Current Concept in the Management of Brachial Plexus Birth Palsy

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Additional information is available at the end of the chapter
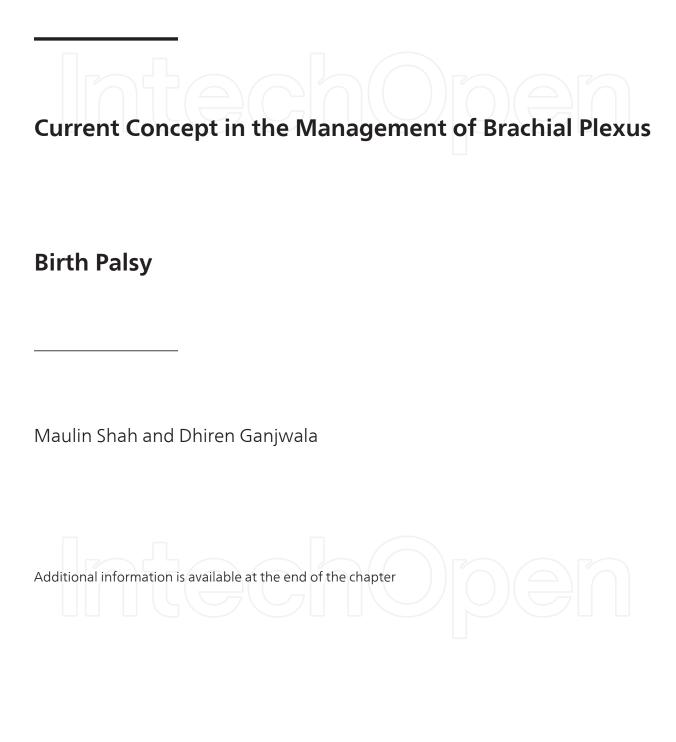
Abstract

Most infants with brachial plexus birth palsy with signs of recovery in the first 6 weeks of life will improve spontaneously to have a normal function. However, infants who fail to recover in the first 3 months of life carry the risk of long-term disability. Panplexopathy and Horner's syndrome carry worst prognosis. Plastic neural reconstruction is indicated for the failure of return of function by 3–6 months. There is no consensus about the ideal timing of intervention, and subject is still open to debate. With microsurgical reconstruction, there is improvement in outcome in a high percentage of patients. However, any of these reconstructions is not strong enough to provide a normal function. Limited shoulder abduction and external rotation are the main elements of limitations in residual brachial plexus birth palsy children. Infants with internal contracture can be benefited with Botulinum toxin injection. Internal rotation contracture release and shoulder-rebalancing surgeries for residual brachial plexus birth palsy patients in the form of tendon transfers for congruent glenohumeral joint clearly benefit patients. Patients with noncongruent glenohumeral joint would need a derotational humeral/glenoid anteversion osteotomy. All the mentioned procedures will substantially improve but not normalize the function in children.

Keywords: obstetric palsy, natural history, microsurgery, shoulder rebalancing, bony procedure

1. Introduction

The brachial plexus is a network of peripheral nerves providing innervation to the upper extremity. Brachial plexus can be injured during labor and delivery [1]. This injury can cause stretching, rupture or avulsion of some, or all, of the cervical and first thoracic nerve roots. We prefer the term 'Brachial plexus birth palsy (BPBP)' to the more commonly used term 'obstetrical brachial palsy,' which carries implications of cause.

2. Incidence

Incidence varies from region to region and depends on the obstetrical care available in the region. The incidence of 0.42 per 1000 live births (1 in 2300) was reported in United Kingdom and Republic of Ireland [2]. Incidence is estimated to be between 1.6 and 2.6 per 1000 births [3].

