Birth Brachial Plexus Palsy: An Indian Perspective

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Abstract

Birth brachial plexus palsy (BBPP) is an unfortunate outcome of a difficult labor, which can often lead to long-lasting upper limb impairments. Spontaneous recovery may or may not occur. Timely diagnosis of the condition and initiation of the appropriate treatment can be instrumental in decreasing the functional impact. The management begins right from the day the child presents first and ranges from physiotherapy to surgical intervention such as nerve repair/transfer or grafts. The sequelae of the condition are also quite common and need to be detected preemptively with initiation of appropriate treatment. However, prevention is the key to reducing the incidence of secondary deformities. In this study, the team of authors, based on their considerable experience, discuss their approach to the management of BBPP. This is done in the background of Indian cultural practices and social constraints. A detailed discussion has been done on importance of preoperative passive joint mobilization regime and role of botulinum toxin in the authors' preferred ways of surgical correction of primary as well as secondary deformities. An extensive review of peer-reviewed publications has been done in this study, including clinical papers, review articles, and systematic review of the subject. Good results are possible with early and appropriate intervention even in severe cases.

Keywords
- birth brachial plexus palsy
- co-contractions
- Botox
- brachial plexus surgery
- brachial plexus secondary deformities

Birth brachial plexus palsy (BBPP) is unfortunately a relatively common condition found in newborns. The current literature abounds with various terminologies for describing the condition, viz., obstetric brachial plexus injury, obstetric brachial plexus palsy, birth brachial plexus injury, brachial plexus birth injury, neonatal brachial plexus palsy, etc., but the basic underlying entity of traction or strain to the plexus remains unaltered. To avoid any unjustified implications to the obstetricians, the authors prefer to refer to the condition as BBPP. The authors strongly condemn the derogatory nomenclature, as we believe that it is always a question of "saving whom" during the stressful times of shoulder dystocia, an unpredictable event. The obstetrician is not left with any choice but to pull. This should be borne in mind very carefully to avoid falling into medicolegal tangles and unfairly blaming the obstetrician for an event that is typically not in their control. Additionally, there is literature regarding occurrence of BBPP owing to intrauterine maladaptation or even following cesarean section deliveries, which is important to remember.[1–3]

Diagnosis

Diagnosis is usually simple. A newborn infant presents typically with a unilateral (rarely bilateral) upper limb partial or complete palsy of the lower motor neuron type. There may or may not be history of shoulder dystocia or assisted delivery. In our personal series, almost 50% of cases do not have such a history. Cerebral palsy can occasionally be confused but the spasticity is usually obvious.

Role of Therapy

Early referral to a brachial plexus/hand surgeon plays a vital role in the management of babies with BBPP, including

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therapy. We believe that parental mobilization of the limb under guidance of a hand therapist is the key. Gentle mobilization of all joints of the affected limb is recommended to avoid stiffness and thus to have supple joints. We strongly recommend five set of exercises to be done by mother, during each breastfeeding session. The five exercises are the following:

- *Shoulder circumduction* to get full range of shoulder motion and to relax co-contracting adductor internal rotators (Narakas I and II babies). At one point, the mother can feel the shoulder relaxing completely after initial resistance. We call it the "gear stick falling in neutral feel" (like manual change of gear of a car).
- *External rotation (ER) of shoulder* with arm adducted and elbow flexed.
- *Hand to mouth and elbow extension.*
- *Pronosupination with elbow flexed.*
- *Fingers and wrist mobilization.*

The shoulder circumduction exercise should be always the first in order to make the affected side relax and thereby to avert any unpleasant experience by the baby during ER. Each exercise is generally advised to be done with 10 repetitions and, in the case of the ER exercise, to hold final position to a count of 5. On an average, during the day, the neonate ends up doing the passive therapy at least 100 times a day. The authors have obtained a positive response for this passive therapy in the form of prevention of internal rotation (IR) contractures to some extent. This is continued till breastfeeding is on.

After this, we like to involve both parents in active and passive exercises. It is our observation, over the last three decades, that babies with active involvement of both parents show a far superior outcome. All therapy is supervised periodically by the hand therapist, which can vary from weekly to monthly depending on the social and economic situation as well as the travel burden involved. We do not do any stimulation both for logistical reasons and for lack of definitive evidence of its benefit balanced against the burden of care.

In our view, therapy serves to prevent contractures of the shoulder and create cerebral awareness of the affected limb, which is crucial in these babies to avoid limb neglect.

Role of Botulinum Toxin

Botulinum toxin (Botox), although controversial, has a role in improving the functional outcome of an affected child and occasionally to decide if primary nerve surgery is needed. Botox in our unit is used for three main indications.

- In a child with severe co-contractions between shoulder abductors and adductors as well as between shoulder external and internal rotators, leading to development of an IR contracture/deformity of the shoulder. The dilemma is then deciding between formal muscle transfers and/or trial of Botox injections. We basically decide on a trial of Botox if:
  - Clinically and electrophysiologically, the deltoid is looking reasonably good, i.e., good clinical recovery with good compound motor action potential (CMAP) but co-contraction preventing function.
  - Magnetic resonance imaging (MRI) of the shoulder reveals a congruent or majorly congruent joint (e.g., [percentage of humeral head anterior to the scapular line (PHHA)] on MRI 40% vs 50%).

  We document co-contractions clinically and on electrophysiology and typically the teres major (TM)/latissimus dorsi (LD) is more significant than the pectoralis major (PM) in our patients. The subscapularis cannot be documented currently with this technique. Typically, 50 units of the Botox is administered—25 units to TM in the midpart of the belly and 25 units to subscapularis. This probably partly affects the conjoint LD too. This is followed by the child doing a set of five exercises mimicking the Mallet score in 4 sets of 25, i.e., 100/day. For the abduction exercise, a splint holding the elbow in extension is used as it improves the abduction by eliminating the biceps co-contraction. If the child does well over the next 6 months in terms of significant improvement in the Mallet score, we repeat the MRI to see if congruence and glenoid version has improved. If it has not deteriorated or improved, we continue vigorous exercises as before. If there is deterioration in these parameters, we would then do a formal shoulder muscle transfer (SMT) with or without an anterior shoulder release (ASR) based on MRI results and passive ER.
- In cases of Narakas I and II, for whom elbow flexion has not recovered by 6 months. If (1) there is a visible strong biceps both seen and felt, (2) co-contraction between biceps and triceps is documented clinically and on electrodiagnostic studies (Edx), and (3) the biceps CMAP on Edx is comparable to the contralateral limb, then a trial of Botox to triceps is done to see if that restores elbow flexion. If it does, primary nerve surgery is not done.
- In all cases of formal shoulder surgery (SMT), we use Botox on the subscapularis and PM in addition to transferring the TM/LD to the infraspinatus.

Role of Shoulder Orthoses

Several groups have demonstrated very good prevention of shoulder dislocation by using a orthoses.[4–6] We have no experience in this technique, and in our socioeconomic milieu, it is difficult to implement.

Indications for Primary Plexus Surgery

Narakas classified BBPP into four grades[7] (►**Table 1**). In grades I and II, there is reasonable hand function but shoulder and elbow functions get affected. In grades III and IV, the palsy is global with or without Horner's sign. All the discussion about indication, timing, etc., actually refer to grades I and II of the palsy.

We operate and reconstruct all cases of grades III and IV at or around 3 months. In our experience, any meaningful

Table 1 Narakas classification for birth brachial plexus palsy

Group	Name	Roots injured	Site of weakness/paralysis
1	Upper Erb's	C5, C6	Shoulder abduction/external rotation, elbow flexion
2	Extended Erb's	C5, C6, C7	As above with wrist drop and weak triceps
3	Total palsy without Horner's syndrome	C5, C6, C7, C8, T1	Complete flaccid paralysis
4	Total palsy with Horner's syndrome	C5, C6, C7, C8, T1	Complete flaccid paralysis with Horner's syndrome

recovery of hand function is not possible in these babies without nerve repair. In Narakas grades I and II, we wait at least till 3 months for spontaneous recovery. In early referrals, we perform Edx at 1 month, which is a good indicator of prognosis.[8] If biceps innervation is noted at 1 month, the chance of good spontaneous recovery is better. The biceps is the only exclusive C5–C6-innervated muscle whose action of elbow flexion with supination cannot be replicated. The shoulder function is guided by a multitude of muscles with very varied innervation. The biceps therefore is in our opinion the most reliable indicator of the health of C5- C6 roots.

The child is seen monthly till 3 months for antigravity elbow flexion. At 3 months, if there is no antigravity elbow flexion, we look at (1) whether biceps contraction is seen or felt, (2) CMAP of the biceps and triceps compared with the opposite normal side, and (3) clinical and Edx evidence of triceps co-contraction. If the biceps is flaccid or poorly felt, we operate at this time i.e., 3 months. If a good biceps is felt and CMAP is good, we continue passive flexion exercises and wait and watch till a maximum of 6 months. A lack of convincing antigravity elbow flexion at 6 months is, in our opinion, indication for surgery. The exception with co-contraction of triceps is discussed earlier in the section on Botox.

