Management of shoulder problems following obstetric brachial plexus injury

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ABSTRACT

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Obstetric brachial plexus injuries are common, with an incidence of 0.42 per 1000 live births in the UK, and with 25% of patients being left with permanent disability without intervention. The shoulder is the most commonly affected joint and, as a result of the subsequent imbalance of musculature, the abnormal deforming forces cause dysplasia of the glenohumeral joint. In the growing child, this presents with changing pattern of pathology, which requires a multidisciplinary approach and a broad range of treatment modalities to optimize function.

INTRODUCTION

Obstetric brachial plexus injuries (OBPI) are common, with an incidence of 0.42 per 1000 live births in the UK [1], and with 25% of patients being left with permanent disability without intervention [2]. The shoulder is the most commonly affected joint and, as a result of the subsequent imbalance of musculature, the abnormal deforming forces cause dysplasia of the glenohumeral joint. In the growing child, this presents with changing pattern of pathology, which requires a multidisciplinary approach and a broad range of treatment modalities to optimize function.

PATHOLOGY

Patho-anatomy

Risk factors associated with injury include shoulder dystocia, a high birth weight (>4 kg), prolonged labour, breech alignment and forceps delivery [1]. The mechanism of injury is a forced lateral flexion of the cervical spine, resulting in injury initially to the upper cervical roots (C5–C7) causing an Erb's palsy and, in more severe cases, the entire brachial plexus (C5–T1). As a result of this mechanism, isolated lower root injuries (C8–T1, Klumpke's palsy) do not tend to occur in OBPI. The severity of injury has been classified by Narakas [3], in which the most common pattern (group 1) involves only the C5/6 roots presenting with shoulder abduction and elbow flexion weakness. In group 2, the C7 nerve root is also involved with associated wrist drop. These groups have a higher rate of spontaneous recovery. Group 3 is complete

paralysis, and group 4 is also associated with Horner's syndrome; both of these have a worse prognosis.

The binding of the nerve roots to the axial skeleton by connective tissue is important. This is greater in the upper roots, resulting in a more distal, post-ganglionic nerve rupture compared to the pre-ganglionic avulsion, directly from the spine, seen in lower roots. Surgically, this is important because the presence of a root stump can be used in the neonatal period for nerve grafting (Fig. 1), which has connotations on surgical options and prognosis [4].

Horner's syndrome is a consequence of sympathetic neurone involvement at the level of T1. It signifies a severe, total plexus injury and presents with dry skin, miosis, ptosis and enophthalmos. Being a consequence of more severe injuries, it may also be associated with phrenic nerve involvement, which is important because this poses a higher anaesthetic risk and also limits the use of intercostal nerves as potential nerve donors.

Muscle imbalance

The shoulder girdle is a highly mobile unit, controlled by muscles that are innervated from branches derived from all regions of the brachial plexus (Fig. 2). It is widely accepted that the relative weakness of the external rotators lead to an internal rotation contracture; however, other postulated theories include direct trauma to the proximal humeral growth plate or traumatic fibrosis of the subscapularis muscle [5].

OBPI lesions involving the upper roots in isolation (Narakas 1 and 2) cause weakness to the supra- and infra-spinatus muscles

Fig. 1 Patterns of pre- and post-ganglionic injury depend on the nerve root level.

Fig. 2 Schematic diagram of the brachial plexus illustrating the branches that involved with shoulder movement. DSN, dorsal scapular; SCN, supra-scapular; LPN/MPN, lateral/medial pectoral; MCN, musculocutaneous; USSN/LSSN, upper/lower subscapular; TDN, thoracodorsal; A, axillary.

(because of involvement of the supra-scapular nerve) and the rhomboids (dorsal scapular nerve palsy) leading to weakness of external rotation and abduction, with unopposed action of the sub-scapularis (supplied by the upper and lower subscapular nerves) leading to an internal rotation contracture.

Shoulder abduction and deltoid function are often abnormal in these patients. However the axillary nerve is supplied from multiple levels and the deltoid muscle belly often appears healthy at the time of surgery [6], and it is more likely the deltoid dysfunction is a result of lack of synergistic function of supraspinatus.

Teres minor (also supplied by the axillary nerve) may have some function in Narakas 1 or 2 injuries, although it is too weak to oppose the action of subscapularis. The pectoralis muscles may also be weak, although their supply from both the medial and lateral

Fig. 3 Glenoid and humeral dysplasia associated with obstetric brachial plexus injury.

pectoral nerves ensures that some function remains in isolated upper root injuries.

In total plexus injuries (Narakas 3 and 4), the lower root involvement not only leads mainly to hand weakness, but also to increased weakness of the deltoid, subscapularis and pectoralis muscles. This results in a flail shoulder, although with less internal rotation contracture.