3. Etiology

Shoulder dystocia is the most common cause of BPBP. The neck on the side of the anterior shoulder is stretched, and this stretch injures the brachial plexus on that side, causing a varying degree of injury. The right side is more affected as the left occipito anterior (LAO) is the most common presentation during delivery. In one study incorporating 305 infants, the author reported that 60% of patients were affected on the right side and 37% on the left side [4]. The incidence of LAO position is almost 90%, and it does not explain a higher occurrence of the left side involvement, and therefore other mechanisms like intrauterine injury to plexus is also thought of. In one study, it was observed that almost half the cases they reviewed had not shoulder dystocia, and authors concluded that it could be caused by intrauterine maladaptation and not birth trauma [5]. Another hypothesis is that the posterior shoulder can get stuck on the sacral promontory and cause injury through a stretch while the baby is in the early stage of labor before shoulder dystocia takes place [5]. There is some electrophysiological evidence to suggest that BPBP could have occurred in the intrauterine period because denervation potentials are seen in EMG performed on day 1 after delivery. This is not possible if it has occurred at the moment of delivery [6]. Interestingly, BPBP is also seen following cesarean sections [7]. Bicornuate uterus is thought to cause BPBP with phrenic palsy [8].

Macrosomia has been defined as birth weight greater than 4000–4500 g. The Royal College of Obstetricians and Gynecologists reported that BPBP is a major complication associated with macrosomia [9].

Two strategies are attempted to reduce the incidence of BPBP. The first is to consider for cesarean section when fetus is macrosomic and the second is to train obstetricians regarding the effective management of shoulder dystocia. A study to compare the incidence of BPBP from 1994 to 1998 and from 2004 to 2008 did not observe significant differences in the incidence [10], although the cesarean section rate had increased from 10.7 to 18.4%. The authors of this study concluded that despite training in the management of shoulder dystocia and a rising institutional cesarean section rate, the incidence of BPBP has remained unchanged compared with 10 years earlier.

4. Natural history

Most cases of OBPI are transient and have full recovery spontaneously. However, 10 [11]–27% [12] of children have incomplete recovery. They have lifelong functional impairment due to muscle weakness, muscle imbalance, muscle contracture, bone and joint deformities.

A cohort of 70 participants (age range 7–20 years) with different severity was assessed. Functional difference between the age of 5 years and follow-up (2–15 years) was noticed. While active shoulder and hand function remained unchanged or improved, there was a marginal reduction noted in elbow function [13].

5. Early management

5.1. Immobilization

The absolute immobilization of extremity is not advised except the child has associated clavicle or humerus fracture. Limb can be immobilized in a simple sling or a Velpeau sling for extremity fracture for a period of 2 weeks. Few mothers like to apply a pin between forearm sleeve and shirt to prevent the flaccid limb to fall on a side or get compressed while feeding the baby.

5.2. Passive range of motion exercises

Passive range of motion exercises should be started immediately to prevent the development of contractures at shoulder, elbow and wrist while waiting for brachial plexus to recover. Birch et al. suggested to carry out exercises frequently in a day, preferably before every meal [14].

5.3. Splinting

Eng et al. reported using a wrist/hand cock-up splint with thumb in opposition in patients who were developing early contractures despite regular physiotherapy [2, 15]. Shoulder external rotation splint (airplane splint) can be used to prevent internal rotation contracture at the shoulder.

5.4. Electrical stimulation

Though electrical stimulation is commonly used in practice, its efficacy is not proved.

6. Follow-up examination of newborn with BPBP

A regular monthly follow-up of patients with BPBP is recommended for various reasons in the first 3 months of life. It helps in identifying the morphologic type of injury, adaptation to different therapy protocols based on the recovery, making decision about the timing of plastic neural reconstruction of plexus and to identify and address internal rotation contractures early in its course. Neuropraxic injury recovers fully by the second month and parents can be reassured. A flaccid limb with Horner's syndrome at 3 months mounts to an indication for plastic neural reconstruction [3, 16]. Waters et al. found that children with absent biceps function at 3 months had incomplete recovery [4, 17]. Children with recovering palsy after 3 months can be followed up every two monthly. The main purpose of these visits is to see the further development of power in muscle and to identify the development of early contracture

in shoulder internal contracture. Botulinum toxin injections can be considered for patients developing progressive internal rotation contracture [5, 18]. The failure to bring a cookie to the mouth without bending torso more than 45° (Cookie test) at 9 months mounts to an indication for plexus exploration and reconstruction [6, 19].