To Summarize

All group III and IV cases	➡	Surgery at 3 months
Group I and II cases with no antigravity elbow flexion	➡	Surgery between 3 and 6 months (as discussed)

Role of Imaging

All children undergo a chest X-ray, both for anesthesia fitness and to check for phrenic nerve palsy. The X-ray can also be informative on the status of clavicle and humerus bone fracture if they happened at birth. The authors do not routinely perform MRI scans in infants for the primary diagnosis. The reasons are more economic. If possible, MRI adds value to Edx and clinical findings specially to determine preganglionic lesions. Our group has shown that a combination of Edx and MRI increases the sensitivity and specificity of the diagnosis in adults.[9]

We routinely and regularly use imaging with MRI to document and follow up the shoulder deformity in terms of the angle of glenoid version as well as PHHA. After the age of 5, we shift to computed tomography (CT) of the shoulder for the same indication. We have not used ultrasound for this indication, and we believe MRI gives far better and accurate data to help in therapeutic decision making.

Role of Electrodiagnostic Studies

Also termed electrophysiological studies, the authors routinely use them at presentation (minimum age, 4 weeks) and in a sequential fashion. The components of Edx are as follows:

- Electromyography (EMG).
- Nerve conduction studies: both motor and sensory, i.e., sensory nerve action potentials and CMAPs.
- Spinal evoked potentials (SEPs).
- Somatosensory evoked potentials (SSEPs).

The first Edx is advised at around 4 weeks of age. The information obtained from a good quality Edx report is on the following:

- Status of each root commenting on pre- or postganglionic injury.
- Reinnervation and its progress, if any.
- Status of important individual muscles.
- CMAP of recipient and donor nerves in cases involving distal nerve transfers. For example, flexor carpi ulnaris (FCU) and flexor carpi radialis CMAP bilaterally to determine if donor fascicle is good enough for an Oberlin-type repair. We have shown that CMAP of donors corelates well with elbow flexion outcome in adult palsies and follow this concept in babies too.[10]
- Documenting co-contractions, especially useful if botulinum toxin injections or muscle transfer is being considered.

SEP and SSEP are rarely used in infants. Electrophysiological testing in infants is more challenging than in adults, owing to difficulty in maintaining complete relaxation of muscle(s). Smith[11] in 1996 had suggested that EMG gives far too optimistic an evaluation compared with the actual clinical. However, the author believes that Edx gives a good estimation of the severity and extent of the injury when judiciously interpreted with clinical and intraoperative findings.

Surgical Technique for Primary Plexus Surgery

Counselling of parents is critical and clear open communication is strongly recommended. No guarantees can ever be given. This must be clear at all times. Having done the counselling, a well-written informed consent from the parents is a must. We often explain also about the expected time duration of functional outcome and the need for secondary procedure(s) based on the outcome of the primary surgery and regular dedicated physiotherapy/mobilization.

The microsurgical approach involves a complete exploration of the supra- and infraclavicular plexus. The decision for the possible nerve repair(s) is customized based on the anatomical finding. Neurolysis alone is not indicated any longer in the management of BBPP. A landmark paper by Lin et al[12] published in 2009 concluded that neurolysis had no place as a standalone treatment in BBPP.

The two basic methods of microsurgical nerve repair are intraplexal nerve repair and distal nerve transfer. A bundle of free-cable nerve grafts is interposed in between the nerve defects following excision of neuroma. Intraplexal neurotization uses existing healthy root stumps, which are ruptured, for reconstruction, by joining them with the distal target trunks, cords, or nerves using nerve grafts. It is considered the standard of care. Distal nerve transfer of peripheral nerves makes use of other intact nerves. A distal denervated nerve is repaired by making use of a nearby healthy nerve as the donor of axons, which reinnervates the distal targets. Distal transfers are used in special circumstances. Based on the two common types of nerve injuries, viz., avulsion and rupture, the approach varies from use of extraplexal donors (e.g., contralateral C7 root, phrenic nerve, intercostal nerve [ICN], XI nerve) to, if indicated, intraplexal donors such as ulnar and median nerves for an Oberlin-type transfer.

The actions to be restored are, in order of priority:

- Hand prehension.
- Elbow flexion and shoulder stability (rotator cuff via suprascapular nerve [SSN]).
- Shoulder abduction.

Positioning

The child is placed in supine position, the neck is turned to the unaffected side, and a pillow is kept under the shoulders to allow neck extension, the arm is adducted, and traction is applied in an inferior direction to allow the posterior triangle to open out and the incision to be marked (►**Fig. 1**).

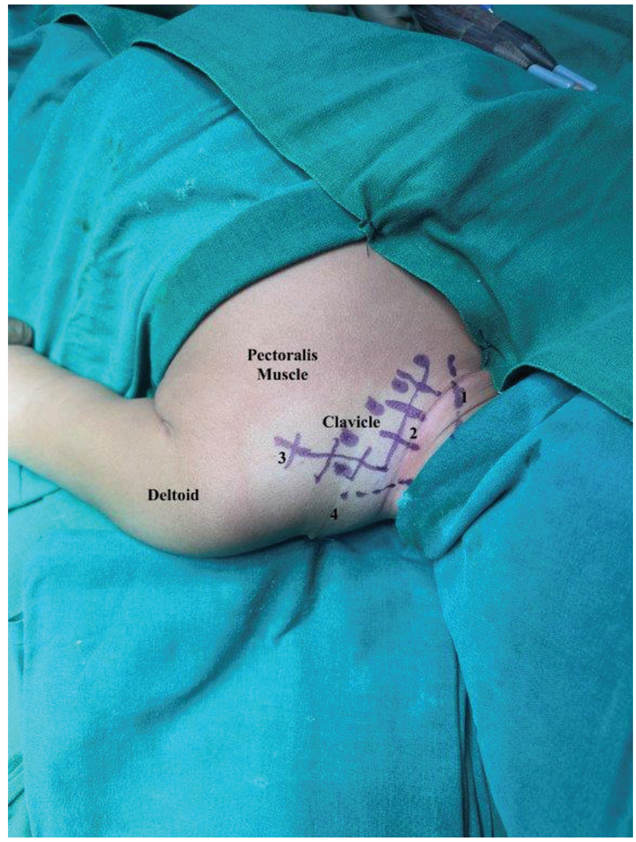

Fig. 1 Surface markings for the incision for exploration of brachial plexus in pediatric patient. Key: 1, sternocleidomastoid muscle; 2, supraclavicular incision; 3, infraclavicular incision; 4,trapezius muscle.

Preparation

The involved upper limb, affected side of the neck with the shoulder, and hemi-chest up to the xiphisternum of the affected child is prepared and draped. One or both lower limbs are also prepared for nerve grafts if required.

Infiltration

We use a solution, colloquially labelled as the "stock solution." It contains adrenaline (1:500,000) and one vial of hyaluronidase in a base of normal saline. This is infiltrated in the dose of 2.5 mL/kg. In case of very young infants, the adrenaline can be further diluted to 1:1,000,000 to allow a dose of 5 mL/kg. No local anesthetic is added, as it would interfere with intraoperative nerve stimulation. The solution is infiltrated in two planes: intradermal and subcutaneous. Standard precautions of aspirating before injecting are recommended in view of proximity of multiple major vessels. Infiltration is done before painting and draping, allowing adequate time for it to act. We get very good results with this diluted saline adrenaline solution in terms of reduced bleeding and excellent planes of dissection.

Anaesthesia

The choice of anesthesia is a general anesthesia but without administration of any muscle relaxant. Muscle relaxants (short acting) may be used during the induction, so that its effect wears out by the time the plexus gets explored. The theater temperature is kept raised to maintain the infant's temperature along with warming blankets to prevent thermal stress. The core temperature is regularly monitored during surgery.

