Published online: 2020-01-15

Special Article

Primary repair of the obstetrical plexus

Alain Gilbert
Institut de la Main, Paris, France

Address for correspondence: Dr. Alain Gilbert, Institut de la Main, 6 square Jouvenet - 75016 - Paris, France.
E-mail: agilbert@wanadoo.fr

INTRODUCTION

The name Obstetrical Palsy was given in 1872 by Duchenne de Boulogne (La Paralysie Obstetricale) in his book: De l'Electrisation Localisée.[1] He recognized the traumatic origin of the lesion, although some controversy has existed until recently. Modern series in which operative exploration has been carried out have confirmed the pathology.

The aetiology is a tearing force due to traction on the head or arm. There are two basic types of lesion:

1. Overweight babies (over 4 kg) with vertex presentation and shoulder dystocia who require excess force by traction, often with forceps or ventouse extraction for delivery. This results in upper plexus injury most commonly to the C5 and C6 and occasionally the C7 roots but never the lower roots [Figure 1].
2. Breech presentation usually of small (under 3 kg) babies requiring excessive extension of the head and often manipulation of the hand and arm in a fashion which exerts traction on the upper roots as well as on the lower roots. This may cause rupture or avulsion of any or occasionally all of the roots [Figure 2].

CLINICAL PRESENTATION

The initial diagnosis is obvious at birth. After a difficult delivery of an obese baby by the vertex presentation or a small baby by the breech the upper extremity is flail and dangling. A more detailed analysis of the paralysis pattern of the various muscles of the upper extremity is not necessary as the picture will change rapidly. Examination of the other extremities is important to exclude neonatal quadriplegia or diplegia. Occasionally birth palsy may be bilateral. Forty-eight hours later a more accurate examination and muscle testing can be performed. At this stage it is usually possible to differentiate the two types of paresis:

1. The Erb-Duchenne type paralysis of the upper roots. The arm is held in internal rotation and pronation. There is no active abduction or elbow flexion [Figure 3]. The elbow may be slightly flexed (lesion of C5-C7) or in complete extension (lesion of C5-C6). The thumb is in flexion and sometimes the fingers will not extend. As a rule the thumb flexor and the flexors of the fingers are functioning. The pectoralis major is usually active, giving an appearance of forward flexion of the shoulder. There are no vasomotor changes or gross impairment of distal sensation.
2. Complete paralysis: The entire arm is flail and the hand clutched [Figure 4]. Sensation is diminished and there is vasomotor impairment giving a pale or even 'marbled' appearance to the extremity. Often a Horner's sign is present on the affected side.

A shoulder X-ray should be taken to eliminate fracture of the clavicle or the upper humerus, which can occur in association with the paresis. Occasionally a phrenic nerve palsy can be detected by fluoroscopy.

The clinical development during the first month is variable and many pareses will recover during this stage.[2] However, Wickstrom et al[3] reported that only 10% of total palsies recover to any useful extent. These patients should be carefully evaluated at the age of 3 months clinically, electromyographically and by cervical myelography. Gentle physiotherapy should be used during this recovery period to minimize the development of contractures while awaiting spontaneous recovery. At this stage

complete paralysis with Horner's sign will remain unchanged and early operation should be considered in these babies at 3 months.

Paralysis of the upper roots may show spontaneous recovery during the first 3 months. These babies should be treated with physiotherapy and assessed clinically and electromyographically by the age of 3 months.

SPONTANEOUS RECOVERY

The literature reports varying rates of spontaneous recovery from 7% to 80%. Useful guidelines are given in the thesis of Tassin,[4] who came to the following conclusions:

1. Complete recovery is seen in those infants showing some contraction of the biceps and the deltoid by the end of the first month and a normal contraction by the second month.
2. No infant in which neither the deltoid nor the biceps contract by the third month can be expected to obtain a good result. Testing the deltoid can be difficult. As a result assessment of the biceps is the most reliable indicator for operative intervention. If there is no evidence of any recovery in the biceps by the end of the third month operation is indicated. Clinical assessment is more reliable than electrical testing. If surgery is not undertaken some recovery will continue to take place spontaneously, but it is likely to be less satisfactory than that following surgery.

