TOTAL OBSTETRIC BRACHIAL PLEXUS PALSY: RESULTS AND STRATEGY OF MICROSURGICAL RECONSTRUCTION

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From 2000 to 2006, 35 infants with total obstetric brachial plexus palsy underwent brachial plexus exploration and reconstruction. The mean age at surgery was 10.8 months (range 3–60 months), and the median age was 8 months. All infants were followed for at least 2.5 years (range 2.5–7.3 years) with an average follow-up of 4.2 years. Assessment was performed using the Toronto Active Movement scale. Surgical procedures included neurolysis, neuroma excision and interposition nerve grafting and neurotization, using spinal accessory nerve, intercostals and contralateral C7 root. Satisfactory recovery was obtained in 37.1% of cases for shoulder abduction; 54.3% for shoulder external rotation; 75.1% for elbow flexion; 77.1% for elbow extension; 61.1% for finger flexion, 31.4% for wrist extension and 45.8% for fingers extension. Using the Raimondi score, 18 cases (53%) achieved a score of three or more (functional hand). The mean Raimondi score significantly improved postoperatively as compared to the preoperative mean: 2.73 versus 1, and showed negative significant correlation with age at surgery. In total, obstetrical brachial plexus palsy, early intervention is recommended. Intercostal neurotization is preferred for restoration of elbow flexion. Tendon transfer may be required to improve external rotation in selected cases. Apparently, intact C8 and T1 roots should be left alone if the patient has partial hand recovery, no Horner syndrome, and was operated early (3- or 4-months old). Apparently, intact nonfunctioning lower roots with no response to electrical stimulation, especially in the presence of Horner syndrome, should be neurotized with the best available intraplexal donor. © 2010 Wiley-Liss, Inc. Microsurgery 30:169–178, 2010.

Published data on obstetrical brachial plexus palsy (OBPP) reported an incidence of 58–90% of upper palsy and 10–58% of total palsy.[1] In contrast to upper OBPP, it has been generally agreed that microsurgical reconstruction should be undertaken as early as possible for infants with total plexus lesions and Horner's syndrome. Surgical treatment of total OBPP presents complex scenarios because of the frequent occurrence of multiple root avulsions and the scarcity of intraplexal donors. As opposed to adults with total brachial plexus palsy, there is a possibility of restoring good hand function and even intrinsic muscle function if early plexus reconstruction is performed in infants with total palsy.[2] Majority of the previously published reports have discussed total palsy as part of the spectrum of OBPP, and not as a separate entity. Different authors have set different priorities and consequently have proposed different plans for plexus reconstruction. Outcome of hand function following nerve repairs in these papers is difficult to interpret either because the details of nerve lesions and repair strategy are not provided, or because the results of nerve repair and secondary surgery are pooled together. There has been a paucity of publication concerning the outcome of hand function following primary nerve reconstruction in infants with OBPP. The only study that provided details of operative findings and repair strategy is that of Pondaag and Malessy[3] who reported the outcome of hand function in 16 cases following primary reconstruction after an average of 50 months.

This work reports the results of microsurgical reconstruction of total OBPP in 35 cases. The results are analyzed according to the age at surgery and method of reconstruction: neurolysis, grafting, or neurotization. As the key for good hand function is intrinsic recovery, special emphasis is given to the nature of T1 root lesion and the method was used for its reconstruction. Finally, a proposed reconstruction plan is suggested based on the results.

MATERIALS AND METHODS

From July 2000 to April 2006, 35 infants with total OBPP underwent brachial plexus exploration and reconstruction. All babies in this study were delivered normally, none via cesarean section. Males were more commonly affected than females: 51.4% versus 48.6%, respectively. The right side was involved in 62.9% of cases and the left side in 34.3%. Bilateral affection was noticed in one case in which the left side was treated conservatively and the other was explored surgically.

In all cases with total palsy, particularly with positive Horner's syndrome, surgery was scheduled as soon as possible depending on the general condition of the infant, usually at or just after the age of 3 months. In infants who presented late, the indication for surgery was biceps power $\leq$ grade two and flail anesthetic hand.

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Table 1. Nerve Grafting Procedures

Root	No. of procedures	No. of cables/root	Average cable length (cm)
C4	5	2.2	2.9
C5	25	2.76	3.37
C6	25	2.47	3.73
C7	6	2.5	2.6
C8	3	1.33	3
T1	2	1.5	2.25

Table 2. Neurotization Procedures

Neurotization	Number of procedures
SA to SSN	17
Intercostals	14[a]
Contralateral C7	3[b]

SA, spinal accessory; SS, suprascapular nerve.
[a]*Twelve to musculocutaneous nerve, one to axillary nerve, and one to radial nerve.*
[b]*To median nerve, posterior divisions of upper and middle trunks, and C8.*

The mean age at surgery was 10.8 months (range 3–60 months), and the median age was 8 months. All infants were followed for at least 2.5 years (range 2.5–7.3 years) with an average follow-up of 4.2 years. During the follow-up period, 10 infants (28.5%) required secondary surgery (tendon transfer) to correct established deformity at the shoulder.