Incision Type

Landmarks for the incisions are the clavicle, anterior border of trapezius, sternocleidomastoid (posterior edge), and the deltopectoral groove. The choice of incisions for exploring the plexus has been modified with evolution of the authors' approach to the injured plexus over the last two decades. In 2011, the authors used to take two different—supra- and infraclavicular—incisions on the involved side[13] (►**Fig. 2**). The bipedicle flap between the two incisions was not ideal for visualization below it. Subsequently, the two incisions were united, forming a laterally oriented and medially based cervicopectoral flap (►**Fig. 2**). The supraclavicular incision

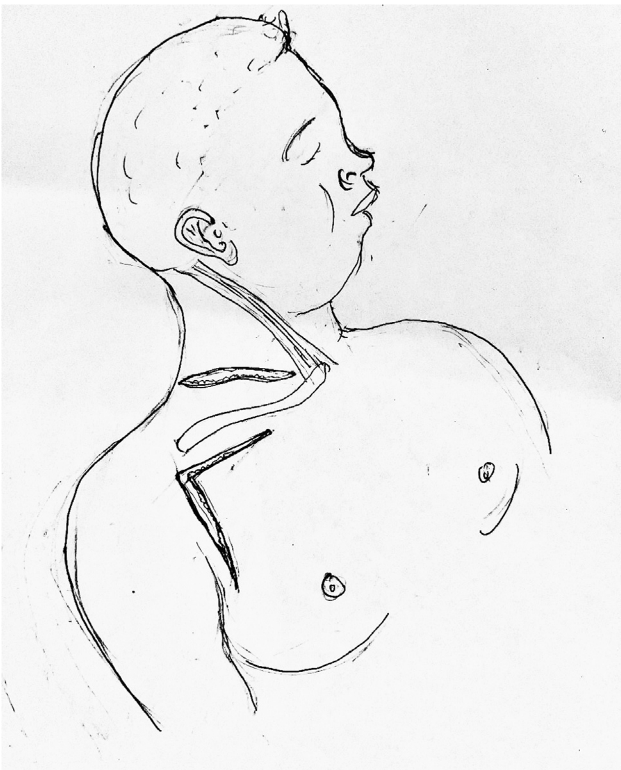

Fig. 2 Previous incision surface markings for exposure of brachial plexus. Key: *Dotted line* 1, sternocleidomastoid muscle; 2, supraclavicular incision marking; 3, clavicle; 3, infraclavicular incision marking.

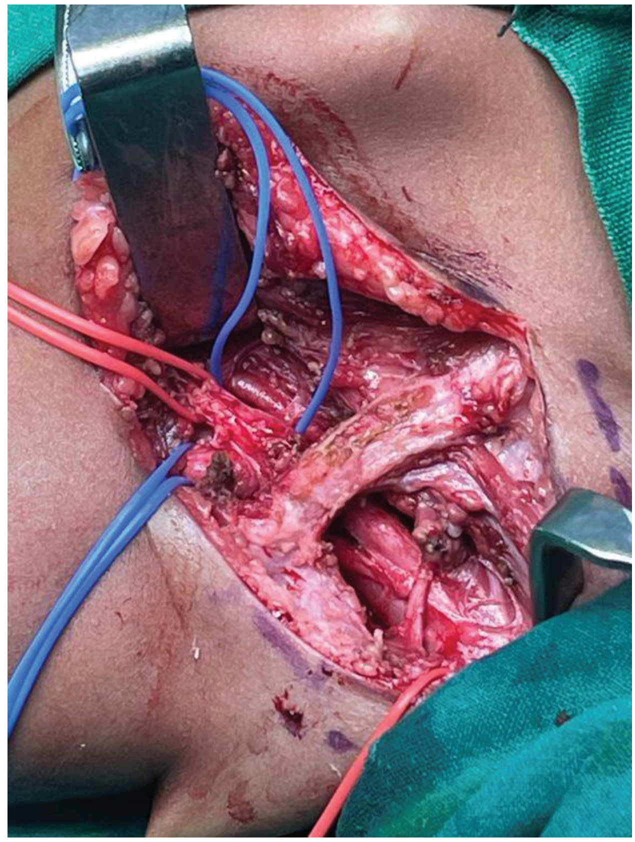

Fig. 3 Exposed brachial plexus, both supraclavicular and infraclavicular, via the current choice of incisions by the authors.

corresponds to the line bisecting the angle between sternocleidomastoid muscle and medial end of clavicle and extending till the anterior border of the trapezius. This incision facilitates exposure of the roots, trunks, divisions, and the spinal accessory nerve (XIth cranial nerve). We make it a point to identify the phrenic nerve, keep it under vision and protected, and then remove the scalenus anteroposterior and medial to it till we can trace the roots up till the foramina. Thereafter, a line drawn from the superolateral limit of supraclavicular incision and following the deltopectoral groove till the coracoid marks the infraclavicular incision. The incision falls approximately 2 to 3 cm short of anterior axillary fold. Thus, a medially based cervicopectoral flap results, the current approach used by the authors (►**Fig. 1**). This facilitates exposure of supraclavicular, retroclavicular and infraclavicular plexus, namely, cords and branches (►**Fig. 3**).

Pathology

The basic three possible pathologies that can be encountered on exploring the injured plexus are as follows:

- *Rupture*: This is a postganglionic neurotmesis, causing a separation of proximal and distal ends often bridged by scar tissue.
- *Avulsion*: This is a preganglionic lesion showing avulsed ganglia in the neck and/or pseudomeningoceles on imaging and sometimes in the neck.
- *Neuroma-in-continuity*: Indicative of postganglionic rupture, but has healed with fibrosis, and some axons traverse the scar tissue. May be conducting or nonconducting type.

Use of Operating Microscope

At least 3.5× loupe magnification is recommended for the general dissection of the brachial plexus. For the purpose of coaptation, the authors prefer to use a standard microscope with 10× magnification.

Clavicle Osteotomy

The practice of clavicle osteotomy is now abandoned by the authors. The reason behind this is increased incidence of clavicle nonunion and also because it became an issue in adolescents who were operated for brachial plexus in their childhood. Till 2011, clavicle osteotomy was done in order to have an easy exposure of the retroclavicular plexus, viz., divisions and cords, especially for a postganglionic rupture scenario. The clavicle was exposed. Two holes were drilled in two portions of the clavicle using 1-mm Kirschner wires and an oblique osteotomy was done between the two holes. The two ends of the cut clavicle were retracted so that the entire plexus comes into view. At the end of the reconstruction, the clavicle was reapproximated by thick absorbable sutures passed through the holes created earlier. We were not happy about the method of fixation or its results in a significant percentage of the babies and stopped using it.

The advantage of the osteotomy was the ease of exploring the neuroma in the retroclavicular aspect and thus the ease of operation. Since more than a decade, the author has stopped the practice of osteotomy and the current approach is to safely and precisely excise the subclavius muscle from the undersurface of clavicle and then judiciously use shoulder motion to bring nerves above and below in view. If all soft tissue between the clavicle and the plexus (in line with the supraclavicular plexus) is divided, including ligation of a couple of constant veins and one artery present, the view is as good as an osteotomy.

Management and Assessment of Neuroma-in-Continuity

Use of Intraoperative Neurophysiology

We use nerve stimulation intraoperatively to judge the nature of the neuroma as well as intact roots. Intraoperative stimulation also helps to identify and confirm donor nerves such as the XIth, ulnar, and median nerves. We tried intraoperative measurement of action potentials using a portable EMG machine and realized the judgment required to separate the true from false signals (including the 50-cycle hum of the background grid if you are not careful) was beyond our expertise and the electrophysiology department could not be called upon every time to be present in the operation theater. On reflection, perhaps, the one thing electrophysiology can do is an SEP/SSEP from a reasonable looking root stump to ensure proximal continuity. This is very difficult for most surgeons to perform *reliably*.

Neuroma-in-continuity is dealt with based on preoperative clinical findings of muscle function, particularly the deltoid. If the neuroma is conducting and stimulation above and below it results in shoulder abduction and visible deltoid contraction (corroborated by similar finding clinically in the preoperative examination), a diagnosis of dissociated recovery can be made specially in group I lesions. In that case, an isolated Oberlin transfer for biceps and perhaps but not always an XIth nerve to SSN transfer is done. If it is weakly conducting or nonconducting, we excise it and do an intraplexal repair. In our country, we do not always get consent for this, and in those cases, do a set of distal transfers. We have published the results of this strategy as a primary treatment modality.[14]

Use of Frozen Section Pathology

Our department does not use this facility.

Abundant literature exists to support the current concept of excision and grafting of the neuroma encountered. Studies by Gilbert,[15] Kawabata et al,[16] Capek et al,[17] Sloof,[18] and Birch et al[19] advocate this as the ideal method for the reconstruction. Neurolysis alone has no role.[12] Once the neuroma is excised or resected, the proximal and nerve roots are assessed for availability and quality. An operative microscope is helpful for it. Nerve grafts are then utilized for bridging the gap of the cut nerve ends and thus reestablish the continuity of nerve. The authors prefer autologous grafts.