Figure 1: A typical C5-C6 paralysis

INDICATIONS FOR OPERATION

If recovery of the biceps has not begun by 3 months the prognosis is poor and surgical repair of the plexus is indicated. The following clinical situations pose particular problems:

1. Complete palsy with a flail arm after 1 month, particularly with a Horner's syndrome, will not recover spontaneously and is a prime candidate for surgery. These babies are best treated by early operation at the age of 12 weeks. Absence of recovery of the hand is the most important even with recovery of the shoulder or elbow.
2. Complete palsy of C5 and C6 occurring after breech delivery with no sign of recovery by the third month have to be explored. In these cases, avulsion injuries of the upper roots is common.
3. The commonest C5, C6 and sometimes C7 palsies almost always show some sign of recovery, which can be misleading, and which has in the past encouraged

Figure 2: Complete paralysis

Figure 3: The Horner's sign

a conservative approach. If, however, after careful examination the biceps is completely absent at 3 months, surgery should be considered.It is important to look for Biceps recovery but not elbow flexion which can be given by the Brachioradialis muscle. Great difficulty arises when infants are seen late, i.e. towards the 6th to 8th month, and show minimal recovery of biceps function. The parents are often encouraged by the beginning of recovery and will not accept the idea of an unsatisfactory final result. Under these conditions it is difficult for the surgeon to advise surgery that cannot promise a definitive result. In order to avoid this situation it is important to try to make decisions by the third month.

When the operation has been decided, the patient should be explored in depth in order to minimize any operative or anesthetic risks and to predict as precisely as possible the lesions.

PRE-OPERATIVE EXPLORATIONS

EMG is done at this stage. Although it rarely gives precise indications on the extent of the lesion and the quality of recovery, it may be very useful in predicting avulsion injuries. The association with evoked potentials will even give more precisions. The avulsion of an isolated root in the central or lower part of the plexus is not clearly showed by EMG. Association with a Horner's syndrome will be almost pathognomonic[5] of T1 avulsion.

However, in upper root avulsions, especially after breech delivery, the EMG is very clear, showing a total absence of muscle reinnervation. This absence, in conjunction with the obstetrical record will almost certainly confirm the avulsion at exploration.

Some authors[6] have developed methods of exploration, which could give a better precision in the prognosis of the obstetrical lesions.

Conventional radiology is necessary in order to assess the possibility of diaphragmatic paralysis, which can sometimes occur at birth concurrently with the plexus lesion. It is important to know the status both medically and legally before the operation.

Myelogram and CT myelography

For many years we used to do myelograms in our patients.[7] The results were not entirely satisfactory with a large number of false positives and false negatives. The advent of CT myelography has changed the situation and gives precise information. However, the indications of CT myelography are rare as there is little information that we will not be given by direct observation during operation. Furthermore, this examination needs a general anesthesia in a neonate.

It can be useful mostly in upper root lesions suspected of avulsion. In these cases the roots are often in place and the operative diagnosis is difficult. The myelogram may be very useful in these cases.

Magnetic Resonance Imaging

MRI has been used extensively for brachial plexus. Although it may give excellent results in adults, we feel that it is unreliable in children. With the improvement of the surface antennas, this will probably change but at the moment the necessity of general anesthesia and the lack of information lead us to prefer, when necessary, the CT mylogram.

Surgical approach

The child is in a supine position, with a small towel rolled and placed under the superior spine and scapula, in order to allow a large opening of the neck and thoraco-brachial area. The head is turned completely to the opposite side with the neck in slight hyperextension. The neck and upper thorax are prepped, as well as the entire upper extremity and both legs and knees. No tourniquet is used.

For several years, we have used preoperative evoked potentials but we have stopped now, as the results were quite unpredictable and the variations due to anesthesia or temperature too large.

The incision will vary according to the type of injury. For C5 C6 or C5 C6 C7 lesions, we use only a supraclavicular triangular flap based on the posterior border of the S.C.M. muscle and the superior aspect of the clavicle.

In complete palsy, the incision extends distally over the delto pectoral groove.

The skin is infiltrated with a 1/1000 solution of adrenaline. It usually raises the heart rate by 15 or 20/min. In order to obtain a good efficiency and a bloodless field, it is best to wait for the rhythm to return to its pre-injection

level.

Approach

After supra-clavicular incision, the skin and sub-cutaneous fat are lifted and held with a stay suture. If the SCM muscle insertion on the clavicle extends laterally, it may be necessary to de-insert its lateral part.

The plexus is covered with a thick layer of fat and multiple ganglions. This layer is lifted from its medial position, over the jugular vein and reflected laterally. The field is then stabilized with a self-retaining retractor.