7. Investigations

7.1. Neurophysiologic investigations

7.1.1. Electromyography

The role of electromyography (EMG) in BPBP is doubtful as it frequently gives optimistic results in a severe nonresolving clinical picture. One explanation for this is the reflex-activated contraction of muscles in young children. Another explanation for this discrepancy is 'Luxury Innervation' of muscles. Until the age of 3 months, children may have polyneuronal innervation, which may give positive EMG findings in the absence of adequate nerve regeneration [7, 8, 20, 21].

7.1.2. Nerve action potentials

Although the isolated use of EMG has limitations in BPBP, according to few investigators, combining it with nerve action potentials (NAPs) may help in determining the nature and level of lesion. In selected cases, the authors have reported their ability to even differentiate axonotmesis from neurotmesis [9, 10, 14, 22].

7.2. Radiologic imaging

7.2.1. X-ray

Imaging of shoulder and upper limb can be used to diagnose the birth trauma. Chest X-ray can also give evidence of hemi diaphragm paralysis associated with C4 or phrenic nerve palsy. The diaphragm routinely lies relatively higher by two ribs level on the right side owing to liver, but in hemidiaphragm paralysis, it lies at the level of the fifth or the sixth rib.

7.2.2. Ultrasonography

Dynamic ultrasonography (USG) can help in the diagnosis of hemi diaphragm paralysis. Vathana et al. found good interobserver and intraobserver reliability in diagnosing glenohumeral deformity by ultrasound [11, 23]. Donohue et al. found measurements of glenohumeral deformity by USG reliable, but there was poor agreement between USG and magnetic resonance imaging (MRI) for diagnosing it. They questioned the use of USG as a standalone investigation for this purpose [12, 24].

7.2.3. Computed tomography scan and magnetic resonance imaging

Computed tomography (CT) myelography was considered better modality than MRI to diagnose root avulsions before a decade. Root avulsions were diagnosed based on contrast-filled

meningoceles and by following the course of anterior and posterior roots from spinal cord to the respective exit foramen. But it has the disadvantage of radiation, the need of intrathecal contrast injection and the inability to reliably diagnose extra-foraminal injuries. These issues have made MRI the modality of choice for imaging brachial plexus [13, 25].

Different MRI sequences can give excellent imaging of intra-spinal as well as extra-spinal imaging of plexus. MRI can also give a clue about nerve edema, scarring and neuroma formation [14, 26].

Waters et al. reported an MRI axial image-based classification of glenohumeral deformity. It reliably measured the amount of glenoid retroversion and the percentage of humeral head anterior to mid-scapular line [15, 27]. Correlation was found between clinical parameters and MRI findings [16, 28]. The decision about surgical intervention is made on the defined congruency of glenohumeral joint on axial MRI imaging recently.

Van der Sluijis et al. found humeral head retroversion in children with BPBP after performing simultaneous axial imaging of shoulder and distal humerus [16, 28]. However, Pearl et al. recently reported that the retroversion of humeral head on the affected side is usually less compared to the normal side and discussed its merits in surgical planning [17, 29].

8. Plastic neural reconstruction

8.1. Nerve repair

8.1.1. Basis of nerve repair

Gilbert and Tassin were the first to report the comparison of conservative and surgical treatment of brachial plexus birth palsy infants in 1984 [30]. Both the groups with a similar clinical neurologic examination were compared. Sixty-three (63%) patients achieved Mallet IV shoulder function in surgical group while maximum Mallet III recovery was seen in patients with spontaneous recovery. About 27% of conservatively managed infants who showed full spontaneous recovery had gained biceps strength of MRC grade 3 by 2 months of age. End-stage improvement was incomplete in children whose biceps recovery was delayed beyond 3 months. This chapter recommended surgical intervention at 3 months, if biceps muscle has not recovered by then.

Capek et al. [31] compared the outcome of graft repair (26 patients) versus neurolysis (16 patients) of conducting neuromas. End results were found to be more promising in nerve repair group.

In patients with global injury, achieving hand function is crucial. Pondaag and Melessy have shown improved hand function after lower trunk reconstruction in about 70% of patient [32]. Gilbert and colleagues suggested that unlike adults, infants with brachial plexopathy may have the potential to regain hand function after nerve reconstructions.

8.1.2. Decision about nerve repair and its timing

It is imperative to differentiate avulsion injuries from ruptures to make microsurgical recommendations. Microsurgery is advised before 3 months of age in avulsion injuries, as

spontaneous recovery cannot be expected. Ruptures can recover at different degrees, and there exists debate about the ideal indication and the time of surgery.