Over three decades of practice, the authors have devised a strategy for the various possible injury patterns in global palsy and partial plexus palsy. The strategy for global palsy[20] is based on the number of available proximal usable roots:

- *Four or five roots available*: nerve grafts to respective trunks/roots. This is rare.
- *Three roots available*: one each to medial, lateral, and posterior cords and spinal accessory nerve to SSN. Best root to the lower trunk/medial cord.
- *Two roots available*: root 1 (better one) to the lower trunk/medial cord, root 2 to the lateral cord (or shared between lateral and posterior cords), and spinal accessory nerve to SSN.
- *One root available*: root to the lower trunk/medial cord + spinal accessory nerve to SSN, two or three ICNs to biceps. Shoulder will need secondary transfers if possible.
- *One poor quality root and/or total avulsion*: we used opp. C7 to the lower trunk/medial cord, for the rest our typical strategy was to target elbow flexion by using the spinal accessory nerve to musculocutaneous nerve (MCN) via nerve graft or by end-to-end coaptation with the lateral cord/anterior division of upper trunk; use any available root (if available) to the posterior division of upper trunk; coapt cervical motor nerves to the SSN; coapt the supraclavicular sensory nerves to the lateral cord/anterior division of upper trunk. Our results in a series of 19 cases are now published, which show that 73% of patients got useful hand function.[21]

Strategy in upper plexus palsy C5–C6 ± C7

- *Both roots available*: typically, C5 to posterior division of upper trunk and C6 to anterior division of upper trunk plus spinal accessory nerve to SSN.
- *One root available*: available root to anterior division of upper trunk or both divisions if good quality root and spinal accessory nerve to SSN. ICNs can be used for additional neurotization, if necessary; rarely used.

Nerve Transfers

This nerve transfers can be either extraplexal or intraplexal. Some of the commonly encountered extraplexal nerve transfers have been the transfer of XIth cranial nerve to SSN and ICN to MCN. Outcomes of nerve transfers are better when transferred end to end without any nerve grafts interposed.

Intraplexal nerve transfers are typically done near the desired response site. Therefore, the correct terminology would be distal nerve transfers. The authors, however, prefer exploring the plexus beforehand irrespective of plan for distal nerve transfer. In case healthy roots are encountered, they are utilized, and distal transfers are kept in reserve. However, if there is paucity of good roots or avulsion, then a judicious combination of intraplexal neurotization and distal transfers is preferred. In a dissociative recovery where good shoulder abduction is present but no elbow flexion, we use an Oberlin-type distal transfer with or without XIth nerve to SSN coaptation depending on the findings. Ultimately, each surgeon has to be aware of all options and use his/her judgment to make informed choices.

In Narakas group I lesion (C5, C6), the distal transfers allow leaving the neuroma undisturbed and doing a distal transfer consisting of XIth nerve to SSN, Oberlin, and sometimes Somsak transfers (depending on deltoid response to neuroma stimulation) to reconstruct shoulder abduction and ER, as well as elbow flexion. If the C7 is involved, then the triceps is often not functioning and the Somsak transfer is not possible; it also often means wrist extension is affected. In these cases, intraplexal neurotization can be used for the C7 posterior division to help reinnervate both the triceps and wrist extension. There is considerable disagreement about pure distal transfer as a repair. The two European doyens Gilbert and Raimondi[22] argue that if roots are available, it is preferable to do a classical reinnervation and reserve distal transfers for later use. This allows reinnervation of all muscles supplied by those trunks/cords in a proper manner and yet leaves the distal transfers in reserve in case of unfavorable outcome. As mentioned earlier, distal transfers can be done at a late stage as they reach the muscle very rapidly. There is also no conclusive evidence in the form of a properly conducted prospective study to show that distal transfers give better results compared with classical neurotization in the long run. A study from our unit by Ghanghurde et al in 2016 where we used distal transfers as a primary modality showed good outcomes with distal nerve transfers in BBPP children.[14]

In the South Asian scenario, distal transfers have a great benefit of targeting select muscles with no visible function without cutting the neuroma. Thus, for late referrals where some movements are seen, these are not lost even temporarily due to resection of the neuroma. This has social implications in this country because many parents and grandparents are not willing to risk losing existing movements (however inadequate they may be) to gain an eventual better result and refuse consent for neuroma excision without guarantees from the surgeon, which obviously cannot be given. Gilbert has reported similar social taboos in the Middle East.[15]

Technique and Donor Sites for Nerve Graft Harvest

Grafts are utilized to bridge the gaps between the nerve ends and thus reestablish the nerve continuity. Grafts may be coapted individually or as cable bundles, made by grouping several nerve segments held together with fibrin glue only at either end, leaving the central four-fifths loose to allow revascularization. In our unit, only autografts are used (►**Figs. 4**, **5**, and **6**).

Various nerve grafts commonly used by the author are discussed in the following.

Sural Nerve

This nerve is harvested either from one or both the lower limbs. A longitudinal, posterior, midline incision is made from the popliteal fossa to the lateral malleolus under tourniquet to minimize blood loss. Around 10 to 12 cm of

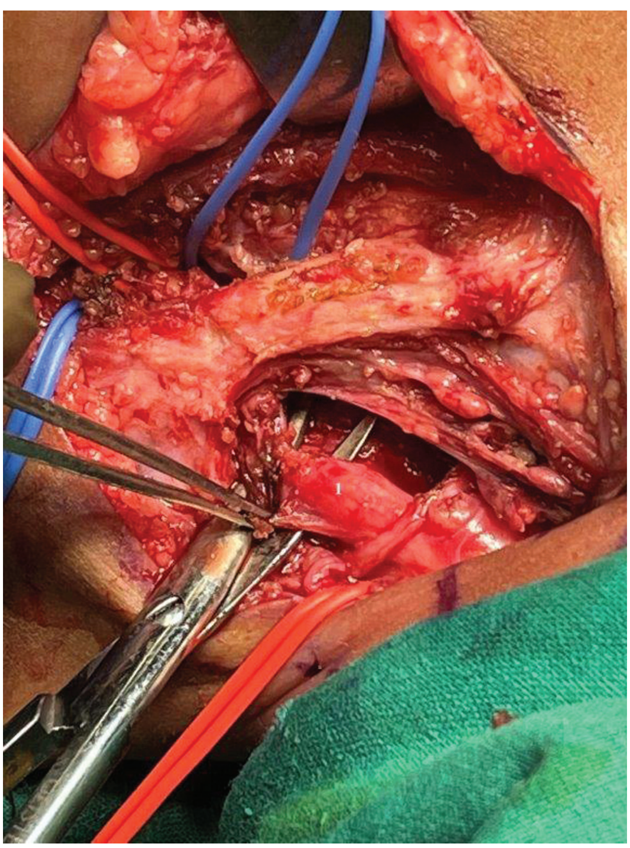

Fig. 4 Clinical picture showing the exposed right-side brachial plexus with rupture of C5, C6, C7 roots at the level of trunks. Key: 1, neuromas over the upper and middle trunks.

Fig. 5 Clinical picture showing the cables formed from the various nerve grafts harvested for the purpose of bridging the nerve gaps after excision of the neuromas.

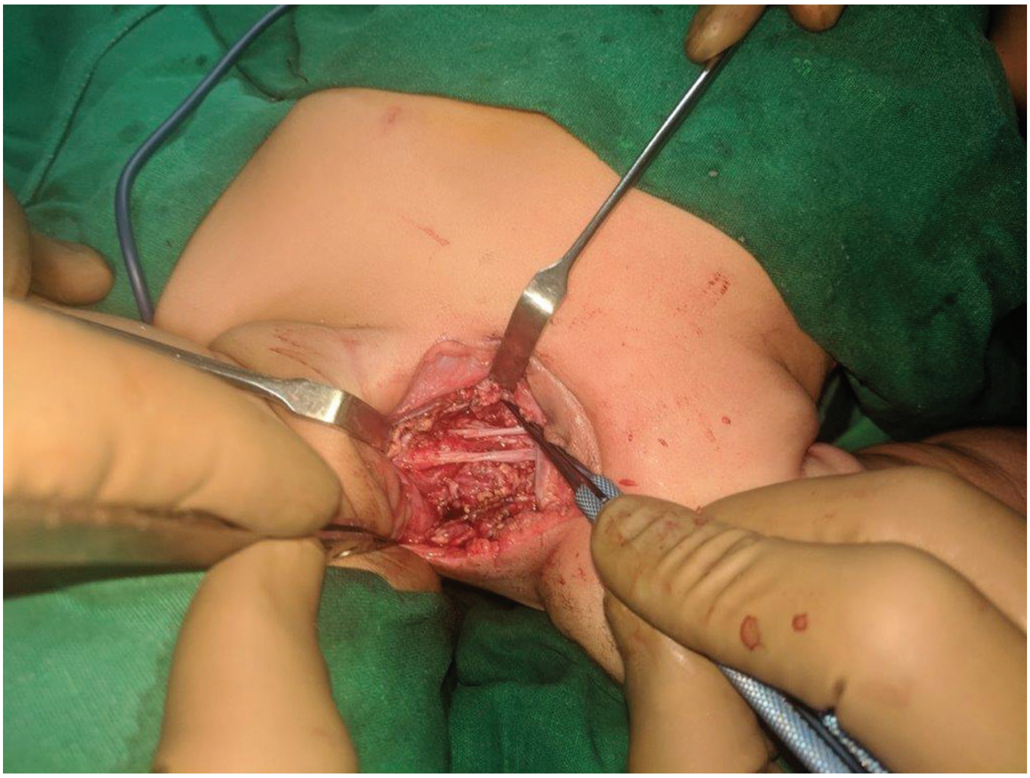

Fig. 6 Clinical picture showing the nerve grafts in situ used to bridge the gap between the roots and trunks.

sural nerve is obtained per leg in a 6 to 8 kg baby. We always give local anesthetic in appropriately calculated dose diluted with saline for pain relief postoperatively in the sural harvest incisions.