Preoperative Evaluation

All infants were examined and followed up using the Toronto Active Movement Scale described by Clark and Curtis.[4] A baseline dynamic video study with a standard series of activities was performed on all infants. Horner syndrome was observed in nine cases. Sensory evaluation in infants is extremely difficult. In many cases, it was possible only to determine whether the child responds to painful stimuli and to examine for signs of self-mutilation. In our series, sensory loss was observed in 19/43 infants (44.2%). X-rays of chest, clavicle, shoulder, and elbow were obtained to detect associated fractures and elevated copula of diaphragm, indicating phrenic nerve injury. Computed tomographic (CT) myelography was done for 20 cases and magnetic resonance imaging myelography was done in four cases. Images were examined for the presence of spinal canal alignment, intraspinal canal hematoma, and meningocele and nerve root visualization.

Surgical Procedure

The anterior approach to the brachial plexus was used in all cases. In the first five cases, the supraclavicular brachial plexus was exposed through a hockey stick-shaped skin incision that followed the posterior edge of the sternocleidomastoid muscle, curved inferiorly, and then paralleled the clavicle extending to the delto-pectoral groove. In the latter cases, this was replaced by two separate incisions: transverse one along the neck crease starting from the posterior border of sternocleidomastoid muscle to the anterior border of the trapezius muscle. The second incision was parallel to inferior border of the clavicle starting from the middle of the clavicle and curved laterally to continue in delto-pectoral approach.

Inspection was done root by root, and exploration was completed up to the neural foramen, particularly for C8 and T1. After identifying the macroscopic appearance of the brachial plexus, each nerve root was stimulated electrically and the resulting muscle contraction was noted.

Atracurium was used as the muscle relaxant in a dose of 0.3–0.7 ml/kg bodyweight in the induction phase, and the same dose/hour for the maintenance, and was stopped prior to the stimulation by 15–20 minutes. If a nonconducting neuroma was the case, it was resected and either end-to-end suture or interposition nerve grafting was done. If the neuroma was conducting and stimulation produced muscle contraction of a specific muscle or group of muscles, then neurolysis was carried out.

Planning of the reconstructive procedure was done after the complete exploration of the plexus. Surgical procedures included neurolysis (45 roots), neuroma excision and grafting (56 roots), direct suture and neurotization, or combinations. The details of grafting and neurotization procedures are shown in Tables 1 and 2.

Primary anterior shoulder release was performed in 13 infants. It included tenotomy of subscapularis and sometimes Z-pasty of the pectoralis major tendon. Shoulder capsule was preserved in all cases to avoid anterior subluxation.

The arm was adducted and the hand was kept close to the opposite shoulder using crepe bandage without embarrassing respiratory movements. The neck was supported by Philadelphia collar to prevent side bending of the neck. All infants were admitted to the microsurgical intensive care unit. They were observed for vital signs and were kept sedated for the first 24 hours. The average intensive care unit stay was 1.9 days (1–7). Oral feeding was allowed as soon as the infant was aware and fully conscious.

Postoperative Evaluation

All infants were assessed clinically using the Toronto's Active Movement Scale.[4] Results were assessed for every joint motion (shoulder, elbow, wrist, and fingers) and according to each surgical procedure (neurolysis, grafting and intra- and extraplexal neurotization). Recovery was classified as poor, fair, good, and full when the

Table 3. Intraoperative Findings in 35 Patients

	C5		C6		C7		C8		T1		Total	
	N	%	*N*	%	*N*	%	*N*	%	*N*	%	*N*	%
Grossly intact	0	0	0	0	1	2.9	18	51.4	18	51.4	37	21.1
Conducting neuroma	4	11.4	6	17.1	3	8.6	2	5.7	2	5.7	17	9.7
Rupture	28	80	15	42.9	10	28.6	5	14.3	4	11.4	62	35.4
Avulsion	3	8.6	14	40	21	60	10	28.6	9	25.7	57	32.5
Nonvisualized									2	5.7	2	1.14
Total	35		35		35		35		35		175	100

Toronto muscle grade was four or less, five, six, and seven, respectively. Poor and fair recovery was considered unsatisfactory, while good and full recovery was considered satisfactory. The hand recovery was also evaluated using the Raimondi grading system[5] which correlated better with the functional status of the hands.

Video study was used to confirm motor examination findings and document the degree of functional recovery. Limb integration into the normal daily activities was evaluated through observation of the child and a family questionnaire; and graded either poor if the affected limb is never used, fair if used on command, good if used spontaneously on certain bimanual activities, and excellent if always used.

