Part 4

Results of nerve surgery

Eventually, the main point of interest to the surgeon is the result achieved for the patient. This photo represents the result two years and two months after the first documented surgical repair of the brachial plexus (12 Feb 1902)

Robert Kennedy. Further notes on the treatment of birth paralysis of the upper extremity by suture of the fifth and sixth cervical nerves. 1904

Chapter 10

External rotation as a result of suprascapular nerve neurotization in obstetric brachial plexus lesions

Willem Pondaag
Ralph de Boer
Rietje S. van Wijlen-Hempel
Sonja M. Hofstede-Buitenhuis
Martijn J.A. Malessy.

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Objective Obstetric brachial plexus lesions (OBPLs) may cause lifelong limitations of upper limb function. Nerve repair is widely advocated in infants who do not show spontaneous recovery. Typically, the suprascapular nerve (SSN) is involved in the lesion. Neurotization of the SSN routinely is performed, aiming at reinnervation of the infraspinatus muscle to restore external rotation. The results after SSN neurotization have not, as yet, been studied in detail; therefore, this study was undertaken. Of special interest was the comparison of two commonly applied SSN neurotization procedures: nerve grafting from C5 versus nerve transfer of the accessory nerve (XIN).

Methods Infants with OBPL after nerve grafting of C5 to the SSN (n=65) or nerve transfer of the accessory nerve to the SSN (n=21) were selected for retrospective analysis after a mean follow-up period of 3 years. Outcome was expressed in degrees of true glenohumeral external rotation. This was defined as the angle between the position of the 90 degrees (actively or passively) flexed elbow resting against the abdomen and the position of the flexed elbow after external rotation with the upper arm held in adduction by the investigator. This movement can be executed only by infraspinatus muscle contraction. In addition, functional external rotation was evaluated by testing the ability to reach the mouth and the back of the head.

Results Only 17 (20%) of the 86 patients reached more than 20 degrees of external rotation, whereas 35 (41%) were unable to perform true external rotation. There was no statistically significant difference between nerve grafting from C5 and extraplexal nerve transfer using the accessory nerve. Functional scores showed that 88% can reach the mouth, and that 75% can reach the head.

Conclusion The restoration of a fair range of true glenohumeral external rotation after neurotization of the SSN in infants with OBPL, whether by grafting from C5 or by nerve transfer of the accessory nerve, is disappointingly low. However, it seems that compensatory techniques contribute to effectuate a considerable range of movement.

The obstetric brachial plexus lesion (OBPL) is caused by traction during delivery.[1,2] Incidence varies from 1.6 to 2.9 per 1000 births in prospective studies.[3,4] Spontaneous recovery may occur depending on the severity of the traction injury. Although neurapraxia and axonotmesis eventually see complete recovery, neurotmesis and root avulsion result in permanent loss of arm function. Fortunately, most children show good spontaneous recovery. The natural history of this injury, however, has never been studied systematically. The percentage of children with residual deficits is estimated at 20% to 30%.[5]

The upper part of the brachial plexus, which includes spinal nerves C5, C6, and the superior trunk, is affected in the vast majority of infants. The loss of suprascapular nerve (SSN) function results in paralysis of the infraspinatus and supraspinatus muscles. The infraspinatus muscle is the primary external rotator of the arm as shown by biomechanical and electromyography studies.[6-8] In combination with the loss of deltoid and biceps muscle functions, upper plexus lesions present with the typical "waiters tip" position: the extended arm in internal rotation and adduction without elbow flexion and supination. Hand function is additionally impaired in approximately 15% of patients when spinal nerves C8 and T1 are involved.[3,9,10]

Reduced external rotation is one of the most common deficits in OBPL. 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.[11]

The extent of neural damage after OBPL can be assessed only by evaluation of recovery in the course of time, because nerve lesions of different severity initially present with the same clinical features. At present, most authors advise surgical exploration at a preset age if spontaneous recovery is considered to be insufficient by that time.[12-15] Commonly applied nerve repair techniques consist of nerve grafting after neuroma resection and nerve transfer in the case of root avulsion.[12,15-19]

The results of these nerve repairs have been published in a number of series, from which at first glance it can be concluded that global shoulder function recovery is good.[14,17,20] From these studies, however, it is difficult or impossible to learn which degree of external rotation as a solitary movement was achieved as a result of SSN neurotization. This lack of specific information can be explained as follows. First, different scoring systems are used to evaluate external rotation, which commonly include other shoulder movements such as abduction. Second, results of nerve repairs and secondary surgery by tendon transfers are pooled.