Supraclavicular Nerves

These nerves are obtained below the platysma via the supraclavicular incision. These are the superficial sensory supraclavicular nerves (anterior, middle, posterior). These nerves are preserved if possible or divided if obstructing the dissection. If divided, they can be harvested for grafts by dividing near the clavicle. Cable lengths of 2 to 3 cm are available. In avulsions, they are also useful as donors to add sensory input.

Medial Cutaneous Nerve of Arm (MCNA) and Medial Cutaneous Nerve of the Forearm (MCNF)

It is harvested by a longitudinal incision over the medial aspect of the arm. Often, the length of the graft can be increased by dividing the nerve proximally from its origin from the medial cord. This is facilitated by the exposure obtained by the infraclavicular incision. In this case, an extra 5 cm is obtained. Around 10 to 15 cm of graft length is available.

Superficial Radial Nerve (SRN)

It is harvested by an incision taken over the radial border of the forearm. Approximately, 10- to 12-cm graft length is available.

Method of Nerve Coaptation

We measure the size of the defect between the proximal and distal stumps. We calculate the number of cables required for all the distal targets and arrive at total graft length required. For example, if 12 cables of 2.5 cm are required, then we need 30-cm nerve graft, which will mean 1 sural plus MCNF plus SRN. Grafts are made into bundles and both ends are glued together with fibrin glue; the central four-fifths is not glued to allow ingress from neoangiogenesis.

The authors typically opt for epineural suturing. The graft bundle is coapted to both stumps with two to three sutures of 9–0 or 10–0 nylon to ensure spatial match of the ends and the final union is strengthened by fibrin glue. The tissue glue also finds its use in formation of cable bundles as mentioned earlier. From the wound biology point of view, every suture on a nerve forms a granuloma resulting in fibrosis. Hence, the authors are in favour of using less sutures and more glue for the neural coaptation process (►**Fig. 7**).

In the end, we move the neck, shoulder, and arm to do a stress test on the coaptation. The coaptation is always done with the shoulder pulled inferiorly to avoid any tension when the child is in sitting position and the shoulder is affected by gravity. Typically, no stress is noted from either neck or shoulder movements.

Postoperative Immobilization

The child is put in a bulky dressing with the arm strapped to the chest. We never use a plaster cast over the head, neck, and chest and have no reason to regret it. We always check intraoperatively that neck movements are putting no stress on the coaptation.

The patient's shoulder is immobilized by strapping his arm to his body to minimize unnecessary movement. The wound is

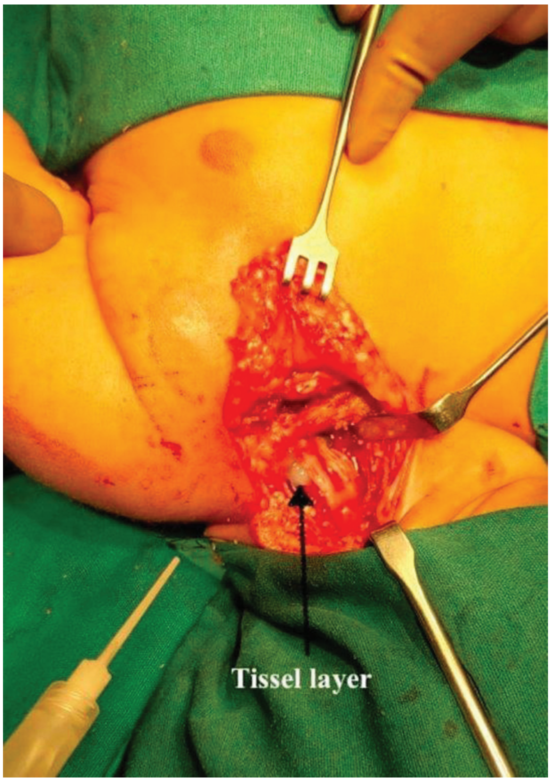

Fig. 7 Clinical picture showing the judicious use of Tissel fibrin glue, at the sites of coaptation sites for brachial plexus reconstruction.

inspected weekly, and removal of staples/sutures is done on the 8th or 10th postoperative day. The strapping is then reapplied, which is kept for a total of 4 weeks. Mobilization is started 4 to 5 weeks after surgery, which includes passive abduction, ER, and flexion exercises of the shoulder and passive pronosupination exercises for the forearm; these exercises are taught to both the parents. After 4 more weeks, full passive mobilization program is reinstituted.

Management of Shoulder

Only children who recover spontaneously within the first 2 months of life seem to avoid developing the long-term secondary deformities of BBPP.[23,24]

The shoulder is a multiaxial joint with a huge array of diverse muscles working on it. Co-contractions affects a large percentage of babies with BBPP, both with spontaneous recovery, especially those occurring after 3 months, and with standard intraplexal repair. The four big adductors and internal rotators, viz., the LD, TM, PM, and subscapularis, overwhelm the abductors, viz., the deltoid and supraspinatus, as well as the external rotators, viz., the infraspinatus and teres minor. The most common and earliest consequence of this is the progressive loss of passive ER. Co-contraction of abductors with adductors and internal with external rotators lead to IR contracture combined with poor abduction (►**Fig. 8**). This continual rotational pull causes the glenoid to distort and go in retroversion. Eventually, the head of the humerus slips behind the central axis going through the scapula (in MRI axial sections) and causes a posterior dislocation. The shoulders of these children are internally rotated and are unable to abduct fully despite a well-developed deltoid. They also go into forearm pronation as an adaptation to their attitude, which can lead to further sequelae in the forearm.

Initial Management

Be it either a BBPP child on conservative wait-and-watch policy or an operated case of upper BBPP, the authors tend to maintain a regular 3 monthly follow-up. Each time, the clinical assessment begins with clinical examination of the affected limb and evaluation with the movements of the Mallet's score actively or passively to understand available range of motion, especially ER. Depending on the age of the child, the intended motion is first described and demonstrated in a playful way. If this is not productive or the child is still an infant, then the movement is attempted by

Fig. 8 Clinical photographs showing restricted external rotation of the right upper limb owing to co-contraction between the muscles leading to changes in the glenoid over time if untreated.

Fig. 9 Clinical photograph showing the restricted right shoulder abduction in a BBPP kid with internal rotation attitude of the limb.

strategically positioning desirable objects such as toys. Finally, if necessary, the child's arms are passively moved to the desired position, showing him/her what to do, and then asked to repeat the same movement. If the child shows poor abduction in the presence of a good deltoid bulk and if passive ER is affected, we tend to investigate further immediately.

This includes an Edx study and an appropriate radiological investigation, viz., MRI shoulder glenoid version (<5 years age) or the CT scan shoulder glenoid version (>5 years age).

For a child at risk of developing secondary deformities, the Edx would show a range of significant and nonsignificant co-contractions between the opposing group of muscles. Evidence of co-contractions between the deltoid and TM/LD muscles and between infraspinatus and TM/LD are supportive of limited excursion of the shoulder joint. These co-contractions manifest in the child in the form of limited shoulder abduction and an IR attitude (►**Figs. 8** and **9**). On MRI or CT, glenoid version angle is calculated as the angle between the glenoid line and the line perpendicular to the scapular axis. The higher the glenoid angle, more is the degree of retroversion of humeral head. The retroversion alters the normal glenohumeral mechanics, leading to subluxation of the humeral head, as measured by the PHHA score.[25] Water mentioned that both CT and MRI provide reliable means of evaluating the status of the glenohumeral joint and are valuable in the preoperative planning and postoperative follow-up of these patients.[26] However, MRI appears to offer the most information regarding the cartilage of the humeral head and glenoid in younger patients, whereas the lower cost and ease of multiplanar reconstruction make CT the preferable modality for older patients. MRI is thus preferred for children who are younger than 5 years for evaluation of the articular cartilage surfaces of the glenoid and the humeral head because these structures are still incompletely ossified at this age.[27] Based on the findings of MRI/CT, revealing the PHHA and glenoid version, one comprehends the degree of damage to the shoulder joint.

Various treatments options available include the following:

- Botulinum toxin
- Soft tissue surgery viz. Muscle Transfers
- ASR
- Humeral and Glenoid osteotomies.

Botulinum Toxin (Botox)

An isolated use of Botox per se by the authors is limited. It is restricted only for kids with relatively reasonable congruence on MRI with proven co-contractions clinically and on Edx. In such cases, the Botox is administered, under short general anesthesia, to two of the four adductors, typically TM and subscapularis muscle with or without a spica in ER.