To approach the plexus, it will be necessary to cut the Omohyoid muscle and divide the transverse cervical vessels.

The plexus is then visible and the first move is to separate and protect the phrenic nerve. In following it upwards, C5 is found automatically as the nerve has a connection with the root in almost every case.

The Anterior Scalene is retracted gently and the roots can be seen and dissected free. As they are followed distally, the neuroma is obvious, hard, surrounded with scar, reaching often the superior part of the clavicle.

The suprascapular nerve is systematically dissected free as well as the long thoracic nerve and its branches when the neuroma is lifted.

Assessment of the extent of the lesion, the quality of the roots and the length of the defect can then be done.

When the infra claviclar approach is needed, the second flap is lifted and sutured to the skin of the thorax. The Pectoralis Major is de-inserted from the inferior part of the clavicle and retracted. The retractor will also take the pectoralis minor, demonstrating the upper, middle, and lower trunks and their branches.

A large periosteal flap is designed on the clavicle with a lateral pedicle. It is elevated and the posterior periosteum elevated. The clavicule is then cut obliquely, using electric saw. Using a 12G-K wire, holes are drilled into the two opposite pieces of bone. Once they are elevated, the posterior periosteum is sectioned laterally, making another flap. It is necessary at this stage to cut also the Subclavian muscle.The two parts of the clavicle are held with a self-retaining retractor and the whole plexus becomes visible.

Every trunk is dissected and isolated. Care is exercised not to injure the subclavian artery and vein.The lower trunk has to be followed up to its division from C8 and T1 and the two nerves dissected up to the foramen. This may be dangerous due to the proximity of the vessels. It is however absolutely necessary and no decision can be taken without appraisal of the roots at the level of the foramen.

Intra operative stimulation may be of help, especially when there is a suspicion of avulsion (Horner, EMG) and the root is found into the foramen. In these cases, if there is no response to direct stimulation, the root will be considered as avulsed, cut at the foraminal level and grafted.

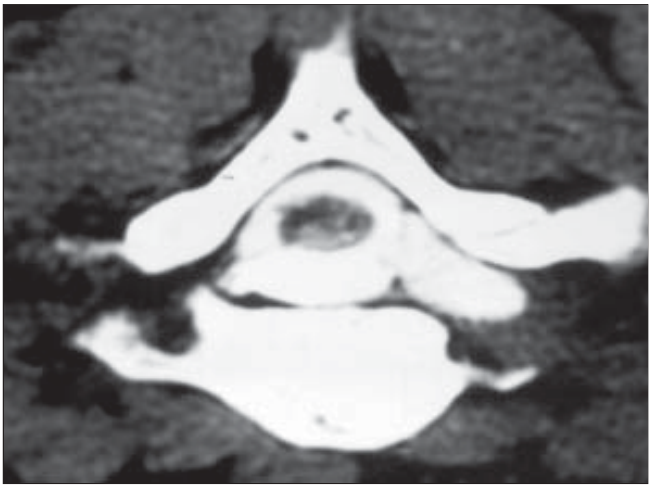

Figure 4: Myelo-scan showing a large meningocoele

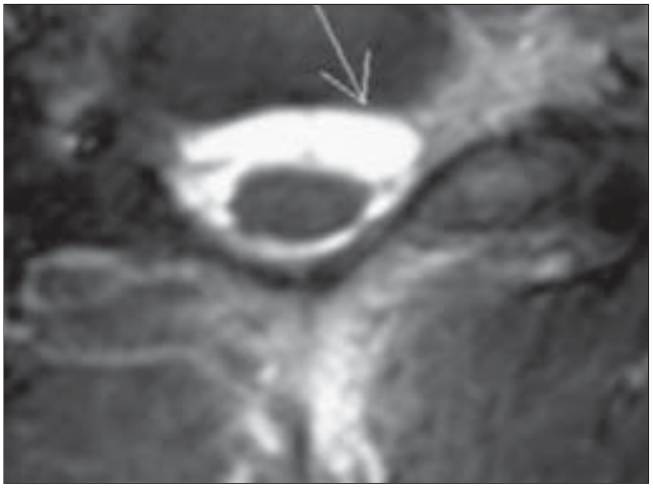

Figure 5: The MRI is more difficult to interpret

At the beginning of our experience, we have left several of these roots in place, with the hope of some recovery if there was no visible proof of avulsion. We always regretted it and these patients went on to get poor results in the hand.