Glenohumeral dysplasia

The stages of glenoid dysplasia were described by Pearl and Edgerton [7], and this was correlated with passive external rotation by Kon et al. [8], Table 1.

The internal rotation muscle imbalance leads to progressive flattening and retroversion of the humeral head. The glenoid becomes bi-concave, with a false postero-inferior facet, which is lined by hyaline cartilage [6]. With time, the humerus dislocates posteriorly creating a pseudoglenoid, in which the humeral head articulates with the joint capsule overlying cortical bone (Fig. 3).

Secondary adaptive changes occur with overgrowth of the acromion and lateral clavicle. The coracohumeral and coracoacromial ligaments become elongated and tight, further restricting external rotation [6]. Reduction and rebalancing of the joint stimulates appropriate remodelling, particularly in younger children [9].

ASSESSMENT

Accurate assessment of the brachial plexus is difficult and this is complicated further in a neonate or anxious young child. The child should be relaxed, warm and recently fed, with repeat assessments to ensure accuracy. In the infant, differential causes of a flail limb such as clavicle or humeral fracture and septic arthritis should be excluded.

The Toronto score [10] assesses neonatal shoulder abduction, elbow flexion and wrist, digit and thumb extension, with normal function scoring 2, reduced function scoring 1 and no function scoring 0. In older children, the Mallet score [11] is a more comprehensive clinical assessment of shoulder function and, together with degrees of external rotation and abduction, is a commonly used outcome measure.

Assessment for surgical planning includes differentiating between supra- versus infra-clavicular involvement to guide the surgical approach. In all cases, access to the upper roots is

Fig. 4 Assessment of the glenoid in a normal and a dysplastic shoulder. (A) Glenoid version relative to the spine of the scapula. (B) Amount of humeral head lying anterior to the midline of the glenoid (posterior humeral head articulation).

required, utilizing a supra-clavicular approach. In more severe total plexus injuries, an extended approach involving an additional infra-clavicular approach is also required. Differentiating between pre- and post-ganglionic injuries clinically is difficult at the best of times, and even more so in neonates. Awareness of the common patterns of injury is important: isolated upper plexus injuries (Narakas 1 and 2) are usually post-ganglionic (and so graftable), whereas total plexus (Narakas 3), particularly if Horner's syndrome is present (Narakas 4), are more likely to be pre-ganglionic, and need extra-plexus nerve transfers. With this in mind, it is important to assess muscle function from potential donor nerves (such as spinal accessory nerve and the intercostal nerves).

Dynamic chest fluoroscopy can be used to assess phrenic nerve function. Electromyographic studies and a computed tomography (CT) myelogram attempt to assess the involvement of the dorsal root ganglia, although they are frequently unhelpful. Surgical exploration is more beneficial because it enables a direct assessment of the injury and nerve stimulation, and is often combined with neurolysis and primary nerve reconstruction. Total plexus involvement, pre-ganglionic injury, Horner's syndrome or a Toronto score of < 4 at 3 months are all indications for surgical exploration. Return of biceps function at 3 months is an often-quoted good prognostic sign [12]; however, it is falsely positive in 12% of cases [10].

In a child aged < 18 months, as a result of the lack of ossification of the proximal humerus, clinical examination is the most useful assessment of shoulder. Ultrasound provides dynamic assessment of instability, although it is less good for assessment of dysplasia, which is better evaluated by arthrography and examination under anaesthesia.

CT and magnetic resonance imaging are the best imaging modalities in the older child, although the former carries the risk of ionizing radiation [13]. Using axial slices on a CT scan, glenoid version can be measured relative to the spine of the scapula and is normally 10–20° retroverted (Fig. 4, angle A). Joint reduction may be assessed using the posterior humeral head articulation (PHHA), comprising a measure of the percentage of the humeral head anterior to the middle of the glenoid fossa (normally 50%, Fig. 4, ratio B) [14].

MANAGEMENT

Primary neurological reconstruction

Initial management involves urgent referral to specialist for appropriate triage and assessment, followed by appropriate neurological reconstruction. This has a narrow window of opportunity, with evidence suggesting that intervention within 3 months improves outcome [4], especially in total plexus involvement. From birth, parents should perform supervised stretching exercises to prevent contractures, which may be augmented by splinting.

Microsurgical options in the neonatal period include neurolysis and repair of the injured nerve to its original or an alternative nerve stump (direct and indirect neurotization). Potential donor nerves must be functional and expendable and may be either intra-plexus (the C5–7 stumps if intact) or extra-plexus (spinal accessory nerve, intercostal nerves and even the contra-lateral C7 root). Neurotization may be facilitated with sural, saphenous or artificial nerve grafts.