All types of Mallet exercises are encouraged starting 1 week after the injection or after spica removal. All children are given a customized splint to hold the elbow in extension, which is used during the abduction exercise. In our experience, this splint makes a remarkable difference to abduction (►**Fig. 10**).

Surgical Strategy for Internal Rotation Contracture

Indications for Release

- Limitation of active abduction and ER function.
- Shoulder dislocation and/or greatly increased retroversion with low PHHA on MRI.

Age at Release

There is no fixed age. We try to avoid formal shoulder surgery before 1 year as postoperative therapy is significantly more difficult in very young patients. If feasible, we try to manage with Botox. Unless forced by an adverse MRI, we tend to operate at 18 months or later. The youngest kid operated so far by the authors has been of 9 months and the oldest patient operated has been a 24-year-old male. Of late, in a few cases of severe deformity in infants we have combined a formal ASR with Botox and a spica in ER for 4 weeks but have not done the muscle transfer.

Technique of Release

Background: Sever in his article in 1916 first mentioned about the release of subscapularis and PM muscles.[28] L'Episcopo described a surgery via combination of anterior and posterior approach in which he divided the tendinous origin of the TM and LD and repositioned them under the lateral head of the triceps, thus converting them into external rotators.[29] Over the years, various modifications of technique have been proposed with the basic principle being conversion of internal rotators to external rotators. Chuang in 1998 proposed release of antagonistic muscles (PM and TM

Fig. 10 A child with left-sided BBPP, showing the utility of straight elbow splint in achieving straight overhead abduction. The elbow often remains in a flexed position, in the absence of an adequate support via splint.

muscles) and augmentation of paretic muscles (transferring TM to the infraspinatus muscle, and reinserting both ends of the clavicular part of the PM muscle laterally).[30]

Anterior Shoulder Release

It is done if there is restriction to passive ER after general anesthesia and MRI findings corroborate. In all operated cases, we aim for full passive ER at the end of surgery. Keeping the arm abducted, an anterior incision is taken in the deltopectoral groove. Through this incision, the coracoid process is identified. It shows three structures, viz., tendon of pectoralis minor, tendon of coracobrachialis, and coracohumeral ligament (►**Fig. 11**). The authors prefer doing a subperichondral release of the pectoralis minor and coracobrachialis from the coracoids process, and then release of the coracohumeral ligament. At this stage, many children attain full ER. If not, the capsule of the shoulder joint is cut to obtain full ER and reduction of the subluxated head in those cases where it was fully subluxated. In some cases, partial excision of the hypertrophied tip of the coracoid process is done if found to be impinging on the humerus in rotation or abduction.

This is combined with a transfer of the conjoint tendon of TM/LD to the infraspinatus tendon in an attitude of full ER and about 30- to 60-degree abduction (if abduction is the bigger issue, then we use 60-degree abduction to fix the tendon; if ER is the bigger issue in the child, then 30-degree abduction is used).

After achieving hemostasis and closure of the incisions, a plaster spica is applied keeping the arm in abduction and full ER with the elbow flexed to hold the rotation more easily and the forearm supinated. A detailed description of the methodology of applying the shoulder spica cast has been elaborated by Shah et al in 2020.[31] This spica is worn for 4 to 6 weeks, after which a controlled rehabilitation program is started by a hand physiotherapist, which includes active and passive range of motion exercises along with strengthening exercises. An elbow extension splint is used to prevent flexion of the elbow during active shoulder abduction. This splint is to be removed while doing other physiotherapy for ER, hand to mouth, etc.

Technique of transfer: Thatte et al published a series of 150 consecutive patients where the procedure involved combination of ASR and tendon transfer aimed to determine the effect of these soft tissue rebalancing procedures on glenohumeral function based on shoulder movements as well as functional grading.[32] The study showed that LD and TM tendon transfers are useful in improving shoulder function in brachial plexopathies, and glenohumeral changes are best treated early with muscle rebalancing procedures before the development of irreversible changes.

Procedure of Muscle Transfer

The child is placed in a lateral position, with the affected arm draped free and able to move in all directions. The surgical incision is infiltrated with 1:500,000 (2.5 mL/kg) or 1:1,000,000 (5 mL/kg) concentration of saline adrenaline and lignocaine as per calculated dose for a bloodless operative field depending on weight of the child. This concentration allows much larger volumes to be injected without reducing the quality of vasoconstriction. The first incision

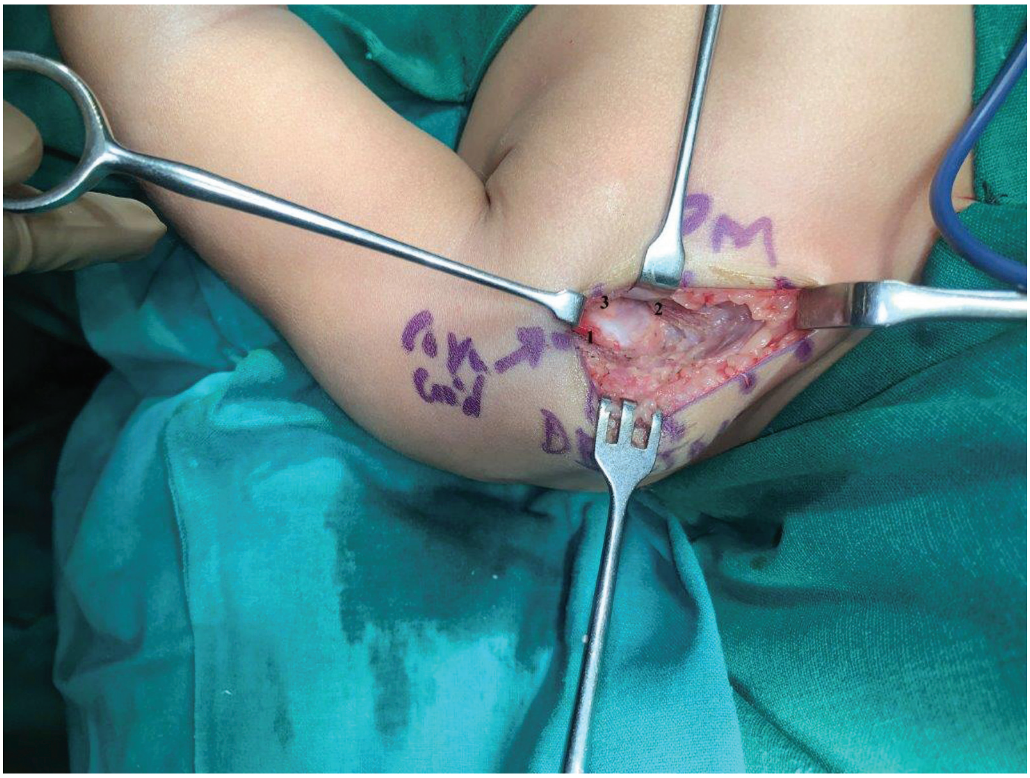

Fig. 11 Showing ASR exposure. 1, coracohumeral ligament; 2, pectoralis minor attachments; 3, coracobrachialis.

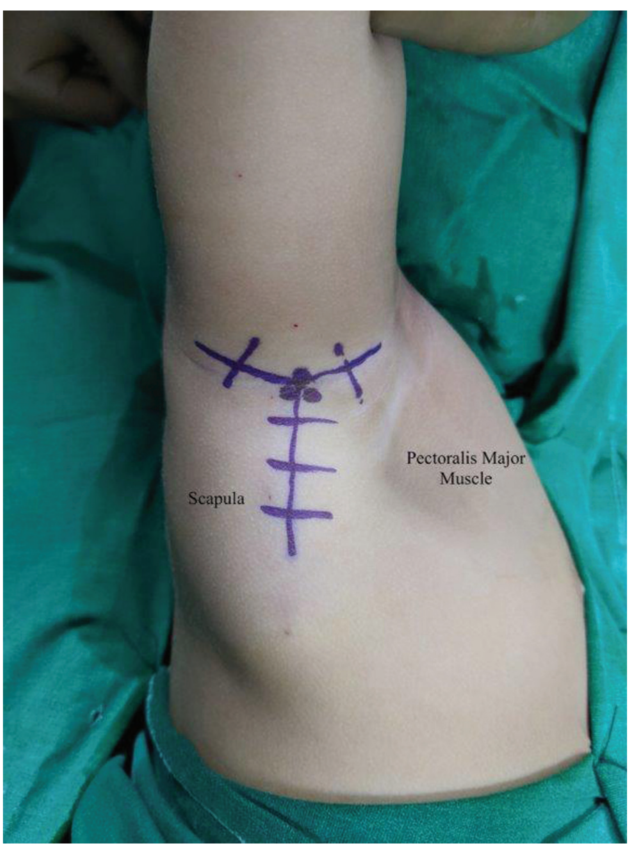

Fig. 12 Surface marking of the incision over the axillary region for the procedure of shoulder muscle transfer.

is taken on the lateral margin of the scapula toward the axilla with two extensions laterally and medially at the superior end (►**Fig. 12**) to expose and detach the tendons of the conjoined muscles, TM, and LD from their insertion on the humerus. These conjoined muscles are then elevated up to their neurovascular pedicle found proximally along the lateral border of the scapula. Through a second incision, basically a posterior extension of the superior end of the lateral scapular incision, the tendon of the infraspinatus is exposed, after retracting the posterior fibers of the deltoid away. The detached conjoined tendon is then transposed without tension and woven on to the tendon of the infraspinatus using a braided 2–0 suture material.

