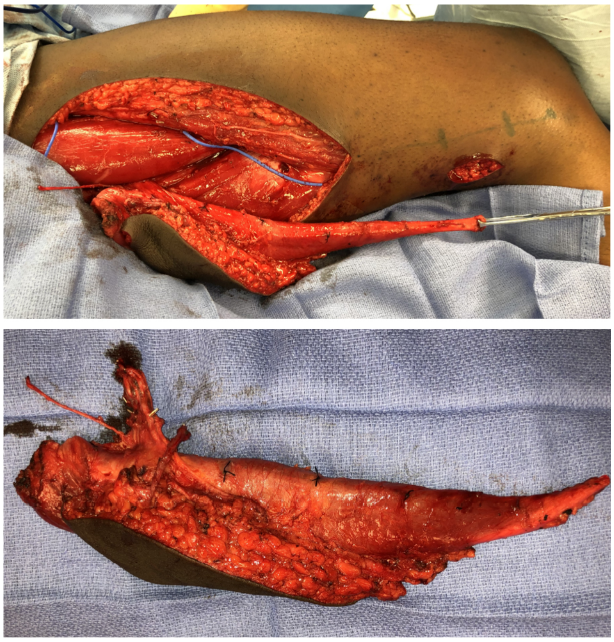

Figure 3. Medial thigh approach and final product of gracilis free functional gracilis muscle harvest. Gracilis FFMT utilizes medial femoral circumflex vessel, obturator nerve and a skin paddle.

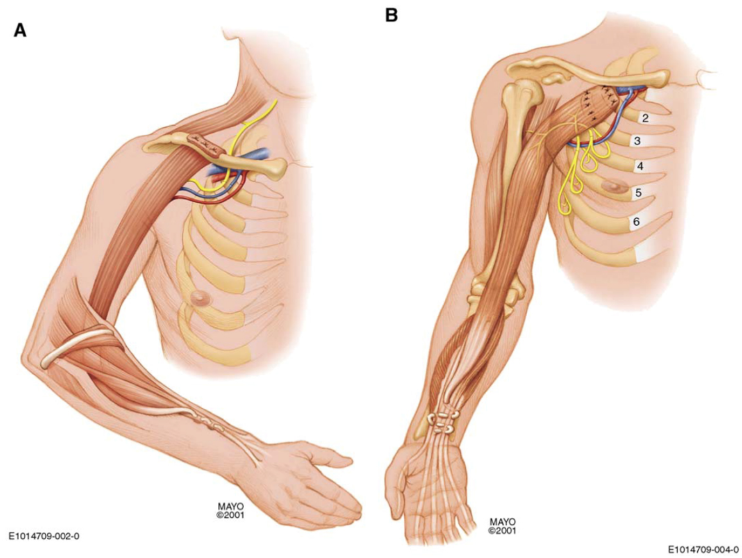

Figure 4. Modified Doi procedure for two-stage double free functional gracilis transfer. A) Stage 1 transfer, innervated by a SAN transfer, attempts to restore elbow flexion and wrist extension. B) Stage 2 transfer, innervated by ICN 5-6, augments elbow flexion while adding finger flexion. Additional ICN 3-4 transfers are performed for triceps neurotization. Copyright Permission: Bishop AT. Functional free-muscle transfer for brachial plexus injury. *Hand Clin.* 2005;21:91-102.

Hand sensation

In the same surgical setting as the second FFMT, sensory rami of the ICN are harvested and transferred to LCMN. These lateral sensory rami pierce the muscles of the lateral thoracic wall and divide into an anterior and posterior sensory branch. Within the submammary flap created for motor ICN harvest lies the sensory nerve branches. Recommended techniques involve the harvest of three sensory rami and direct coaptation with the LCMN.

Although results are sub-optimal, several studies have shown a reliable return of S2 sensation, which is meaningful as this is sufficient enough to provide protective sensation[31,32,45]. Ihara *et al.* demonstrated a more reliable restoration of this S2 level of sensation following ICN nerve transfers compared to supraclavicular sensory transfers[32].