The situation is different in the upper roots, after breech delivery, as we shall see later.

Repair of the lesions

The neuromas are excised largely and systematically. There is no point in doing neurolysis if the clinical situation has led to a surgical exploration. Neurolysis does not provide improvement[8] and there are very few indications left.

When the roots are avulsed, the ganglion is often found with its small motor branch. This part should not be sacrificed, as sometimes only one or two roots are available for grafting. Directing the grafts on the small motor root will allow the grafting of all the plexus which otherwise could not be repaired due to the discrepancy between the donor roots and the large volume of the trunks to graft.

These repairs done directly on the motor component have given some very satisfactory results.

Harvesting the nerve grafts

In the babies we use only the sural nerve and on rare occasions the superficial cervical plexus.

We feel that the use of trunk grafts as for instance the vascularized ulnar nerve should never be done as it could sacrifice the chances of recovery in the hand.

The sural nerves are harvested by posterior zigzag incisions, after adrenaline injection.The nerve is too fine to be taken by separate incisions and its anatomy[9] precludes the use of a stripper.

Some authors have proposed to harvest the sural nerve endoscopically. Capek[7]has applied the technique to pediatric cases. It is appealing as the scars of this area are usually visible. The drawbacks are the necessity to start the operation in a prone position and then turn over the patient and mostly the length of the procedure, which in some cases took several hours.

Preparing the nerve grafts

The sural nerve is, in most cases Y- shaped (De Moura, 1984)[9] and it is important to keep as much length as possible.

The defect between the two ends is measured at the plexus level and the grafts (usually both legs) are divided on the table, performing a cable. We feel that the discussion about the direction of the grafts is not important; if one chooses to use the grafts in an anterograde direction, there will be a loss of axons through the multiple branching; If it is used in a retrograde manner, the distal part will have many empty conduits. There has never been any proof that one way or another was better.The grafts are cut and placed on the table for their final organization. The end of each cable bundle is then glued as to make a trunk and this trunk is sharply cut transversally.Then, in a bloodless field, the graft is placed at once between the plexus extremities and simply glued in place.

We started gluing the nerves almost 20 years ago, immediately after Narakas. The fibrin glue has proven to be safe in our hands and has given better results than sutures. We use only glue without any sutures. It is used also with end-to-end and end-to-side anastomoses.

End-to-side anastomoses

Several authors have shown the feasibility and effectiveness of end-to-side anastomoses in the experimental area. Very few reports show yet the results in the clinical area.

There are cases where there is no simple solution to repair the plexus:

- In isolated avulsion of one or two roots. This may occur especially with breech delivery. The alternative may be a complicated extra-plexual neurotization.
- In repair of extensive lesions, when there is a lack of donor area (rupture of a small C5 avulsion of C6 C7 with intact C8 T1). A relatively less important root (C7) may be sutured to C8.
- In complete upper roots avulsion, the neurotization of musculo-cutaneous nerve by the ulnar trunk (Oberlin, 1994) may be done as end to side instead of sacrificing a bundle from the ulnar nerve.

The recipient root is dissected and the perineurium is split longitudinally. No dissection is done inside the nerve. The end of the avulsed nerve is placed into the opening and simply glued. It should hold without tension and we do not use sutures even in this situation.

If it is proven that the results of end-to-side anastomosis equal those of neurotizations, its simplicity will make it a valuable tool.

Neurotizations

A large number of extraplexual neurotizations have been described in the literature, mainly for adults.

In the obstetrical palsy, we have used many of them but the development of multiple intraplexual repairs and of the end to side anastomoses have reduced their indications.We are reluctant to use the intercostal nerves; especially in complete paralysis, since we studied the ventilatory capacity in these children and showed that the extensive use of intercostals would decrease severely this capacity.[20] This was confirmed recently by Gu .[14]

The occipital nerve is very small and too far from the plexus itself.

We still use the terminal part of the spinal accessory nerve. It can be found in the wound and its size allows repair or grafting of a suprascapular nerve or a musculo-cutaneous nerve. It should be taken after its division, in order not to affect the trapezius muscle.