Gilbert and Tassin [30] considered the absence of return of biceps function by 3 months as an indication for microsurgery. Poorer global shoulder function was reported at 5 years and was associated with the further need of secondary surgeries in patients who regained biceps after 3 months. Although other researchers have followed more conservative guidelines, they have found that absent elbow flexion alone at 3 months can overestimate the poor final recovery and can lead to unneeded plexus exploration [17, 22]. They also documented that those patients who achieved biceps recovery between 4 and 6 months of age gained good global shoulder function with secondary interventions [34].

Clarke and Curtis routinely used return of biceps function at 9 months of age to determine microsurgical intervention [19, 33]. The child's ability to bring a cookie (the 'cookie test') to his or her mouth without bending the torso forward to more than 45° is a defining factor guiding treatment. Chuang et al. reported poor results of hand function while microsurgery was performed after infancy [35].

8.1.3. Technique of nerve repair

The spectrum of nerve surgery historically includes neurolysis, neuroma resection, and nerve grafting. Nerve transfers [36] and nerve conduits have led to an expansion of procedures available for nerve reconstruction. Neurolysis alone is no longer indicated in BPBP. Although few authors have reported good outcome in younger patients, direct repair of nerve endings is seldom performed after neuroma excision [37]. Nerve grafts replace the injured nerve tissue and connect the proximal and distal viable nerve endings. A number of donor grafts from the ipsilateral limb have been used; however, autologous sural nerve grafts are most commonly used [38]. Excision of neuroma with primary nerve grafting is the accepted management of nerve ruptures.

8.1.4. Outcomes of nerve repair

Clarke et al. demonstrated [39] that early improvements in neurolysis group did not sustain for a longer period of time. Patients who underwent nerve repair show significant improvement in Active Movement Scale scores at 4 years of follow-up. Erb's palsy grafting patients had improved function in seven movements, while the total palsy-grafted patients demonstrated better function in 11 of 15 movements.

Gilbert et al. have demonstrated promising long-term results in patients who have undergone nerve repair [40]. At 4 years of follow-up, 80% children with C5 C6 lesions showed good or excellent shoulder function, whereas it was 61% for children with C5–C7 lesions. Eighty-one percent of patients were graded good or excellent elbow functions at 8 years of follow-up.

After complete paralysis, the results of hand functions were quite encouraging. Although at 2 years, only 35% of children have a useful hand, after 8 years and several tendon transfers, 76% of children have a useful hand. This reflected that even lower-root avulsion should be repaired.

Birch et al. [14] published the results of nerve repair in 100 infants at mean postoperative follow-up of 85 months (30–152). They utilized Gilbert score, Mallet score and Raimondi score as outcome measures. Good results were obtained in 33% of repairs of C5, in 55% of C6, in 24% of C7 and in 57% of operations on C8 and T1. They suggested the utility of preoperative electrodiagnosis and intraoperative somatosensory-evoked potentials to detect occult intradural (pre-ganglionic) injury. Results of hand function were largely reassuring after complete paralysis. In spite of only 35% of children having a useful hand at 2 years, 76% of children enjoyed a useful hand after 8 years of follow-up and along with several tendon transfers. These results revealed the importance of repairing lower-root avulsions. Birch et al. summarized their results of nerve repairs in 100 infants after a mean follow-up of 85 months (30–152) by utilizing Gilbert score, Mallet score and Raimondi score as outcome measures. They obtained good results in 33% of C5 repairs, 55% of C6 repairs, 24% of C7 repairs and 57% of C8 and T1 repairs. They also recommended the use of preoperative electrodiagnosis and intraoperative somatosensory-evoked potentials in identifying occult intradural (pre-ganglionic) injury.

8.2. Nerve transfers

8.2.1. Basis of nerve transfers

When nerve root is avulsed from spinal cord, nerve repair is not possible. In such a case, nerve transfer connects extra brachial plexus or intraplexus functioning nerve to the nerve whose function is desired. Nerve transfer has an advantage that it permits faster reinnervation of muscle.