Typical nerve transfers in Erbs palsy would include using a branch of the spinal accessory nerve to reconstruct the supra-scapular nerve with nerve grafting of the upper and posterior trunks to the C5/6 stumps. In total, plexus involvement the trunks are repaired to the proximal stumps if present; however, because the lower roots often have pre-ganglionic injuries, extra-plexus transfers are often necessary.

Proximal shoulder function tends to recover better than hand function, with evidence suggesting that more severe injuries improve if surgery is performed within 3 months [4].

Shoulder reduction and rebalancing procedures

After the age of 2 years, the results of nerve transfer procedures are poor and a different approach to management is required. The aims are to reduce the glenohumeral joint and rebalance the shoulder to promote remodelling and restore function [9]. The fundamental principles are to release tight anterior structures, ensure a concentric reduction and restore external rotation power.

Reduction

The primary structure causing anterior tightness is the sub-scapularis muscle with secondary contractures of the major glenohumeral ligament, inferior glenohumeral ligament and the rotator interval. These can be released through an open approach, although good results can also be achieved arthroscopically using a 2.7-mm scope [15]. Arthroscopic reduction causes less scarring and enables assessment of the whole joint. It is advocated that an isolated arthroscopic release is all that is required in children aged < 3 years, with 75% having a good outcome. In children aged > 3 years and cases of recurrence, they recommend combining the procedure with a latissimus dorsi transfer to improve external rotation power.

They demonstrated external rotation to be improved to 80° following these procedures, with poor outcomes only seen in the oldest children. Kozin et al. found similar improvements in both radiological (glenoid version and PHHA) and clinical outcome measures (external rotation and abduction) following arthroscopic reduction [14].

Fig. 5 Restoration of external rotation using a teres major or latissimus dorsi transfer.

Fig. 6 Management of biconcave glenoid using bone block or opening wedge osteotomy.

Rebalancing

A number of studies have examined the effect of restoring external rotation power to restore function or correct shoulder dysplasia. The most commonly transferred muscle is the latissimus dorsi (with or without the teres major), which are brought from their distal anterior insertion to a proximal posterior position onto the greater tuberosity, thereby counteracting the internal rotation force of the sub-scapularis and depressing the humeral head in a similar fashion to the supra-spinatus (Fig. 5).

Numerous studies have shown an improvement in both shoulder function and the degree of glenoid dysplasia following such tendon transfers. Table 2 shows the radiographic outcomes of a total of 81 patients in three studies [14,16,17] at a mean of 48 months. Meta-analysis reveals that the glenoid retroversion improves by a mean of 5 °C to 20 °C and that the humeral coverage (PHHA) improves from 9% coverage to 37% coverage.

Table 1 Progression of glenoid dysplasia

Stage	Pearl classification	Passive external rotation (°C)
1	Concentric and reduced	0
2	Glenoid flattening	–10
3	Biconcave glenoid	–10
4	Pseudo glenoid	–20

Table 3 shows the functional outcome of 198 patients in 7 studies [14,17–22] following tendon transfers. Meta-analysis reveals that at a mean of 49 months, abduction improves by a mean of 50 °C to 137 °C, and passive external rotation improves by a mean of 53 °C to 73 °C.

Although this appears promising, some caution should be taken because the study with the longest follow-up [17] demonstrated significant deterioration over time. Although they demonstrated a 62 °C improvement in passive external rotation at 1 year, this diminished to a 23 °C improvement at 10 years. This highlights the dynamic nature of the deformity in the skeletally immature and need for careful review.

Bony procedures

A number of bony procedures have been described to address established glenohumeral dysplasia, which may occur despite early neurological reconstruction [23], (Fig. 6). These are usually performed in an older child in whom there is a fixed deformity associated with torsional deformities of the humerus and/or dysplasia of the humeral head or glenoid.

The main problems in the humerus are flattening of the humeral head and excessive retroversion. It is difficult to refashion the shape of the head, and the main way of managing humeral head dysplasia is to contain the head in a concentric articulation from an early age to allow remodelling to occur [9].

For humeral retroversion, a proximal de-rotation osteotomy is indicated in cases of >40 °C retroversion [6]. Correcting the excessive humeral head retroversion improves the glenohumeral articulation; however, it can result in loss of external rotation of the arm, and so should be balanced with placing the arm in the most functional arc of movement [24,25]. A derotational humeral osteotomy is best performed proximal to the deltoid insertion in

Table 2 Effect of tendon transfer on glenoid dysplasia

Study	Patients	Follow-up (months)	Transfer	Glenoid retroversion*	PHHA*
Kozin et al. [14]	24	36	LD + TM	25 (–3)	35 (6)%
Waters et al. [16]	25	43	LD + TM	17 (5)	37 (7)%
Cohen et al. [17]	32	60	SS rel ± LD	18 (11)	39 (14)%
	Total	Mean [†]		Mean [†]	Mean [†]
	81	48 m	–	20 (5)	37 (9)%

*Glenoid version in degrees and posterior humeral head articulation (PHHA) as a percentage with improvement compared to pre-operative values in brackets.