We have used many times the medial nerve of Pectoralis major. It is easy to find, of good size and can be sutured end to end with the musculo-cutaneous nerve. It is very useful in cases of upper roots avulsion to use a branch of the Ulnar nerve to reinnervate the Musculo-cateous nerve. However, our results show that it is better to use it in pure C5 C6 lesions but that it is often too weak when C7 is injured. The results were not so good in these cases

The contra-lateral C7 root has been used by some surgeons (Gu, 1989-1991, 2001, 2002, 2003) and applied to obstetrical paralysis by others.[16,17] The medico-legal situation as well as the length of grafts necessary has prevented us to use it. The possible advent of end to side anastomoses will rarefy the indications of this procedure.

The lesions

There are many types of lesions encountered in the obstetrical plexus paralysis.

The most common is the neuroma in continuity. It is mostly found in the upper plexus; the level is usually at the junction of C5 and C6 but it can extend sometimes proximally, often distally to the clavicular area.

In front of this lesion, there has been a temptation by several authors[8] to preserve the continuity and do only a neurolysis. Some have been able to assess their patients and demonstrate the inefficiency of the procedure.[8] We have always considered that, when the clinical decision of repairing the plexus has been taken, the neuroma must be removed and grafted. In the beginning of our experience[20] a small series of 15 of these neuromas were excised and sent to pathology for serial studies. They showed the almost complete absence of fibers at the distal end of the neuroma. There are almost no indications for isolated neurolysis in this surgery. The intraoperative discovery that a neurolysis may be the appropriate treatment generally comes from excess in the indication.

Rarely there is a complete rupture of the roots or trunks. The extremities may be difficult to find among a scarred area.

Avulsion injury is the most severe lesion. It may be suspected during the approach if there is an uncommon amount of scar, with difficult dissection of the roots. The spinal ganglion and the motor branch are usually found. It is important to preserve them, as it may be useful to repair directly the motor root

No diagnosis of avulsion should be accepted until the root has been dissected up to the foramen. In several papers, authors determine the diagnosis of avulsion on clinical grounds, associated to EMG and Myelogram. These exams are very helpful, but only dissection can confirm the diagnosis.

This exploration of the lower roots C8 T1 can only be done safely with osteotomy of the clavicle.

There are difficult cases where the root is inside the foramen with all signs of avulsion. This situation is found, in particular, in the upper roots lesions after breech delivery.

It is then necessary to make a decision. In upper root lesions, we know by experience[18,19] that approximately 50% of these roots will recover, at least partially. We prefer to close the wound and wait 6 months. After this delay, those patients who have not recovered will be reoperated and these roots, considered as avulsed, will be neurotized. In lower roots, decision has to be taken immediately as reoperation may become dangerous in this area. If there is an associated Horner Syndrome and no response to electrical stimulation, the root is considered as avulsed, and cut at the foramen, to be neurotized.

Strategy of repair

When there is enough donor roots, the repair by grafts is no problem.

The problems start when there are no donor roots (isolated avulsion) or only one or two roots with 3 or 4 avulsed roots.

We then have to mix grafts, neurotizations and end-to-side sutures.

The technical aspects may vary with the lesion, its extent, the length of grafts, etc. The philosophy stays the same: we have priorities:

- The first priority is hand function and especially fingers flexion and thumb movements. These movements are almost impossible to recover through secondary transfers.
- Wrist and finger extension are also a must if the hand has to be usable.
- The next most important movement will be elbow flexion, which can be used only with shoulder external rotation elbow extension and shoulder abduction will come after.

The choice of distal grafting will be determined by these priorities. According to the number of usable roots, the repair can be more, or less ambitious. In using this strategy, one of the main questions was the function after use of a single root to try to repair several movements, sometimes antagonists.

Our experience in very severe lesions (Gilbert 2001) has shown that in many cases, the child is able to control independently the movements he will recover, even from the same root.

In some instances, we found co-contractions between biceps and triceps, which are of difficult treatment (see later).