Management of Weak Shoulder Abduction

Weak shoulder abduction signifies either a good deltoid but strong co-contraction with adductors or a poor deltoid due to inadequate reinnervation. It is often seen in untreated late presentation. Typically, it arises from the certain degree of co-contractions between the four adductors and two abductors of the shoulder joint. The detailed pathophysiology remains the same, as explained earlier. For such children, our typical approach is to offer SMT surgery option, wherein an attempt is made to nullify the muscular imbalance as well as the break the tendency of co-contractions by administering Botox to one set of adductors and by doing a muscle transfer from adductors to abductors, viz., conjoint tendon to infraspinatus muscle. Posttransfer, the congruency of the ipsilateral shoulder joint is assessed by externally rotating the limb with the elbow in flexion. A shoulder spica cast is worthwhile, to maintain the position as well as to utilize the benefit of muscle-paralyzing effect of the Botox.

In case the deltoid is weak or underdeveloped, the following options exist:

- We prefer Chuang's technique (if we see a strong PM) where the clavicular head of the PM is added to the anterior fibers of the deltoid to bolster abduction. This requires a moderately strong deltoid hampered by co-contraction of adductors.
- Alternatively, a trapezius transfer of the upper third of the trapezius to the deltoid gives moderate results.
- In the absence of good donors, we have also added the levator scapulae as a new motor for the deltoid but results are uncertain as the muscle bulk is inadequate.
- In cases of weak donors, initial good results do not keep up with growth and puberty-induced weight changes.

Assessment of Outcomes

The assessment of outcomes in a BBPP infant is the most challenging part. The quest for a reliable method to quantify the motor functional outcome has led to development and availability of many assessment score scales/systems.

Medical Research Council Grading

Proposed by the British Medical Research Council (MRC)[33] (►**Table 2**), in 1943, it is the most widely used method for assessment of motor power in infants with BBPP. In 1990, the MRC grading system was modified by Mendell and Florence. Modified MRC scale[34] (MMRC) (►**Table 3**) is also useful for grading the power of muscles. Gilbert and Tassin[35] (►**Table 4**) suggested another modified British MRC classification, simplifying it to account for the difficulties of examining infants. In general, we prefer the MMRC scoring for various movements.

Active Movement Scale (AMS)

Clarke and Curtis[36] designed an eight-point scale, viz., the Hospital for Sick Children Active Movement Scale (►**Table 5**), to document movement in the arm. The AMS is a reliable tool for the evaluation of infants up to 1 year of age with BBPP when the evaluators are trained in the use of the scale.

Table 2 Medical research council muscle grading system

Observation	Muscle grade
No contraction	0
Flicker or trace of contraction	1
Active movement, with gravity eliminated	2
Active movement against gravity	3
Active movement against gravity and resistance	4
Normal power	5

Table 3 Modified Medical Research Council Muscle Grading System

Definition	Grade
Normal strength	5
Barely detectable weakness	−5
Same as grade 4, but muscle holds the joint against moderate to maximal resistance	+4
Muscle holds the joint against a combination of gravity and moderate resistance	4
Same as grade 4, but muscle holds the joint only against minimal resistance	−4
Muscle moves the joint fully against gravity and is capable of transient resistance, but collapses abruptly	+3
Muscle cannot hold the joint against resistance, but moves the joint fully against gravity	3
Muscle moves the joint when gravity is eliminated	2
A flicker of movement is seen or felt in the muscle	1
No movement	0

Table 4 Gilbert and Tassin muscle grading system

Observation	Muscle grade
No contraction	M0
Contraction without movement	M1
Slight or complete movement with weight eliminated	M2
Complete movement against the weight of the corresponding segment of extremity	M3

Table 5 Hospital for sick children, active movement scores

Observation	Muscle grade
Gravity eliminated	
No contraction	0
Contraction, no motion	1
Motion ≤ 1/2 range	2
Motion ≥ 1/2 range	3
Full motion	4
Against gravity	
Motion ≤ 1/2 range	5
Motion ≥ 1/2 range	6
Full motion	7

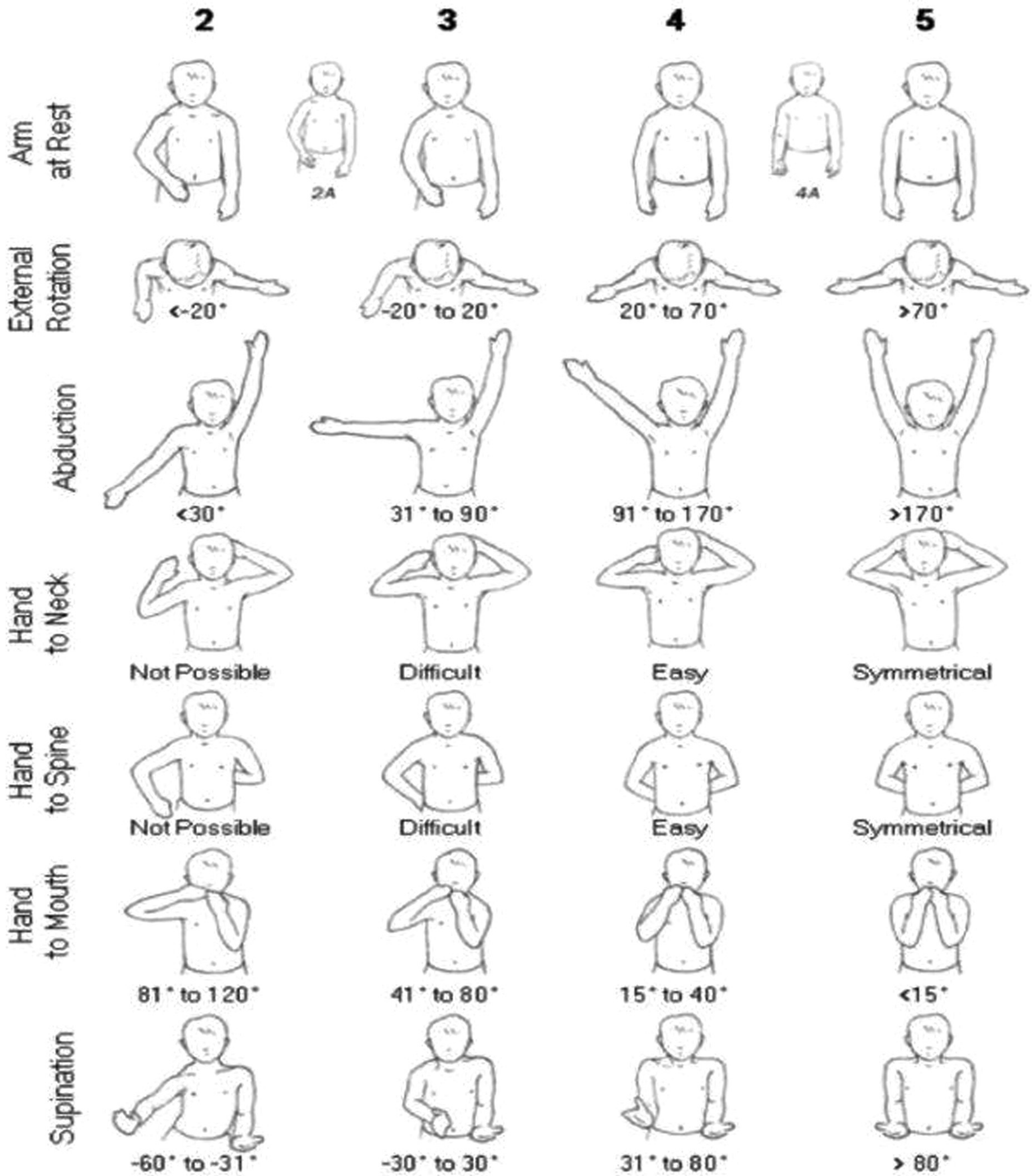

Fig. 13 Modified Mallet scoring system. Maximum score (sum of individual score) is 25. Scale 1 for every action is no movement possible. Fixed forearm supination is noted in the resting position as indicated by the drawings labelled 2A (first web space visible) and 4A (palm visible).