RESULTS

Intraoperative Findings

One hundred seventy-three roots were explored, T1 root was not visualized in two cases, and C4 was ruptured in five cases and had a conducting neuroma in one case. The condition of the nerve roots was recorded as grossly intact, conducting neuroma, rupture or avulsion. Table 3 shows a summary of intraoperative findings. The most common root lesion was rupture, 35.4%, and the least common lesion was conducting neuroma, 9.7%. C8 and T1 were grossly intact in 51.4% of cases and avulsed in 21.7%.

A concomitant peripheral nerve lesion was observed in two cases. In one case, the supraclavicular lesion was accompanied by perineural fibrosis of the musculocutaneous, radial and axillary nerves. The musculocutaneous nerve was avulsed at its entry into the coracobrachialis muscle in another case.

Computed Tomographic Myelography

CT myelography was performed in 20 cases. In two cases, there was a bad window to interpret, and in another one, there was insufficient dye. A total of 85 roots were examined. The results and correlation between the CT findings and the intraoperative findings for each root are shown in Table 4. The C7 root had significantly higher true positive and negative results compared to the other roots. Using chi-square test, CT myelography findings correlated significantly with the intraoperative findings, ($P < 0.05$), for the C7 root only. In general, CT myelography was 50% sensitive, and 64.4% specific, and it was more sensitive, 80%, and specific, 83%, to C7 lesions.

Table 4. Sensitivity and Specificity of CT Myelography for Individual Nerve Roots

Root	Sensitivity (%)	Specificity (%)
C5	25	54
C6	25	46
C7	80	83
C8	66	72
T1	50	69
Total	50	64.6

CT, computed tomography.

Functional Results

The mean pre- and postoperative scores, and the percentage of satisfactory (good and excellent) results are shown in Tables 5 and 6. The differences between the pre- and postoperative scores were statistically significant. The best recovery was that of elbow flexion and extension and the least was that of thumb and wrist extension. Tendon transfer significantly improved shoulder external rotation in seven of 10 cases, but did not significantly improve abduction. There was an overall positive but insignificant correlation between the recovery of shoulder abduction and external rotation $r = 0.014$, $P = 0.935$. Neurolysis was best for lower trunk conducting neuroma as it effectively restored finger and thumb flexion in 77.8–83% of cases. On the other hand, neurotizing the medial cord with the intercostal nerves or the median nerve with the contralateral C7 root failed to restore finger flexion. Grafting destined for radial nerve restored elbow extension better than wrist and finger extension: 76% versus 35 and 48%, respectively. Intercostal neurotization was more effective for restoration of elbow flexion than grafting the upper trunk; 91.6% versus 72%, respectively. Spinal accessory (SA) neurotization was less effective than grafting the upper trunk for the restoration of shoulder external rotation. Overall, there was a negative

Table 5. Pre- and Postoperative Functional Scores and Percentage of Satisfactory Results

	Shoulder		Elbow		Wrist	Fingers		Thumb	
	Abduction	External rotation	Flexion	Extension	Extension	Flexion	Extension	Flexion	Extension
Preoperative score	1.23	0	0.8	2	2	1.23	0.09	1.06	0.09
Postoperative score	4.74	4	5.8	5.7	3.09	5.4	3.94	5.51	3.14
% Satisfactory	37.1	34.2/54.3[a]	77.1	77.1	31.4	62.9	45.8	68.6	28.6

[a]*Following teres major to infraspinatus transfer.*

significant correlation between age at surgery and functional recovery i.e., the younger the child at operation the better was the recovery. Finger and thumb flexion had the highest correlation with age at surgery. An exception is the recovery of elbow flexion and shoulder abduction, which did not correlate with age.

All cases were additionally evaluated using the Raimondi scoring system, 18 cases (53%) achieved a score of three or more (functional hand), and the rest (47%) had a score of two or less (Fig. 1). The mean Raimondi significantly improved postoperatively as compared to the preoperative mean, 2.73 versus 1, respectively, $P = 0.000$, SD = 1.263. The Raimondi score showed significant negative correlation with age at surgery, $r = -0.356$, $P = 0.049$, i.e., the younger the child the better is hand recovery (Fig. 2).

As regards limb integration into normal daily activities in three cases were poor, nine fair, 15 good, and eight excellent. Limb integration did not show significant correlation with any of the regained functions except for a positive significant correlation with shoulder external rotation $P = 0.396$, $r = 0.027$. Examples of the operated cases are shown in Figures 3 and 4.

The key for good hand function is intrinsic recovery, even in cases with good recovery of long flexors; hand function was greatly affected if intrinsics did not recover concomitantly. Hand recovery was analyzed according to the condition of T1 root. In cases with T1 avulsion ($n = 9$), nothing was done in three cases and the hand remained functionless, in four cases ≤9-month old intraplexal neurotization achieved a score of at least three with good intrinsic function, and in another 1-year-old case the same procedure was not satisfactory. Intercostal neurotization failed to produce satisfactory result in one case. In cases with apparently intact T1 root ($n = 18$), eight cases achieved a functional score of three or more, and 10 cases did not reach a functional level. All cases with satisfactory results showed some preoperative hand recovery. Of the cases with unsatisfactory results, 10 showed no sign of preoperative hand recovery and three had additionally a positive Horner's sign. In cases with T1 rupture ($n = 4$), grafting gave inferior results (score two) to anatomical reconstruction with direct sutures (score three and four). Both cases with T1 conducting neuroma achieved a full Raimondi score after neurolysis. In the two cases in which T1 was not identified C8 was apparently intact and both achieved a Raimondi score of three and four.