Two SSN neurotization procedures commonly are applied, namely nerve grafting from C5 and nerve transfer of the accessory nerve (XIN). It is still not clear whether grafting and transfer render different outcomes.

In the present study we evaluated the restoration of glenohumeral external rotation based on infraspinatus muscle activity as the primary outcome of SSN neurotization. In addition, the results of nerve grafting from C5 and accessory nerve transfer were analyzed to determine specific factors affecting recovery.

Patients and methods

We performed a retrospective analysis of patients who had undergone surgery between 1990 and December 31 2000 at the Department of Neurosurgery, Leiden University Medical Centre. The clinic is a multidisciplinary tertiary referral center for nerve injuries in the Netherlands. During this period, approximately 250 children were referred for evaluation of OBPL.

Inclusion-criteria for the current patient series were as follows.

First, neurotization of the SSN had to have been performed by nerve grafting from C5 or by transfer using the accessory nerve. Other types of reconstruction (for instance, C5-C5 nerve grafting or neurolysis of the C5-SSN nerve trajectory) therefore were excluded from analysis. Second, the patient had to have been followed up for at least 2 years. The preferable end point of evaluation of the nerve surgery was 36 months after the operation to ensure that a neurological end stage had been reached. Five patients, however, were evaluated less than 24 months after nerve surgery (mean, 18.2 mo) because early development of contractures of the glenohumeral joint had occurred. In these patients, the consulting orthopedic surgeon advised early surgical intervention to prevent permanent joint deformities. Exclusion of these patients probably would have led to inclusion bias; therefore, we chose to include them despite the short interval between nerve surgery and evaluation. In this group, the end point of evaluation that was chosen just before the secondary surgery. Eighty-six patients matched the present inclusion criteria. Most infants underwent surgery after 1995. Patient details are provided in Table 1.

The extent of the neurological deficit was determined at the first outpatient visit. The indication for ancillary testing and nerve repair was the presence of a paretic biceps muscle less than M3 (Medical Research Council [MRC]-scale[21]) at the age of 3 months.[12] All patients were investigated before surgery using computed tomographic (CT) myelography under general anesthesia, ultrasound of diaphragm excursions, and EMG. The mean interval between first patient visit and CT myelography was 42 days. Twenty-nine patients were older than 3 months at the time of referral. Both of these factors resulted in a mean age at the time of surgery of 5.3 ± 2.4 months (standard deviation). At admission the indication for intervention was reconsidered and surgery was canceled if spontaneous recovery had occurred.

The operative procedure, performed under general anesthesia, consisted of exposing the supraclavicular part of the brachial plexus in the lateral neck triangle through a straight incision parallel to the clavicle. Depending on the extent of injury, the infraclavicular part was also exposed. Diagnosis of the severity of the nerve lesion (i.e., axonotmesis, neurotmesis or root avulsion) was based on CT-myelography results[22,23] and was combined with the assessment of the extent and location of neuroma formation and inspection of the spinal nerves at the intraforaminal level to exclude root avulsion. Selective electrical stimulation of all involved spinal nerves was performed using a bipolar forceps in combination with a 2.5-Hz pulse generator (Braun-Aesculap, Tuttlingen, Germany) with increasing voltage (maximum, 6 V). Resection of the neuroma was performed when stimulation resulted in contractions of less than MRC 3 of the related muscles. In a frozen-section examination of a slice of the entire cross sectional area of the C5 proximal stump, the neuropathologist assessed the fascicular architecture, epineurial and perineurial fibrosis or neuroma formation, and the presence of ganglion cells. The total quantity of myelin in the entire cross-sectional area of the donor stump was expressed semi-quantitatively: 1) < 25%; 2) ≥ 25% and < 50%; 3) ≥ 50% and < 75%; and 4) ≥ 75%.[24] The proximal stump was used as an outlet for nerve grafting when the following criteria were met: 1) the CT myelography demonstrated intact roots; 2) the fascicular architecture of the nerve cross section appeared normal and no or only slight epineurial fibrosis, perineurial fibrosis, or both, were present; 3) the frozen section showed ≥ 50% myelin; 4) no ganglion cells were found.