Mallet Grading System

Another approach to the evaluation of children with brachial plexus lesions is assessment of global movement of the extremity and patterns of movement that may be either functional or maladaptive. Such a grading scale has been established by Mallet[37] and is commonly used. The main shortcoming of this system is its applicability only to children of 3 to 4 years of age, who can reliably perform voluntary movements on command. The system was modified and published in 2009 by the team of neurosurgeons from Texas, United States[38] (►**Fig. 13**).

Gilbert's Scoring System for Shoulder[39]

The scoring system was devised in 1987 to overcome the limitations of the MRC system with manual resistance. This is specifically based on the shoulder movements, viz., assessment of simultaneous abduction and ER. The shoulder movements are evaluated on a scale of 0 to 5, i.e., flaccid to complete ER at abduction (►**Table 6**).

Raimondi Scoring System for Hand Function

In 1993, the Raimondi score was devised specifically for assessment of movements of hand and wrist. The scale

Table 6 Gilbert shoulder score abduction and external rotation

Degree	Function
0	Flaccid shoulder
1	Abduction to 45 degrees°, no active ER
2	Abduction to <90 degrees, no active ER
3	Abduction to 90 degrees, weak active ER
4	Abduction to <120 degrees, weak active ER
5	Abduction to >120 degrees, complete active ER

Abbreviation: ER, external rotation.

Table 7 Raimondi's grading system for outcome of Hand Function in BBPP patients

Score	Finding
0	Complete paralysis or functionally useless finger flexion. Nonusable thumb without grasping function. Little or no sensation.
1	Limited finger flexion. No finger or wrist flexion. Key grip possible.
2	Active wrist extension and use of the tenodesis effect. Passive key grip in pronation.
3	Complete active finger and wrist flexion. Active thumb movement, including abduction and opposition Intrinsic equilibrium. No active supination (good opportunity for surgical correction).
4	Complete active finger and wrist flexion. Active wrist extension, but weak finger extension (or none). Good opposition of the thumb with active ulnar intrinsic muscles. Beginning pronation and supination.
5	Like 4 with active finger extension and nearly complete pronation and supination.

ranges from 1 to 5 (►**Table 7**). The score incorporates both sensation and motor function in its evaluation. The Raimondi scale is thus able to determine a more global and functional evaluation of hand function.[40] However, the combinations mentioned in the various scores do not always occur together reliably causing issues with scoring.

Authors' Choice

Postsurgery, on regular 3-month follow-up, the authors make use of various combination of the following methods. Per se, the author prefers the MMRC score for individual movements, the usage of serial Mallet's score, and the Raimondi scoring system as the children grow older. Thus, various methods used to assess the surgical results of brachial plexus reconstruction in our unit include:

- Serial changes in MMRC grading across each joint (►**Tables 2** and **3**).
- Serial Mallet scores (►**Fig. 13**).
- The Gilbert shoulder score for abduction and ER (►**Table 6**).
- The Raimondi system for hand function (►**Table 7**).

Management of Secondary Elbow Deformities

Secondary deformities at the elbow joint is the second most common deformity encountered after the shoulder joint. Some of the secondary deformities commonly encountered at the elbow level include:

- Fixed flexion deformity.
- Progressive dislocation of the radial head at the proximal radioulnar joint.
- Persistent pronation deformity.
- Supination deformity.

These deformities are often unresolved or partially resolved problems, especially in untreated children reporting late. The secondary deformities at the elbow typically arise secondary to recovered strong biceps muscle amid weak or absent triceps, pronator teres, and pronator quadratus muscle. Therefore, progressive loss of elbow extension occurs, which may be associated with subluxation or dislocation of the radial head. The unopposed action of the recovered or reinnervated biceps leads to an elbow flexion deformity along with a supination deformity. This gives a characteristic attitude to the affected limb manifesting with progressive difficulties with day-to-day activities, especially eating with fork and spoons. In a large series of follow-up studies by Zancolli and Zancolli, the incidence of the typical flexion contracture at the elbow was reported to be at 62%.[41]

Thus, the corrective restorative surgical procedures are aimed at improving the attitude of the limb at the cubital level. In a large percentage of children, we treat the flexion deformity very successfully with serial plasters holding the elbow in maximum possible extension. This is changed every 2 to 3 weeks and further extension is gained with every change. Typically, by the end of the third plaster, the elbow is usually fully extended passively. This is followed by the use of a static elbow extension splint, which is worn as a night splint. We simultaneously institute antigravity triceps-strengthening exercises vigorously both to strengthen the triceps and to change the brain movement patterns, which favor persistent flexion. We also institute activities of daily living requiring elbow extension. We find very reasonable resolution of the flexion deformity with this approach in the majority of cases. In case the triceps is genuinely weak, we add a transfer of deltoid or trapezius extended by fascia lata to strengthen the triceps. However, in a large percentage it is reasonable and requires isolation (in the child's mind) and vigorous training to bring it up to function better.

The authors have so far done approximately 20 cases of trapezius to triceps transfer, with a good functional outcome of up to 140 to 150 degrees of extension. The oldest patient of

BBPP operated for trapezius to triceps transfer was of 26 years.

For cases presenting with strong triceps and relatively weaker biceps action, transfers such as long head of triceps to biceps and Steindler flexorplasty can be useful for restoring the elbow flexion.

Management of Secondary Forearm Deformities

The integrity of the proximal and distal radiohumeral joints and a well-coordinated functioning of muscles, namely, pronator teres, pronator quadratus, biceps brachii, supinator, and brachioradialis, are not always present, leading to secondary deformities and sequelae. The study by Zancolli and Zancolli in 2000[41] gave the approximated incidence of secondary forearm deformities, namely, supination contracture at 69% and pronation contracture at 29%. Forearm supination contracture is a progressive deformity that ultimately results into severe retraction of the interosseus membrane and subluxation or dislocation of the proximal radial head and/or distal radioulnar joint.

The selection of the surgical procedures depends on the pathology of the involved soft tissues and joints and the overall muscular condition. In general, a severe shoulder deformity should be corrected before any surgical procedure is attempted on the forearm. Factors playing a critical role in deciding the surgical deformity of supination contracture are the pliability of the interosseus membrane (retracted or contracted), condition of the distal radioulnar joint, and the power of the triceps muscle. Some of the procedures aimed at correction of the deformities are the release of the interosseus membrane along with pronation osteotomy of the radius. In cases where there is a reasonable range of pronosupination and radial head relocates with pronation, the release of the proximal interosseus membrane and rerouting of the biceps tendon to act as a pronator has been the choice of the authors, with a good functional outcome.

For persistent pronation with weak supination, we have done pronator teres recession and interosseous membrane release and obtained improved supination without significant loss of pronation. South Asian people (almost 2 billion individuals) eat with a supine hand and therefore this correction is very important.

In my opinion, radial head dislocation that is advanced and not reducible has very few options apart from an osteotomy and is one of the unsolved issues in BBPP. Prevention with a closely monitored child and biceps rerouting early in the pathophysiology are better options.

Management of Secondary Hand and Wrist Deformities

Zancolli and Zancolli in 2000 had reported the incidence of 27% for the ulnar deviation of the wrist and varying types of finger paralysis as a sequalae to a BBPP pathology. Frequently encountered deformities at the wrist and hand level include the following: weak or absent wrist action, particularly extension; an ulnarly deviated wrist; extended metacarpophalangeal joint or interphalangeal joint; weak or absent flexion of digits; thumb instability; and sensory disturbance. The pathophysiology remains the same: the relative imbalance in the power of different groups of muscles acting over the wrist and hand joints as well as significant co-contraction between flexors and extensors.

For ulnar deviation of the wrist, typically the thumb extensors along with wrist extensors (extensor carpi radialis longus [ECRL] and extensor carpi radialis brevis) are weak in comparison to the strong opposition by the extensor carpi ulnaris (ECU)/FCU and/or extensor digitorum communis muscle. A passive mode of correction in the form of a splint is advisable in the growing age of the patient. Once the growth of the joint is achieved, the option of wrist fusion may be given. The joint gets immobilized and fixed in a functional position of wrist extension of 20 to 30 degrees. Soft tissue restorative procedures in the form of tendon transfers can be offered in cases of extreme difficulties in day-to-day activities. The typical transfers are the FCU/ECU to ECRL.

For those children presenting with wrist drop or weak wrist extension, with relatively recovered forearm flexors, the muscle transfer procedures similar to that of radial nerve palsy (flexors to extensors) can be offered. However, one needs to realize that children with BBPP have relatively weaker donors as they are often reinnervated. Transfers are advised only after about 3.5 to 4 years to get compliance with rehab protocols with the therapy team. Splints are useful in the intervening period. In general, we get suboptimal results with tendon transfers in BBPP compared with isolated nerve injuries and we believe there is a great influence of co-contractions as well as cortical patterns involved here.

For those with weaker forearm flexors and relatively beyond the age of growth of the joint(s), arthrodesis of the joints can be offered with joints immobilized in a functional position. Biceps to flexors of fingers is an option as also free functional muscle transfers to restore finger flexion.

Conflict of Interest
None declared.

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