In terms of reliability, at that stage, we will use the grafts for the key movements; some neurotizations (spinal accessory, ulnar nerve, Pectoralis Major nerve) for the Biceps and use end-to-side for the secondary aims or if nothing else is possible. The results in 436 cases operated on up until 1996 showed the following distribution of root lesions:

1. C5 and C6: 48%
2. C5 to C7: 29%
3. Complete involvement: 23%, of which almost all were avulsions.

POSTOPERATIVE CARE

Stretching the reconstructed area must be avoided in the first 3 weeks postoperatively. This can be achieved by a plaster cast. Physical therapy is then resumed by gentle passive exercises and encouraging voluntary movement. Every effort should be made to counteract retraction and internal rotation of the shoulder and flexion of the elbow. Physiotherapy should be continued throughout the recovery period, usually for 2 years, but regular physiotherapy should then be discontinued. The recovery is slow. It can be seen 4–6 months after direct suture and

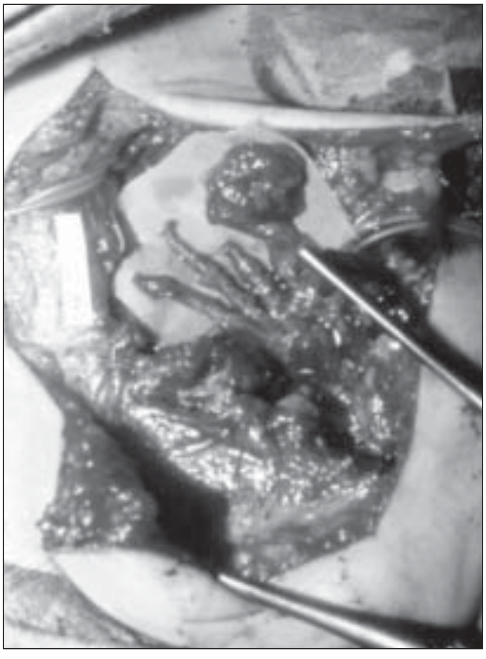

Figure 6: A complete lesion with rupture of two upper roots and avulsion of the others

at 6-10 months following graft reconstruction. It can continue in upper plexus lesions for more than 2 years and in complete lesions for more than 3 years.

RESULTS

Since 1977, more than 3600 patients have been seen and 842 operated for plexus repair.
436 patients operated on between 1976 and 1995 have been reviewed, with more than 4 years' follow up.[21,22] The results in the shoulder using the Mallet scale[24] showed:

C5 C6

at 2 years

Grade IV (good-excellent) 52%

Grade III 40%

Grade II 8%

after two years one third of the patients had secondary surgery:

13 sub scapularis releases

33 Latissimus dorsi transfers

6 Trapezius transfers

and a new evaluation was done at 4 years. (after tendon transfers). The results were as follows:

Grade IV 80%

Grade III 20%

Grade II 0%

C5 C6 C7

at two years the results were:

Grade IV 36%

Grade III 46%

Grade II 18%

After two years, one fourth of the patients had secondary surgery:

7 subscapularis releases

24 Latissimus dorsi transfers

1 trapezius transfer

and the results were evaluated again at four years.

Grade IV 61%

Grade III 29%

Grade II 10%

Complete paralysis

The shoulder results in complete paralysis are less satisfactory because part of the upper roots destined for the shoulder and elbow have to be sacrificed in order to obtain function in the hand. The shoulder results at 4 years are as follows:

Class IV:22.5%

Class III:42%

Class II:35.5%.

Alternatively, the prognosis for the hand which is very poor following spontaneous recovery alone provides 83% of hands with some function and useful function in 75% of patients 8 years after a neurotization.

Complications

There have been no operative deaths. The overall complication rate in the present series was 1%, including phrenic nerve lesions, lesions of the thoracic duct, wound infections and vascular lesions, all of which have been managed satisfactorily without late sequelae.

CONCLUSIONS

Based on the results of the author's series, the following recommendations can be made:

1. Babies who do not recover biceps function by the age of 3 months should be considered for immediate operation.
2. Primary suture without tension is rarely possible. Nerve grafting is usually necessary for root or trunk ruptures.
3. In the presence of root avulsions an internal neurotization should be attempted between different roots, particularly as children seem to have a far greater capacity to accommodate to differential neurotizations.
4. When it is not possible to perform an internal neurotization, an external neurotization can be

Figure 7 and 8: Results at 10 years after C5-C6 repair

performed using one or more of the following donor nerves in the following order of preference:the pectoral nerves, the intercostal nerves, the accessory nerve.

5. The reconstruction should be protected from excessive motion for the first 3 weeks.
6. Physiotherapy should be continued up to 2 years of age but then continued by the parents in the form of play and activities of daily living.
7. Secondary surgery can be considered when it is clear that recovery following reconstruction is not progressing any more.