Preoperatively 20/35 cases had no hand sensibility (57%); two of them had trophic ulcers. Hand sensation was restored via sensory branches of intercostal nerves in four cases, and supraclavicular sensory branches in two cases, the other 14 cases were reconstructed by grafting of the lateral cord or lateral root of median nerve. At the final follow-up visit, all, but one case, recovered sensation. The degree of sensory recovery, two-point discrimination and stereognosis were difficult to be examined in children.

DISCUSSION

The most vulnerable part of the plexus is the upper trunk, if the injury reaches the lower plexus; the injury of the upper plexus becomes more severe.[6] According to Birch et al.,[7] it appears that there is a trend towards worsening of the outcome for repairs of both C5 and C6 in cases with total palsy. Dumont et al.[8] stated that the connection to the deltoid was rarely performed because of insufficient donor nerves. This may partly explain the inferior outcome of shoulder abduction in cases with a total palsy compared to those with upper palsy. Hunt[9] reviewed the modern literature reporting results of brachial plexus repair in infants. With a follow-up period of 5 years, 80% of infants having C5, C6, and C7 lesions, and only 35% of those having C5 through Tl lesions, attained "good" surgical outcomes. Despite progressive improvement of deltoid muscle power and recovery of the rotator cuff (sometimes after tendon transfer) abduction is sometimes hindered most probably due to scapulohumeral, and scapulothoracic disharmonious movement caused by lack of long thoracic nerve innervation.

Reduced external rotation is one of the most common deficits in OBPP. Because external rotation is an important functional part of most daily shoulder movements, its loss results in a definite disability. Even with active supinators, the range of functional forearm supination remains restricted because of the internal rotation position of the upper arm.[10]

From the previously published reports,[11,12] it is difficult or impossible to define the degree of external rota-

Table 6. Percentage of Satisfactory Results Following Neurolysis, Grafting, and Neurotization

	Shoulder		Elbow		Wrist	Fingers		Thumb	
	Abduction	External rotation	Flexion	Extension	Extension	Flexion	Extension	Flexion	Extension
Neurolysis	40% (n = 5)	33% (n = 3)	60% (n = 5)	75% (n = 4)	0% (n = 4)	77.8% (n = 18)	25% (n = 4)	83% (n = 18)	25% (n = 4)
Grafting	35.7% (n = 28)	50/87.5%[a] (n = 8)	72% (n = 18)	76% (n = 29)	35% (n = 29)	60% (n = 10	48% (n = 29)	60% (n = 10)	27.6% (n = 29)
Neurotization	50% (n = 2)	33/50%[a] (n = 18)	91.6% (n = 12)	100% (n = 2)	50% (n = 2)	0% (n = 3)	50% (n = 2)	33% (n = 3)	50% (n = 2)

[a] *Following teres major to infraspinatus transfer.*

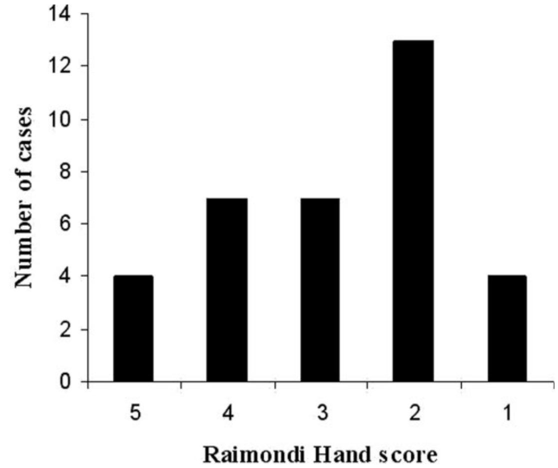

Figure 1. The overall distribution of Raimondi hand score.