[†]Mean calculation based on the number of participants in each study.

LD, Latissimus Dorsi transfer; TM, Teres Major transfer; SS rel, Subscapularis release.

Table 3 Effect of tendon transfer on shoulder function

Study	Patients	Follow-up (months)	Transfer	Abduction*	External rotation*
Ozkan et al. [18]	70	38	LD + TM	133 (60)	81 (59)
Aydin et al. [19]	46	41	LD + TM	140 (41)	82 (49)
Cohen et al. [17]	32	114	SS rel ± LD		13 (23)
Kozin et al. [14]	24	24	LD ± TM	151 (35)	18 (21)
Edwards et al. [20]	10	36	LD + TM	136 (64)	64
Demirhan et al. [21]	10	24	LD + TM	135	70
Vallejo [22]	6	54	LD + TM	109 (42)	72 (21)
	Total	Mean [†]		Mean [†]	Mean [†]
	198	49 m		137 (50)	73 (53)

*Abduction and external rotation in degrees with improvement compared to pre-operative values in brackets.

[†]Mean calculation based on the number of participants in each study.

LD, Latissimus Dorsi transfer; TM, Teres Major transfer; SS rel, Subscapularis release.

Table 4 Summary of key problems and management principles

Age	Pathology	Potential problems	Management
0–3 months	Neuropraxia versus neurotmesis	Awareness Differential diagnosis Prevent contractures	Refer to specialist Exclude infection/fracture Physiotherapy
3–24 months	Irreversible neurological injury	Window of opportunity Surgical planning	Surgical exploration, neurolysis and repair Assess donors and approach
1–3 years	Internal rotation imbalance	Contracture	EUA + arthrogram Arthroscopic release
3–8 years	Glenoid dysplasia	Recurrent dysplasia	Arthroscopic release + lat dorsi transfer
> 8 years	GHJ dislocation	Severe dysplasia Less remodelling potential	Glenoplasty

EAU, examination under anaesthesia; GHJ, glenohumeral joint.

cases of established glenoid dysplasia, although before skeletal maturity to maximize the chance of remodelling [26].

Management of glenoid dysplasia is difficult. A traditional approach is a bone block augmentation of the posterior glenoid, which aims to prevent posterior subluxation/dislocation. However, because this does not fully restore joint congruity and **as** does not provide hyaline cartilage articulation, it can still lead to arthrosis and so should be considered a salvage procedure.

Another approach is to perform a subarticular opening wedge osteotomy of the posterior facet of a biconcave glenoid to correct the dysplasia and stabilize the shoulder [27]. This is usually combined with soft tissue rebalancing procedures and correction of humeral torsional problems. All 29 patients in the series of Di Mascio et al. (mean age 5 years at operation and 34 month follow-up) achieved glenohumeral stability and demonstrated an improvement of abduction from 132 °C to 156 °C, and external rotation from –1 °C to 53 °C [27]. Other studies have described similar improvements by conducting a derotation osteotomy of the scapular girdle [28].

Shoulder arthrodesis is a salvage procedure that is occasionally indicated in the skeletally mature. It is usually used in total plexus injury in which there is a painful, flail shoulder, with best

outcomes seen when the rest of the shoulder girdle muscles are functioning (trapezius, levator scapular, serratus anterior and rhomboids). Wong et al. obtained union in all their six cases of shoulder arthrodesis secondary to brachial plexus injury, achieving a mean improvement of flexion/abduction of approximately 50 °C, and all but one patient having relief of pain [29]. Pruitt et al. described 17 paediatric cases of shoulder arthrodesis secondary to neurolomuscular problems, with six for OBPI [30]. They suggest that excessive flexion or abduction can cause cosmetic concerns for the patient, although Sousa et al. noted that abduction > 35° and flexion > 30° had better functional outcomes, and that internal rotation should not exceed 45 °C to maintain the ability to bring the hand to the mouth [31].

SUMMARY

OBPI present a unique set of problems in the shoulder that require a broadly skilled team to best manage. A detailed knowledge of the anatomy of the brachial plexus and the kinematics of shoulder function is essential to understand how OBPI can best be managed. In the neonatal period, early microsurgical reconstruction of the injured plexus is advocated and, in older children, glenohumeral joint reduction with soft tissue rebalancing and restoration of

bony architecture is also recommended. This is summarized in Table 4.

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