Various extraplexus sources like distal branch of spinal accessory nerve (SAN), intercostal nerves, hypoglossal nerve, cervical plexus, phrenic nerve and contralateral C7 root can be used for nerve transfer. In case of injury affecting C5–6 nerve roots, a fascicle from median, ulnar nerve, medial pectoral or thoracodorsal nerve can be used as donor for nerve transfer. These intraplexus nerves receive contribution predominantly from C8 and T1 roots. In global lesions, local transfers are unavailable so extraplexus nerves like intercostal nerve transfers are preferred.

The commonly used nerve transfers target to improve shoulder external rotation, abduction, elbow flexion, elbow extension and sensory function of the hand.

8.2.2. Transfer to augment external rotation of shoulder

External rotation is primarily carried out by infraspinatus muscle that is supplied by suprascapular nerve (SSN). SSN can be neurotized with SAN which can be considered an alluring extraplexal option for reviving shoulder function as it is a pure motor donor and it remains next to suprascapular nerve.

The outcomes of SAN to SSN have been published in multiple series. Nevertheless, different scoring systems were used in different papers for evaluating shoulder function; all of them implied improved shoulder functions. Only 14% of patients achieved more than 20° of active external rotation. Functional outcomes were measured by the Mallet hand to mouth and hand to neck scores. Ninety percent could reach the mouth (Mallet grade 3 or higher) and that 72% could reach the head (Mallet grade 3 or higher). These data suggest that even though there

is not much improvement in external rotation, there is improvement in shoulder function. Pondaag et al. [41] determined active external rotation and functional outcome score post SAN to SSN transfers in a series of 21 patients.

Grossman [42] reported result in 26 infants who underwent SAN to SSN transfer using a nerve graft, as part of the repair of a brachial plexus birth injury. At a minimum follow-up of 2.5 years, all children had shoulder function of grade 4 or better using a modified Gilbert scale.

In another study, 54 children without return of active shoulder external rotation underwent transfer of SAN to SSN. Thirty-nine of 54 patients achieved more than 20° of active external rotation by 4 months postoperatively [25].

Terzis and Kostas [43] carried out SAN to SSN transfer in 25 children with brachial plexus birth injury. They observed improvement in abduction and external rotation component of Mallet score.

Schaakxs et al. [44] studied the results of SAN to SSN in 65 patients, the age ranging between 5 and 35 months (average 19 months) and the mean postoperative observation period of 2.5 years. They assessed their results by evaluating the recovery of passive and active external rotation with the arm in abduction and in adduction. Results were better for the external rotation with the arm in abduction compared to adduction. In 71.5% of patients, they observed active external rotation between 60 and 90°. The influence of nerve transfer on glenohumeral joint dysplasia was also assessed, and this operation has a positive influence on the glenohumeral joint.

Ruchelsman [45] reported their result of the SAN to SSN in 25 infants with brachial plexus birth injuries as part of the primary surgical reconstruction. At minimum follow-up of 24 months, the mean active external rotation was 69.6°; the mean Gilbert score was 4.1 and the mean Miami score was 7.1. These results suggest good shoulder functional outcomes.

What is the effect of age on the result? It is likely that as the denervation time increases, muscle atrophy also increases. Therefore, the delay may have negative impact on the result. Three papers analyzed this point and provided contradictory suggestions [25, 43, 45].

Satisfactory passive external rotation at shoulder is mandatory for SAN to SSN transfer. Any internal rotation contracture should be rectified surgically prior to this transfer.

8.2.3. Nerve transfer for shoulder abduction

The nerve supplying one of the heads of triceps can be transferred to the axillary nerve to improve shoulder abduction. SAN to SSN transfer aids in attaining infraspinatus and supraspinatus function. Since isolated supraspinatus is a weak abductor, deltoid activity is also required for good abduction. Neurotization of axillary nerve can help in attaining deltoid function. Each of the three heads of triceps is innervated separately by a radial nerve.

Axillary nerve passes through the quadrangular space above the teres major while the radial nerve passes through the triangular space below the teres minor. Both these nerves are in close proximity, so anastomosis is possible without nerve graft.

In a small case series of five patients, McRae reported the results of this procedure in two BPBP cases [46]. Shoulder abduction was preoperatively rated at 2 and 3 by AMS. In addition

to innervations of axillary nerve, one case had SAN to SSN transfer and the other had decompression of SSN. Post SAN to SSN transfer, the respective scores were 5 and 6, illustrating antigravity shoulder abduction.