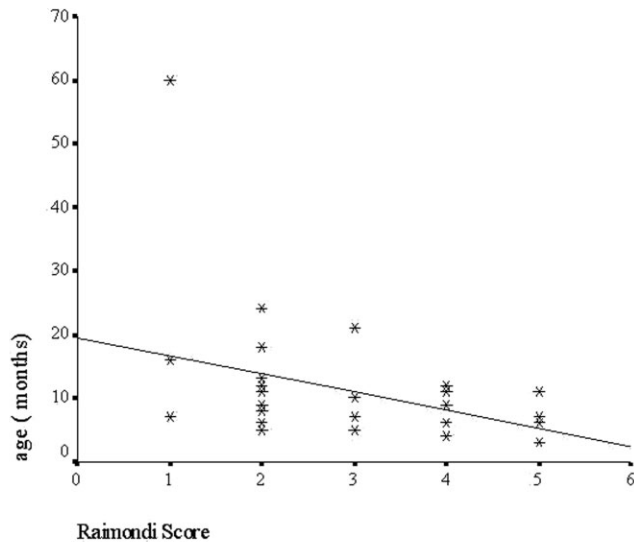

Figure 2. Correlation between Raimondi hand score and age at operation.

tion as a solitary movement achieved as a result of suprascapular nerve (SSN) reinnervation because scoring systems used to evaluate external rotation include other shoulder movements as abduction and also because the results of nerve repairs and tendon transfers are combined.[13] Waters[14] scored the individual items of the Mallet score separately, thereby providing the results of external rotation as an isolated movement. However, the results of only six infants were provided after nerve grafting. In a series of 86 patients, Pondaag et al.[13] found that Only 17 (20%) of 86 patients achieved $>20^\circ$ of external rotation, whereas 35 (41%) were unable to perform true external rotation (with the elbow flexed and the upper arm held in adduction). They concluded that the restoration of a fair range of true glenohumeral external rotation

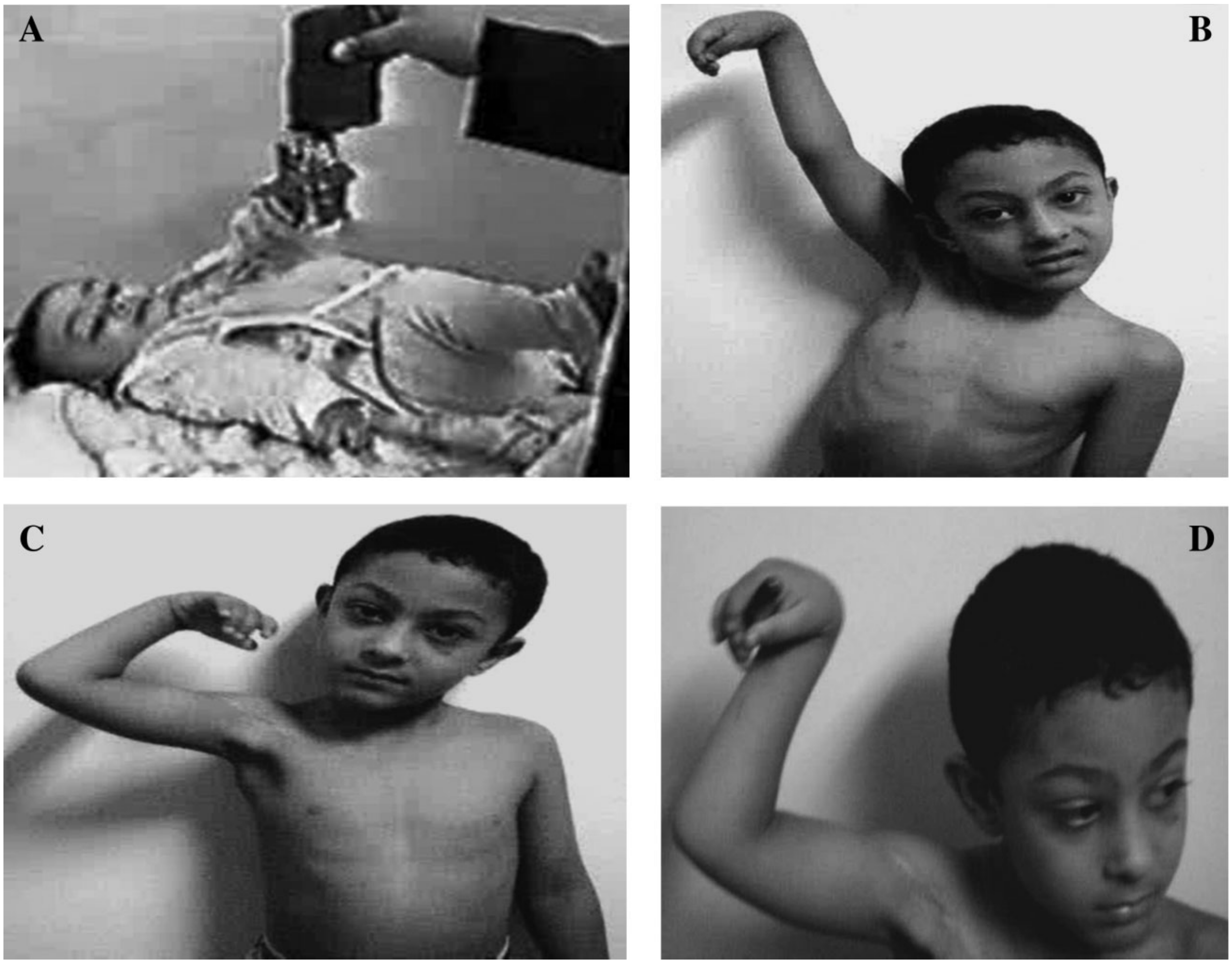

Figure 3. Five-month-old boy with right total OBPP. Exploration revealed ruptured C4–C7, and avulsion C8–T1. C4 and C5 were grafted to the upper trunk, C6 to the middle trunk and C7 to the lower trunk. ***A:*** *Preoperative photograph.* ***B:*** *Six years postoperative photograph showing shoulder abduction.* ***C:*** *Elbow flexion.* ***D:*** *Finger flexion, notice wrist drop.*