REFERENCES

1. Duchenne De Boulogne GB. De L'Electrisation localisée, Paris: Baillère; 1872. p. 353-66.
2. Bennet GC, Harrold AJ. Prognosis and early management of birth injuries to the brachial plexus. Br Med J 1976;1:1520-2.
3. Wickstrom J, Haslam ET, Hutchinson RH. The surgical management of residual deformities of the shoulder following birth injuries of the brachial plexus. J Bone Joint Surg 1958;47A:27-36.
4. Tassin JL. Paralysies obstetricales du plexus brachial, evolution spontanee, resultats des interventions reparatrices precoces. Thèse, Université Paris VIII 1984.
5. Al Qattan M, Clarke H, Curtis CG. The prognostic value of concurrent Horner's syndrome in total Obstetric brachial plexus injury. Br J Hand Surg 2000;25:166-7.
6. Birch R. Surgery for brachial plexus injuries. J Bone Joint Surg Br 1993;75:346.
7. Neuenschwander, Brauner S, Gilbert M, Faure A. Cervical myelography with metrizamide in brachial birth palsies. Ann Radiol (Paris) 1980;23:93-8.
8. Clarke HM, Al Qattan MM, Curtis CG, Zuker RM, Obstetrical brachial plexus palsy:results following neurolysis of conducting neuromas-in-continuity. Plast Reconstr Surg 1996;97:5.
9. De Moura W, Capek L, Clarke HM, Zuker RM. Endoscopic sural nerve harvest in the pediatric patient. Plast Reconstr Surg 1996;98:884.
10. Oberlin C, Beal D, Leechavengvongs S, Salon A, Dauge MC, Sarcy JJ. Nerve transfer to biceps muscle using a part of ulnar nerve for C5-C6 avulsion of the brachial plexus: Anatomical study and report of four cases. Am J Hand Surg 1994;19:232-7.
11. Gu YD, Wu MM, Zhen YL, Zhao JA, Zhang GM, Chen DS, Yan JG, Cheng XM. Phrenic nerve transfer for brachial plexus motor neurotization. Microsurgery 1989;10:4.
12. Gu YD, Zhang GM, Chen DS, Cheng XM, Zhang LY, Yan JG, Cai PQ, Shen LY. Cervical nerve root transfer from contralateral normal side for Treatment of brachial plexus root avulsions. Chin Med J (Engl) 1991;104:208-11.
13. Gu YD, Cai PQ, Xu F, Peng F, Chen L. Clinical application of ipsilateral C7 nerve root transfer for treatment of C5 and C6 avulsion of brachialplexus. Microsurgery 2003;23:105-8.
14. Gu Y, Xu J, Chen L, Wang H, Hu S. Long term outcome of contralateral C7 transfer:a report of 32 cases. Chin Med J (Engl). 2002. p. 115.
15. Chen ZY, Xu JG, Shen LY, Gu YD. Phrenic nerve conduction study in patients with traumatic brachial plexus palsy. Muscle Nerve 2001;24:1388-90.
16. Chuang DC, Wei F, Noordhof C. Cross-chest C7 nerve grafting followed by free muscle transplantations for the treatment of total avulsed brachial plexus injuries: A preliminary report. Plast Reconstr Surg 1993;92:717-25.
17. Terzis JK, Papakonstantinou KC. Management of obstetric brachial plexus palsy. Hand Clin 1999;15:717-36.
18. Geutjens, Gilbert G, Helsen A. Obstetric brachial plexus palsy associated with breech delivery. J Bone Joint Surg Br 1996;78:303-6.
19. Sloof ACJ, Blaauw G. Some aspects in obstetric brachial plexus lesions. In: Traumatic Brachial Plexus Injuries, Alnot JY, Narakas A, editors. Expansion Scientifique 1993.
20. Gilbert A, Tassin JL. Réparation chirurgicale du plexus brachial dans la paralysie obstétricale. Chirurgie 1984;110:70-5.
21. Gilbert A, Whitaker I. Obstetrical brachial plexus lesions. J Hand Surg 1991;16B:489-91.
22. Gilbert A. Long-term evaluation of brachial plexus surgery in obstetrical palsy. Hand Clinics 1995;11.
23. Gilbert A, Razaboni R, Amar-Khodja S. Indications and results of brachial plexus surgery in obstetrical palsy. Orthop Clin North Am 1988;19.
24. Mallet J. Paralysie obstétricale. Rev Chir Orthop 1972;115:58.
25. Haerle M, Gilbert A. Management of complete Brachial plexus lesions. J Pediatric Orthop 2003.