8.2.4. Nerve transfer for elbow flexion

Currently, dual transfer to innervate both biceps and brachialis is preferred for better elbow flexion strength [47]. Elbow flexion is a crucial upper limb function which can be obtained by nerve transfers to brachialis or biceps or both the muscles.

In C5–6 or C5-6-7 palsy, elbow flexion is affected; however, ulnar nerve function is normal. For such case, Oberlin transfer can be of great help for the recovery of the biceps. A fascicle of the ulnar nerve supplying the flexor carpi ulnaris muscle is cut and sutured end to end to the biceps nerve in the upper arm. Oberlin et al. [48] described this transfer in adults and Al-Qattan [49] described it for the first time for obstetric palsy in 2002.

Noaman et al. [50] reported this transfer in seven children with obstetric brachial plexus palsy. Two motor fascicles out of the ulnar nerve were transferred to the nerve to biceps. The average age at the time of operation was 16 months (range 11-24 months). The average follow-up was 19 months (range 13–30 months). Five children had biceps muscle > or = M (3) with active elbow flexion against gravity, and two children had biceps muscle <M (3).

Siqueira et al. [51] performed Oberlin's procedure in 17 infants with brachial plexus birth palsy. The mean age at the time of surgery was 12.9 months (range 4–26 months). The minimum follow-up was of 19 months. The strength of elbow flexion was measured by modified British Medical Research Council scale. Three children obtained grade 3, and 11 children had grade 4 elbow flexion power. Hand function did not deteriorate due to transfer.

Alternatively, biceps can be innervated through a fascicle of median nerve. Al-Qattan in 2014 reported their results of 10 cases of obstetric brachial plexus palsy in which median nerve to biceps nerve transfer was used [52].

Age at the time of presentation ranged from 13 to 19 months. There were seven cases of C 5–6 palsy and three cases of C5–6-7 palsy. The preoperative AMS of elbow flexion ranged from 0 to 2. At the final follow-up (1–2 years after surgery), all seven C5–6 palsy cases obtained a score of 7 out of 7 for elbow flexion. Two cases with C5–6–7 palsy had a score of 6 and 7.

8.2.5. Transfer for elbow flexion and supination

To innervate both biceps and brachialis muscles, one fascicle of both ulnar and median nerve are taken.

In a recently published paper, authors used a combined transfer in five patients and a single transfer by median or ulnar nerve fascicle in 26 patients [47]. The outcome measures were postoperative elbow flexion and supination measured with the Active Movement Scale (AMS). The mean age at surgery was 8.4 months (range 3–20 months). Patients were followed up for at least 18 months postoperatively or till they achieved full recovery of elbow flexion. Combined nerve transfer patients resulted in elbow flexion of AMS = 7 and supination of

AMS ≥ 5. Single-fascicle transfer resulted in elbow flexion of AMS ≥ 6 and supination of AMS grades 2–5. Thus, the combined transfer achieved better function.

8.2.6. Nerve transfer for elbow extension

To restore elbow extension, one possible solution is to reinnervate motor branches of radial nerve to the triceps muscle. Depending on the severity and extent of brachial plexus lesion, the radial nerve can be neurotized by means of intercostal nerves when the palsy involves the whole brachial plexus (thus, inferior roots are damaged), while in upper two or three radicular palsy, the use of fascicles of the ulnar nerve (modified Oberlin's procedure) is advisable [53].

8.2.7. Extraplexus transfer

One or two branches to the pectoralis major can be taken for the transfer so that some pectoralis major supply can be preserved and a direct repair without intervening graft can be performed to the MCN [54] or nerve to biceps [55], in the distal axilla. Intercostal nerves are an extraplexus source. They can be cut 1 cm distal to the mammary line and their stumps can be coapted directly to the MCN in the axilla.