is disappointingly low; however, it seems that compensatory techniques contribute to effectuate a considerable range of movement. In the present study, good and excellent external rotation was achieved primarily in 12/35 infants (34%) and after tendon transfer in 19/35 infants (54.3%). The relatively high average age at surgery in our series (10.77 months), may have given the chance for the development of internal rotation contracture.

Many authors[13,15,16] found no significant difference between results of C5-SSN nerve grafting and SA to SSN transfer. In our series nerve grafting was superior to neurotization, 50% versus 35.2%, respectively. However, statistical comparison between the two groups could not be done due to small number of cases.

In the present series, satisfactory elbow flexion was achieved in 77.1% of cases with the highest percentage of satisfactory results achieved by intercostal neurotization (91.6%), followed by grafting (72.2%). Our results as regards elbow flexion are better than the results presented by other authors[7,8,17] because of the frequent use of intercostal to musculocutaneous neurotization. Kawabata et al.[18] reported his experience with this procedure in OBPP infants and found that 84% of his patients who were operated on earlier than 5 months of age achieved M4. Nagano et al.[19] reported that 70% of children achieved M4 after intercostal transfer. Krakauer and Wood[20] showed that six of eight patients achieved a muscle grading M3 or more. In Terzis and Kostas[21] series, five of six patients achieved an excellent result (muscle grading M4 to M5).

The outcome of hand function in the previously published reports is summarized in Table 7. Outcome of hand function following primary nerve repairs in these papers is difficult to interpret either because the details of nerve lesions and repair strategy are not provided or because the results of nerve repair and secondary surgery