The first goal of nerve repair was restoration of hand function, if this was necessary; the second priority was restoration of elbow flexion; and the third goal was recovery of shoulder movements. Preferentially, nerve grafts were led out from a viable proxi-

Table 1: **Patient characteristics**

	C5-SSN	XIN-SSN
n	65	21
sex #		
male / female	30 / 35	13 / 8
affected side #		
left / right	29 / 36	11 / 10
presentation at birth ##		
cephalic	60 (92%)	16 (76%)
breech	5 (8%)	5 (24%)
neurological deficit #		
C5-C6	20 (31%)	7 (33%)
C5-C7	34 (52%)	8 (38%)
C5-T1	11 (17%)	6 (29%)
age at first outpatient visit		
mean ± SD (mo) *	3.4 ± 1.9	3.4 ± 1.8
age at operation		
mean ± SD (months) *	5.3 ± 2.3	5.3 ± 2.6
surgical diagnosis upper trunk ###		
no root avulsions	58 (89%)	5 (24%)
1 or 2 root avulsions	7 (11%)	16 (76%)
follow-up		
mean ± SD (mo) *	37.6 ± 8.1	36.4 ± 11.6
< 24 months	3	2
24-35 months	24	7
36-48 months	32	10
> 48 months	6	2

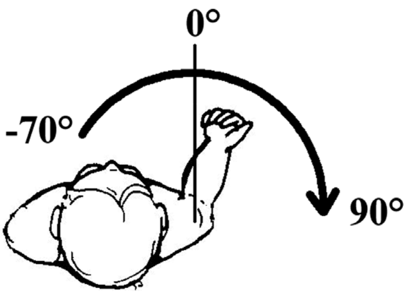
Characteristics are given for number of patients (n), except where otherwise is stated
no significant difference (Pearson chi-square test)
P<0.05 (Pearson chi-square test)
P<0.001 (Pearson chi-square test)
* no significant difference (independent t-test)

mal nerve stump to distal target stumps to achieve these goals. SSS neurotization to reanimate external rotation was pursued preferentially by a single graft from C5, because the cross sectional area of the SSN is usually equal to that of one sural nerve graft. C5-SSN nerve grafting could not be performed when the cross sectional area of the C5 stump was fully covered with grafts to neurotize distal elements for reanimation of hand or biceps muscle function. C5-SSN nerve grafting was also not performed when the C5 stump did not meet our aforementioned criteria for proximal outlets. In these instances, an XIN-SSN nerve transfer was performed, which succeeded with direct coaptation in all patients. After surgery, the child's upper body was placed in a prefabricated body cast for 2 weeks to limit movement of the head and affected arm.

Patients were examined at our outpatient clinic at 6-month intervals. The active and passive range of external rotation was noted in degrees. The results of SSN neurotization were evaluated by measuring the true glenohumeral external rotation which can be executed only by infraspinatus muscle contraction. This movement is defined as the angle between the position of the elbow flexed (actively or passively) at 90 degrees resting against the abdomen and the position of the flexed forearm after external rotation[25] (Figure 1). The patient was asked to stand straight, that is curvature of the spine to compensate for a lack of external rotation was prevented by the examiner. Additionally, the upper arm was held in adduction by the examiner. In this way, glenohumeral external rotation could be distinguished from functional external rotation, which is executed by combined thoracoscapular and glenohumeral movements. Routinely, this movement was evoked first in the unaffected arm to familiarize the child with the movement (Figure 2). In most of the children it seemed particularly helpful to evoke external rotation by offering a toy or a raisin. In addition, two functional features that are also evaluated in the Mallet score[26] were assessed: namely, the ability to reach the mouth and the head with the hand (Figure 3).