9. Soft-tissue surgeries

Children with residual brachial plexus birth palsy frequently end up with incomplete spontaneous recovery of shoulder abduction and external rotation strength. It leads to the development of contracture of shoulder internal rotators. Progressive reduction in passive shoulder external rotation with the arm adducted is the key examination point. Studies show that the reduction of passive external rotation below neutral is associated with glenoid retroversion and humeral head posterior subluxation. Further increase in internal rotation contracture leads to flattening of humeral head and formation of biconvex glenoid, which is termed as 'false glenoid'. The aim of shoulder balancing treatment is to prevent this structural change in glenohumeral joint. Soft-tissue release to correct internal rotation contracture and tendon transfer surgeries to balance shoulder joint are possible when glenohumeral joint is congruent (Waters I–III). Once it turns non-congruent (Waters IV and V), bony procedures are offered to redirect the extremity in functional position.

9.1. Role of Botulinum toxin-A (BTX-A)

Injection of BTX-A in shoulder internal rotators temporarily denervates them while the neuronal recovery is evolving in shoulder abductors and external rotators. It is postulated that the temporary relaxation of internal rotators will help in keeping the subluxating humeral head reduced with adjunctive treatments like physiotherapy and splinting [56]. Botulinum toxin injection has also been used to treat biceps-triceps co-contraction in children with recovered palsy. Authors reported successful treatment in six patients for 18 months, where they required to inject triceps muscle twice or thrice [16, 20, 57].

9.2. Role of soft-tissue release

Subscapularis is considered as the main element responsible for shoulder internal rotation contracture. Different methods of subscapularis lengthening are described in various studies with their positive and negative aspects. Gilbert reported that isolated subscapularis lengthening was enough to balance the shoulder joint in about 50% patients in their study [21, 58]. Thus, he recommended performing tendon transfer surgery in the second stage if required.

9.2.1. Open subscapularis slide from the lateral border of scapula

Subscapularis slide was introduced by Caroliz and Brahimi [58]. It involves an incision along the lateral border of scapula, approaching scapular ridge through the interval between Teres major and Teres minor. Recurrence rate was 50–70% when it was done in isolation [21, 22, 58–60]. Grossman et al. reported no recurrence when it was coupled with tendon transfer surgery [23]. Reports of ischemic necrosis of subscapularis after lateral slide pose question of safety of artery to subscapularis owing to its vicinity to the entry point for release [24, 61].

9.2.2. Minimally invasive subscapularis release

Since 2013, we have started performing subscapularis slide from the medial border of scapula through a centimeter incision placed at the junction of the upper one-third and lower two-thirds. The arm is internally rotated and the shoulder is pressed backward to make the medial border of scapula prominent (**Figure 1**). Artery forceps are advanced to make a plane between rhomboids (**Figure 2**). A small periosteal elevator is introduced in the submuscular and extra periosteal space, and subscapularis slide is done in a clockwise fashion (**Figure 3**). A larger periosteal elevator is then introduced to release stronger muscle attachments at supero-medial and inferior angle of scapula. The arm is externally rotated to achieve 90° external rotation (**Figure 4**). Conventional conjoined tendon transfer surgery was performed after minimally invasive subscapularis release (MISR). Thirty-five patients with congruent glenohumeral joint constructed the study group and were followed up for a minimum of 18 months. Improvements

Figure 1. The arm is internally rotated to make the medial border of scapula prominent.

Figure 2. Rhomboids and trapezius are bluntly dissected with artery forceps.

Figure 3. Periosteal elevator is inserted through the wound.

Figure 4. Shoulder is externally rotated to 90°.

in Modified Mallet scores and axial MRI parameters were comparable to the open subscapularis lengthening from insertion and arthroscopic release of subscapularis. MISR was found to have the advantage of minimal learning curve, no need of arthroscopic setup, lengthening of the muscle without weakening it and the safety of the procedure [25, 62].

9.2.3. Subscapularis lengthening from insertion

Partial lengthening or z-plasty of subscapularis through anterior incision has been described. Van der Juis reported that excessive release of muscle from insertion leads to external rotation contracture and anterior shoulder instability. A subset of patients in their series required secondary internal rotation osteotomy [26, 63].

9.2.4. Arthroscopic subscapularis and soft-tissue release

Pearl et al. reported results of arthroscopic soft-tissue release with the help of a 2.7-mm arthroscope [64]. Children younger than 4 years received the release of tendinous part of subscapularis and capsulo-ligamentous structures, while the older children also had lattissimus dorsi transfer. Four of the 19 patients who received only soft-tissue release required tendon transfer surgery later. Three out of these four children had pseudoglenoid on preoperative imaging. The major issue related to arthroscopic release was the loss of internal rotation range [27].