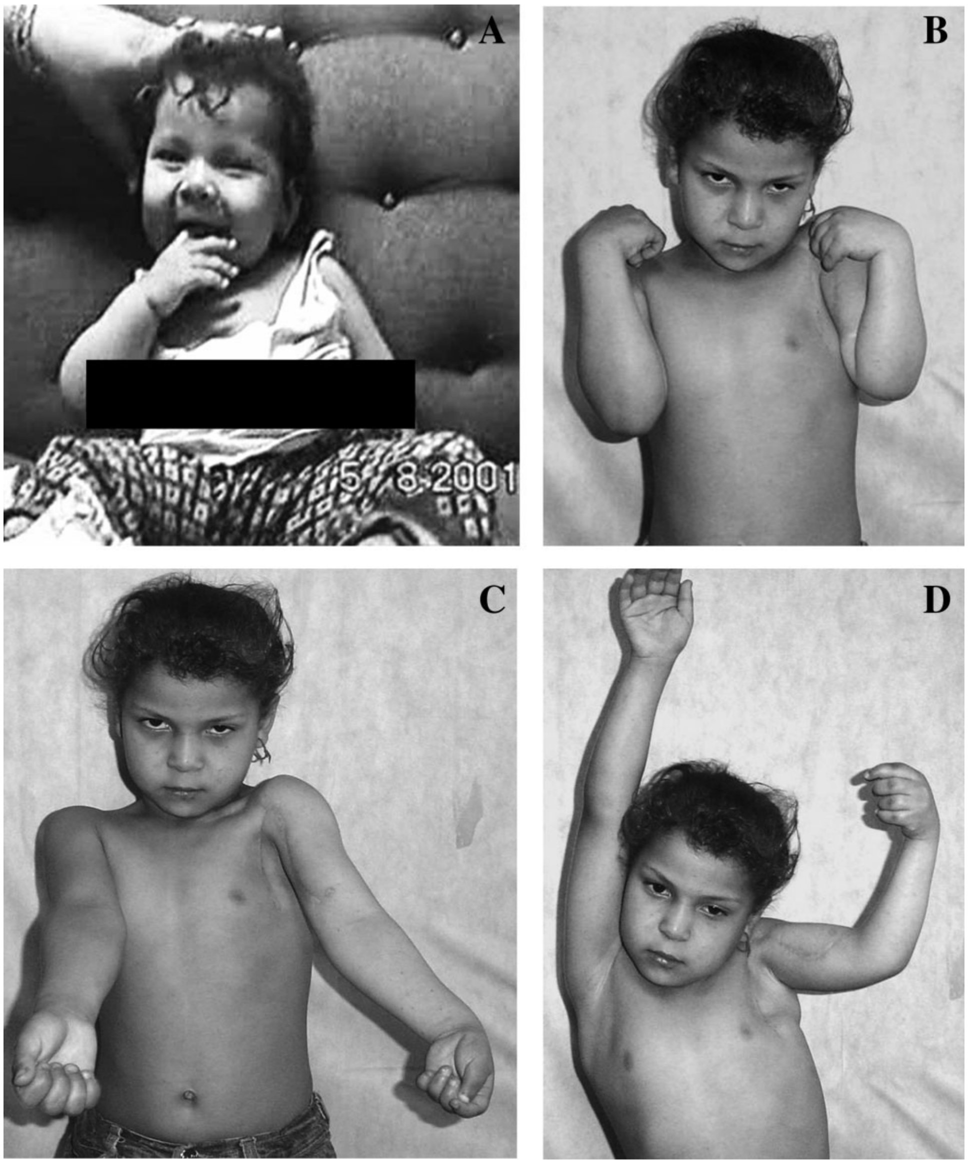

Figure 4. Four-month-old girl with left total OBPP and Horner's syndrome. Exploration revealed ruptured C5 and C6, and avulsion C7–T1. C5 was grafted to the medial cord, C6 to the posterior cord, and Intercostal nerves T3–5 were neurotized to the lateral cord. ***A:*** *Preoperative photograph.* ***B:*** *Four years postoperative photograph showing good elbow flexion.* ***C:*** *Elbow extension and finger flexion.* ***D:*** *Shoulder Abduction and external rotation.*

are pooled together. In addition, the evaluation method and the duration of follow up are variable. According to Haerle and Gilbert,[24] the recovery of the hand is very slow, and is expected to continue up to 8 years.

Recovery of hand function depends on the age at surgery; the younger the age, the better is the outcome. This finding was also documented by Terzis and Kokkalis[29] who reported 100% satisfactory results in six infants cases operated at or before the age of 3 months and 67% in seven cases operated after the age of 7 months. The key for good hand function is intrinsic recovery, even in cases with good recovery of long flexors; hand function was greatly affected if intrinsics did not recover concomitantly. One problem is apparently intact C8 and T1 roots. Hentz[30] has seen infants in whom a Horner sign is present and who, at exploration, have a perfectly normal appearing C8 and T1 roots. However, stimulation of the inferior trunk resulted neither in motor movement nor in somatosensory evoked potentials and judged these roots to be avulsed at the intraforaminal level. Gilbert[23] found some kind of recovery in 50% of the cases with probable avulsion following breech delivery (upper roots), support-

Table 7. Hand Recovery in the Previously Reported Series

Author	Number of patients	Evaluation system used	Secondary procedures included	Results
Gilbert and Whitaker[22]	NAD	Gilbert	NAD	35% had grade III, IV increased to 75% with secondary procedures
Gilbert[23]	NAD	Gilbert	Yes	Grade 0: 1%, grade I: 16% Grade IIa: 23%, grade IIb: 9% Grade III: 26%, grade IV: 25% Grade V: 0%
Dumont et al.[8]	20	Toronto	Yes	Group A patients (with some motor function before surgery) showed a much improved mean hand movement and prehension score Group B patients (with a totally palsied hand) did not regain useful movement of the wrist, fingers, or thumbs after primary or secondary surgery
Haerle and Gilbert[24]	73	Raimondi	Yes	76% of children have a useful hand in 8 years
Grossman et al.[25]	36	Raimondi	NAD	Fair in 19.4%, satisfactory in 58.3%, good in 16.6%, and excellent in 5.5%
Birch et al.[7]	C7:29 repairs in 54 C8 and T1:47 repairs in 80	Raimondi	No	C7: functional extension of the wrist and fingers, was attained in seven (24%) of repaired nerves C8 and T1: repairs were not carried out in any case where some function or recovery was demonstrated at operation Repairs were confined to examples of complete avulsion (type 5). The results were good in 27 repairs (57%), there was some recovery in 17 more and the operation failed in three
Shenaq et al.[17]	NAD	MRC	NAD	1–17% grades IV–V
Kawabata[26]	NAD	Kawabata grading system	NAD	Before operation, the average score was 1.5 in type II and 0 in type III patients. The final result showed that the type II patients were largely improved to 9.2, but the improvement in type III was limited to 3.0 on average. The forearm and wrist function had the same tendency, better in type II than in type III
Terzis and Papakonstantinou[27]	NAD	Raimondi	No	Patients improved (from a preoperative mean of 1.38 to a postoperative mean of 3.38, $P < 0.0001$)
Pondaag and Malessy[3]	16	Raimondi	No	Group I ($n = 13$) with complete discontinuity of C5–T1 a score $\geq$3 was achieved in 69% Group II ($n = 3$) with intact C8 and/or T1, a score $\geq$3 was achieved in 33% Overall a score of $\geq$3 was achieved in 63%
Kirjavainen et al.[28]	25	Raimondi	Yes	Mean scores were 2.16 (0–5)
Terzis and Kokkalis[29]	61	Modified Gilbert–Raimondi	Yes	75.4% Achieved functional level ($\geq$4 score) Results were better (88%) after >8 years follow-up Functional results were achieved in 56% of patients who had primary nerve reconstruction alone
The present series	35	Raimondi	No	53% Achieved a score $\geq$3 (functional hand)