The SPSS package (version 11.0.1; SPSS, Inc, Chicago, IL) was used for statistical analysis. Ordinal regression[28] was applied to model the dependence of external rotation ranked in four ordinal categories (none, < 0°,0°-20°, > 20°) on a set of ordinal and continuous predictors (passive external rotation, age at surgery, extent of lesion and type

Figure 1: **Evaluation of true glenohumeral external rotation**



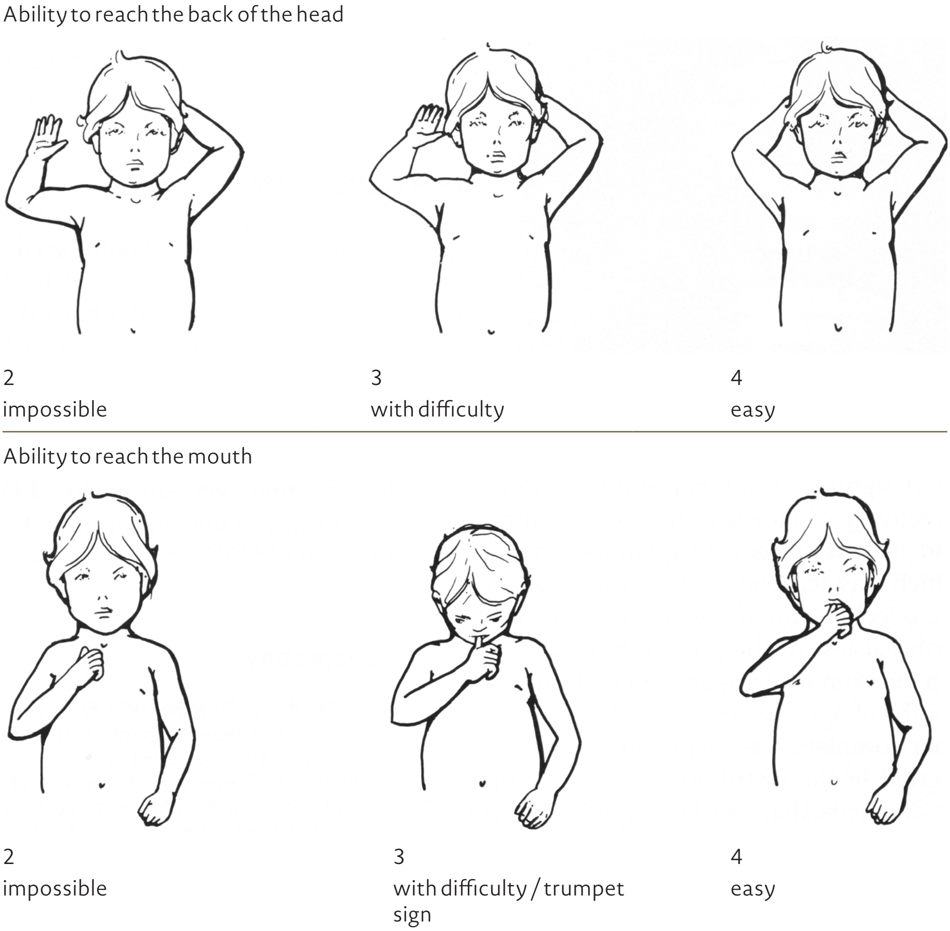
True glenohumeral external rotation is defined as the angle between the position of the ninety degrees flexed elbow resting against the abdomen and the position of the underarm after external rotation. The sagittal plane is define as zero degrees.

of repair). This model was also used to test whether the outcome of external rotation influenced the ability to reach the mouth and the head. Tabular categorical data were analyzed using Pearson's chi square test; comparison of means was performed using the independent t-test.