9.3. Tendon transfer surgery to improve external rotation

L'Episcopo primarily reported muscle transfers for residual brachial plexus palsy patients in 1934 [28]. It was sub-sequentially altered by Hoffer [65]. Latissimus dorsi and teres major transfer to rotator cuff along with the release of pectoralis major has demonstrated enhanced active external rotation of 45° and abduction of 64° at 2–8 years of follow-up [66].

Waters et al. reported halting of glenohumeral deformity from progression after these transfers with extraarticular soft-tissue release [67]. Greenhill et al. compared a combined conjoined tendon transfer to isolated Teres major transfer. They found similar improvements in external rotation in both transfers but the incidence of limited midline function was found more in combined transfers. They recommended isolated Teres major transfer where preoperative midline function was in question [68].

9.4. Tendon transfer surgery to improve shoulder abduction

Cheung et al. proposed the theory of co-contraction between agonist and antagonist muscles while they are recovering, leading to the restriction of particular movement across the shoulder joint. They advocated lateral trans-positioning of clavicular part of pectoralis major along with Teres major transfer to infraspinatus. The authors reported the average gain in abduction of 77° in their cohort [69, 70]. Improvement in abduction has been reported in patients where conjoined teres major and lattissimus dorsi tendons were transferred to infraspinatus without pectoralis major trans-positioning [31].

10. Bony procedures

10.1. Humeral rotational osteotomy

Many late presenting cases may have developed glenohumeral dysplasia at the time of presentation. For such situations, humeral derotation osteotomy is one option to improve the function. Humeral derotation osteotomy does not improve the range of motion (ROM) of glenohumeral motion but reorients the arc of shoulder rotation into a more functional range which improves the function.

10.1.1. Indications of humerus osteotomy

Moderate-to-severe glenohumeral deformity (Waters Grades III–V) has restricted external rotation and abduction.

10.1.2. Surgical technique

Through a delto-pectoral approach, proximal humerus is exposed. Osteotomy is carried out just proximal to the insertion of deltoid. Distal fragment is rotated externally and is held firmly by the bone holding forceps. Before final fixation, it is confirmed that the hand can be easily placed to the mouth, occiput, perineum and midline in an effort to avoid overcorrection. This important step prevents overcorrection as well as under-correction.

10.1.3. Results

Kirkos and Papadopoulos [71] reported the results for 22 patients who underwent humerus derotation osteotomy. The authors have shown improvement in shoulder abduction of 27° and external rotation of 25° at a mean follow-up of 14 years (ranges from 2 to 31 years). An increase in forearm supination was also noted following improvement in shoulder external rotation.

Al-Qattan [72] also reported the results in a series of 15 children. At an average follow-up of 3 years, the patients demonstrated improvement in the mean modified Mallet score for hand-to-neck motion. It increased from 2.2 to 4 points.

Waters and Bae [73] used this operation in 28 patients. Osteotomy was fixed stably with internal fixation. All patients demonstrated improvements in shoulder function postoperatively, as evidenced by improved aggregate Mallet scores. The mean aggregate Mallet classification score improved from 13 points preoperatively to 18 points postoperatively.

10.2. Glenoid anteversion osteotomy

Hopyan and colleagues combined glenoid neck osteotomy with soft-tissue rebalancing surgeries [74]. The purpose of their study was to see whether glenoid reorientation converts a shoulder joint from one where tendon transfer and soft-tissue release cannot restore the active motion to the one where it can. They found improved Mallet scores for global external rotation and hand-to-neck movements. Waters schema was found improved from average of 4.3 preoperatively to 1.6 postoperatively. This novel technique was proposed as an alternative to humeral derotation osteotomy.

11. Conclusion

Results of BPBP have improved substantially by various advances that have taken place in the last four decades. We can achieve functional improvement in a majority of cases, but still most cases do not achieve a full functional recovery. Improvement in the surgical technique will lead to better outcome. On the other hand, efforts to prevent this condition will also yield greater benefit.

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