NAD, No available data; MRC, Medical Research Council.

ing the presence of partial avulsion. Al-Qattan[31] added end-to-side/side-to-side nerve grafts in the same situations and obtained functional recovery 85% of cases. Based on the findings in this study, apparently intact C8 and T1 roots should be left alone if the patient has partial hand recovery, no Horner syndrome and was operated early enough (3- or 4-month old). Apparently intact nonfunctioning roots with no positive response to electrical stimulation, especially in the presence of Horner syndrome should be neurotized with the best available intraplexal donor. We agree with other authors[32] that preoperative CT combined with myelography and the measurement of intraoperative evoked potentials would improve the diagnosis of these lesions, although none of these methods is completely reliable for detecting root avulsion or mixed injuries.

Hentz[30] stated that he has never grafted onto a ruptured T1 root stump, having no faith that any motor regeneration will result. In this study, it was noticed that grafting T1 gave inferior results to anatomical reconstruction with direct sutures while neurotizing T1 or the lower trunk by another intraplexal donor gave satisfactory results in selected cases of young age.

In cases of conducting neuroma, Clark et al.[33] stated that neurolysis of the lower roots did not greatly improve muscle strengths of the wrist or hand in their patients with total palsy. Neurolysis of the lower root is only considered in cases in which the preoperative muscle power in the hand is grade two or more, suggesting that T1 is intact. Capek et al.[34] studied the short-term effect of neuroma-in-continuity resection in OBPP in 26 patients. Compared with preoperative assessment, they found that limb motion scores after neuroma resection were significantly decreased at 6 weeks, and significantly improved at 12 months postoperatively. In comparison to patients undergoing neurolysis only, they found limb motion scores after neuroma resection were not significantly different at 3, 6, and 12 months postoperatively. They concluded that resection of neuroma-in-continuity in OBPP does not significantly diminish motor activity. Recently, Lin et al.[35] documented the superiority of long-term functional results following excision and grafting compared to neurolysis. In contrast to the findings of the previous authors, we had two cases with a neuroma-in-continuity who achieved a full Raimondi score after neurolysis. Generally, we agree with Capek that cases with upper trunk neuroma should be excised and grafted, but when the lower trunk is affected, especially if there is preoperative function, the decision is too difficult.

Different authors have set different priorities and so proposed different plans for plexus reconstruction in total OBPP. Gilbert[22] recommended that the priority be given to the reconstruction of the hand. As the lower roots are avulsed in most cases, they have used part of the upper roots to reinnervate the medial cord through sural grafts.[24] Kawabata[26] categorized total palsy into complete and incomplete types. In the complete type, reconstruction of hand function, especially finger flexion, through grafting to the C8 root or medial cord, is a priority. The lateral cord is reconstructed with intercostal nerves. Posterior cord reconstruction is considered last, and in some instances, contralateral C7 transfer to the posterior cord may be considered. Bahm et al.[36] gave priority to hand and biceps, shoulder, triceps, and pectoralis, in order. The best root stump is used for reconstruction of the hand; intercostal nerves are neurotized to musculocutaneous nerve, contralateral C7 root to the axillary nerve, and SA to SSN.

On the other hand, some authors focus their surgical efforts on regaining shoulder stability and elbow flexion and providing for the recovery of basic prehension and median sensibility.[25] Shenaq et al.[17] recommended that priority be given to restoration of shoulder function, followed by elbow function, and median-innervated motor and sensory functions. This is accomplished with direct neurotization of the SSN by the SA nerve and the transfer of three intercostal nerves to the lateral cord, to allow elbow flexion and protective sensation of the hand via the musculocutaneous nerve and the lateral root of median nerve, respectively. Alternatives include direct intercostal neurotization to the musculocutaneous nerve and utilization of contralateral C7 root or ipsilateral cervical plexus motor donors to neurotize the axillary and median nerves. The strategy of reconstruction we follow is based on our results. If four or five roots are available, anatomical reconstruction is done. If three roots available, the best root available should be neurotized to the medial cord, one root is neurotized to the lateral cord, and the other to the posterior cord. If two roots are available, the best root available should be neurotized to the medial cord, and the other to the posterior cord. Intercostals are neurotized to the lateral cord (musculocutaneous nerve and lateral root of median nerve) and SA nerve is neurotized to SSN. If only one root is available, the same strategy is followed; in addition the contralateral C7 root is neurotized to the postcord via sural nerve grafts.

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