Graftable C5

In the presence of a graftable C5 nerve root, authors who incorporate this technique prefer nerve autograft of C5 to the SSN or posterior division of the upper trunk to attempt to restore shoulder stability and abduction, as opposed to glenohumeral arthrodesis. The remainder of the reconstructive strategy follows as above with a SAN innervated primary FFMT for elbow flexion/wrist extension and a 5th and 6th ICN innervated secondary FFMT for elbow flexion/finger flexion, ICN 3-4 to triceps for elbow extension, and a sensory ICN 3 to LCMN[7].

Method 3: contralateral cervical seventh nerve root transfer

Originally described in 1991 by Gu *et al.* in Shanghai, China, the CC7 transfer has become another viable option for reconstruction in PBPI[46]. While ICN nerve transfers are considered effective options, they are challenging, time-consuming, large dissections with around only 1,300 myelinated axons per donor's nerve compared to the limited dissection and 24,000 axons consistent with a CC7 transfer[47]. Moreover, as most PBPIs occur in high-energy motor vehicle accidents, damage to the chest wall musculature, rib fractures, pulmonary contusions, or diaphragm injuries could be contraindications for and preclude the harvest of ICN.

Elbow flexion

To restore elbow flexion in this technique, the PN is harvested and coapted with the anterior division of the upper trunk. This aims to reinnervate the MCN motor branches to the biceps and brachialis. The PN can be exposed overlying the anterior scalene. It should be released as distally as possible prior to entering the chest cavity. Dissection and isolation of the anterior division of the upper trunk provide the target for this nerve coaptation.

Good/excellent biceps muscle strength was reported by 80% of patients following PN transfer[48]. A recent meta-analysis reported compelling data that PN to MCN transfer is superior to CC7 to MCN transfers in regards to reconstituting M3 or M4 elbow flexion[49]. One concern over this transfer is the pulmonary sequelae of harvesting the PN. However, a series from 2018 demonstrated that this is not a common complication, as no patient developed clinical respiratory problems postoperatively[50].

Shoulder stabilization/abduction

Shoulder abduction may again be accomplished with the transfer of SAN to SSN to reinnervate the supraspinatus and infraspinatus muscle bellies. As one of the most common nerve transfers in brachial plexus reconstruction, there are several studies that have reported encouraging outcomes with this transfer. One study demonstrated good/excellent supraspinatus strength in 79% of patients and good/excellent infraspinatus strength in 55% of patients[18]. Along with strength, the literature has shown that with appropriate coaptation, abduction range of motion recovery can surpass 60 degrees[51].

Elbow extension

This review has mentioned several nerve transfer techniques to reinnervate triceps motor function. While these have shown encouraging results, they are not commonly implemented. Alternatively, it has been an acceptable option to allow elbow extension to be controlled by gravity alone. Coordinated elbow positioning thus will rely solely on whatever elbow flexion motor function is restored.

Hand function

The CC7 nerve root transfer is an integral part of this third reconstructive method. Targeting the median nerve, the CC7 transfer looks to restore hand function and sensation. The brachial plexus of the unaffected side is explored utilizing an incision just superior and parallel to the clavicle extending cranially along the posterior border of the sternocleidomastoid if needed. Branches of the external jugular vein are identified and preserved. Further dissection exposes the supraclavicular brachial plexus. The inferior muscle belly of the omohyoid is retracted and serves as a landmark for the C7 root. Once identified, CC7 is dissected distally until the anterior and posterior divisions of the middle trunk are exposed. The anterior trunk is sharply divided for transfer. For these CC7 limbs to reach their intended target, an interposition nerve autograft is required. To achieve this, sural, saphenous, or a reversed ipsilateral vascularized ulnar nerve graft can be harvested. Once collected, the CC7 donor is tunneled subcutaneously between the contralateral neck incision to a midaxial incision on the affected arm using a specialized nerve passer. In this midaxial dissection of the injured side, the median nerve is isolated for coaptation. Microsurgical coaptation of the anterior division of the middle trunk of CC7 to the median nerve is then completed[7,46]