Results

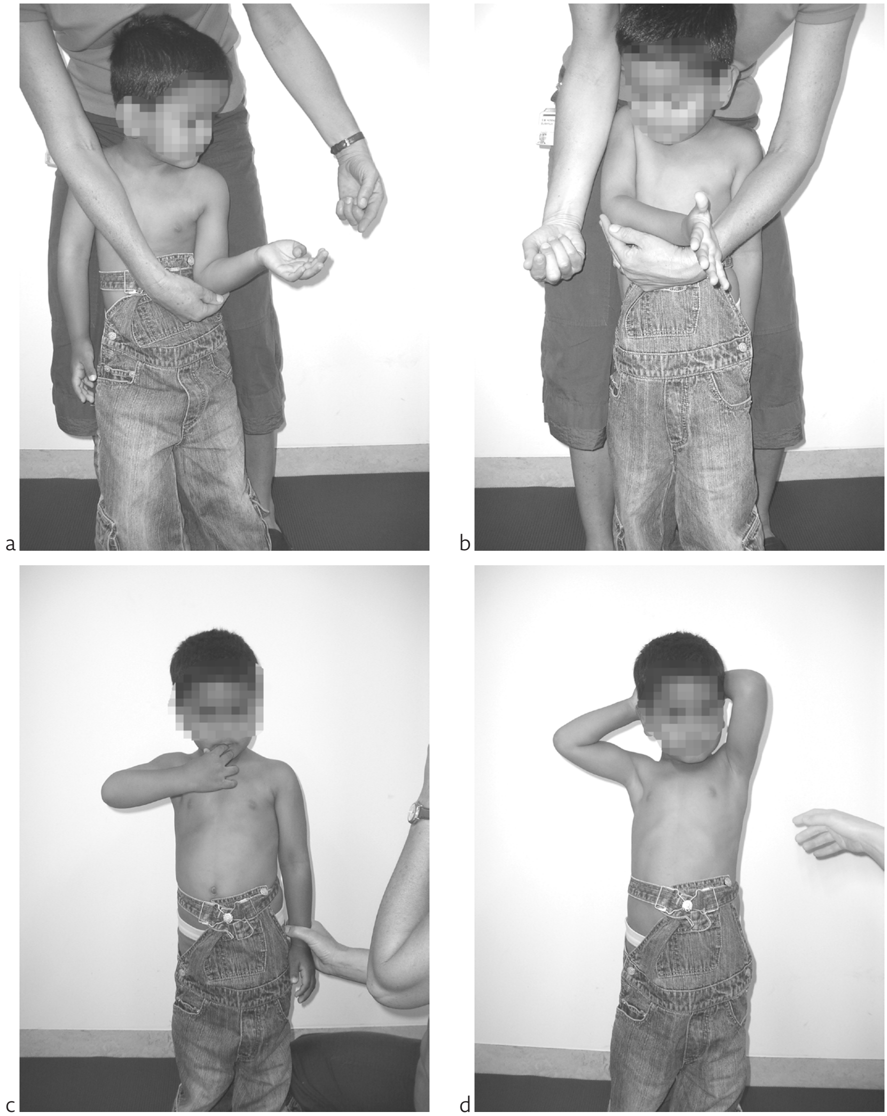
The percentage of total lesions in the XIN-SSN group was 29% as compared with 17% in the C5-SSN group (not statistically significant). Breech presentations occurred in 24% of the XIN-SSN group versus 8% in the C5-SSN group, and in 76% of patients in the XIN-SSN group, one or more avulsions were present compared with 11% in the C5-SSN group (both statistically significant). (Table 1) The mean age at first evaluation, mean age at surgery and length of follow-up were equal in both groups.