In their study of 111 such transfers, Songcharoen *et al.* reported that 30% of patients attained finger and wrist flexion MRC grades of M3[52]. Yang *et al.* reported similar outcomes, with 36% achieving M3 finger flexion and 38% achieving M3 wrist flexion. M4 finger and wrist flexion strength were recovered by only 7% and 11% of patients, respectively[53]. While regaining hand motion is notoriously difficult, this technique has fallen out of favor in many regions of the world. Sammer *et al.* in 2012 published a series of fifteen patients who underwent hemi-CC7 to median nerve transfers with greater than two-year follow-up. Only three out of the fifteen showed electromyographic signs of reinnervation, but none were able to regain M3 grip strength[54]. These underwhelming outcomes have been replicated by other recent publications[55,56]. Regarding contralateral arm deficits following CC7 transfer, triceps and wrist extensor weakness occurred in less than 3% of patients. Sensory deficits were seen primarily in the index finger and were transient in nature, resolving within seven months[52]. This technique has a steep learning curve and its use is noticeably more prevalent in the region of its development[7,57].

Hand sensation

The CC7 transfer to the median nerve provides the secondary benefit of hand sensory reinnervation. A recent meta-analysis reported 56% of patients recovered S3 sensation[53]. These results surpass reported sensation recovery following supraclavicular and ICN sensory rami transfer to the median nerve[31,32].

Graftable C5

Strategy alterations when a viable C5 nerve root is present involve grafting C5 to the posterior division of the middle and lower trunk. This aims to reinnervate axillary and radial motor nerve function, reconstituting shoulder abduction, elbow extension, and wrist extension. Additional support for shoulder stability is obtained through the standard SAN to SSN transfer. PN can be similarly transferred for elbow flexion while CC7 to the median nerve as above for wrist flexion, digit flexion and hand sensation[7].

DISCUSSION

Pan-brachial plexus injuries present a challenging clinical problem with severe impairment of motor and sensory function to the upper extremity. In this review, we have presented three general approaches to performing reconstructions for these challenging patients [Table 1]. Most strategies aim to maximize shoulder and elbow function, while prioritization of hand function and sensation are variable. As seen in

Table 1. Summary representation of three general approaches to pan-brachial plexus injury reconstructions

	Method 1: extra-plexal nerve transfers	Method 2: double free functional muscle transfer	Method 3: contralateral cervical seventh nerve root transfer
Elbow Flexion	ICN 5-6 to MCN	FFMT Stage 1 (SAN) FFMT Stage 2 (ICN 5-6)	PN to ADUT
Shoulder Stabilization/ Abduction	SAN to SSN	Shoulder Arthrodesis	SAN to SSN
Elbow Extension	ICN 3-4 to Triceps	ICN 3-4 to Triceps	Gravity
Hand Function	Wrist, 1st CMC and thumb IP joint arthrodesis	FFMT Stage 1 to FFMT Stage 2	CC7 to Median
Hand Sensation	ICBN to LCMN	Sensory ICN to LCMN	CC7 to Median

Intercostal nerves (ICN), musculocutaneous nerve (MCN), spinal accessory nerve (SAN), phrenic nerve (PN), anterior division upper trunk (ADUT), the contralateral cervical seventh nerve root (CC7), suprascapular nerve (SSN), carpometacarpal (CMC), interphalangeal (IP), free functional muscle transfer (FFMT), intercostobrachial nerve (ICBN), lateral cord contribution to median nerve (LCMN)

this review, there is substantial heterogeneity within the group of patients with PBPI, and intraoperative flexibility is a necessity. The greatest variability in operative plans and strategies hinges on the status of C5 roots, which can provide valuable donor axons, in addition to the extra-plexal SAN, PN, ICN and CC7. It is important to note that in rare cases, a graftable C6 nerve root may be present. In this case, in a pan plexus injury with C5 and C6 roots viable, you could reconstitute shoulder motion with C5 to suprascapular/ PDUT and C6 to ADUT.

The literature has outlined several promising methodologies for the treatment of PBPI; however, there remains much progress to be made to support this patient population with more reliable and more restorative interventions.

DECLARATIONS

Authors' contributions

Completed writing of the manuscript, figure/table creation: Mitchell SM
Made substantial contributions to the conception and design of the study: Zumsteg JW
Performed literature review, as well as provided organizational and editorial support: Desai KA

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Not applicable.

Conflicts of interest

All authors declare that there are no conflicts of interest.

Ethical approval and consent to participate

Informed consent was obtained from all patients.

Consent for publication

Patients have signed a release of intra-operative clinical photos for educational use in publications.

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