Figure 3: **Mallet score**



Items from the Mallet-score to evaluate the ability to reach the mouth and the back of the head.[27]

Figure 2: **Patient evaluation**



Photographs of a 3.5 year old boy with OBPL, who underwent surgery at five months of age. At exploration, a neurotmetic lesion of the superior trunk was found. Nerve grafting was performed from C5 to the SSN. In addition, grafts were led from C5 and C6 to the anterior and posterior divisions of the superior trunk. a) External rotation of the unaffected arm. The examiner asks the boy to move his hand outward to the examiner's hand, while the elbow is fixed in adduction at the side of the body. b) In the affected arm recovery of true glenohumeral external rotation had failed. Note the extension of the wrist and fingers with which the boy tries to overcome the lack of external rotation. Compensatory curvature of the spine was prevented by the examiner. c) The boy can reach the mouth, although compensatory abduction of the upper arm is needed: the so-called trumpet-sign (score 3). d) The head is easily reached (score 4).

Taking the group as a whole, 17 (20%) of the 86 patients gained more than 20 degrees range of external rotation. Restoration of true glenohumeral external rotation failed in as many as 35 patients (41%). (Table 2) The functional evaluation showed that 69 (87%) of 89 patients could reach their mouth (score 3 or 4) (Figure 3), and 57 children (75%) could reach their head (score 3 or 4). Biceps muscle force against gravity was present in 92% of patients.

According to the ordinal regression model, no statistically significant influence of method of repair (grafting versus transfer), extent of the lesion or age at surgery was found on external rotation. There was a significant relation between passive external rotation and true active glenohumeral external rotation ($p<0.001$). The outcome of true external rotation had a statistically significant effect on the hand-to-mouth score ($p<0.001$) and the hand-to-head score ($p=0.001$).

Discussion

To date, it is accepted that infants with OBPL who do not show spontaneous recovery will be treated surgically. In the present series we report on the results of SSN neurotization in 86 patients by means of grafting from C5 or transfer of the accessory nerve

***Table 2:* Outcome**

	C5-SSN	XIN-SSN	Total
n	65	21	86
True glenohumeral external rotation #			
none	24 (37%)	11 (52%)	35 (41%)
to 0°	16 (25%)	4 (19%)	20 (23%)
0° – 20°	11 (17%)	3 (14%)	14 (16%)
> 20°	14 (22%)	3 (14%)	17 (20%)
Passive glenohumeral external rotation			
mean ± SD (degrees) *+	32° ± 37°	44° ± 31°	35° ± 36°
Mallet hand – mouth #			
missing data	5	2	7
not possible (2)	8 (13%)	2 (11%)	10 (13%)
with trumpet sign (3)	22 (37%)	7 (37%)	29 (37%)
without trumpet sign (4)	30 (50%)	10 (53%)	40 (51%)
Mallet hand – head #			
missing data	7	3	10
not possible (2)	14 (24%)	5 (28%)	19 (25%)
with difficulty (3)	13 (22%)	8 (44%)	21 (28%)
without difficulty (4)	31 (53%)	5 (28%)	36 (47%)
Biceps strength #			
missing data	-	-	-
MRC <3	4 (6%)	3 (14%)	7 (8%)
MRC 3	11 (17%)	1 (5%)	12 (14%)
MRC >3	49 (77%)	17 (81%)	66 (78%)

Outcomes are given for number of patients (n), except where otherwise is stated. percentages are calculated from the total of valid observations.
[#] no significant difference (Pearson chi-square test)
* no significant difference (independent t-test)
[+] data missing in 7/65 patients from the C5-SSN and 4/21 from the XIN-SSN group

(XIN). Successful SSN neurotization will lead to recovery of the infraspinatus muscle for external rotation and the supraspinatus muscle for abduction. In this study, the result of the SSN neurotization was defined as the range of true glenohumeral external rotation, which could be effected only by infraspinatus muscle contraction. We did not include abduction as a parameter to analyze the outcome of SSN neurotization for the following reason. In addition to SSN neurotization, grafting to the posterior division of the superior trunk was performed in most of the patients. This grafting ultimately may add to the improvement of abduction because it may result in functional recovery of the medial part of the deltoid muscle. In our opinion, it is not possible to analyze supraspinatus and deltoid muscle in infants with OBPL separately. Good recovery of abduction, therefore, may be attributed wrongly to successful SSN neurotization, whereas, in fact, it may be at least partially based on successful neurotization of the posterior division of the superior trunk.

Some degree of external rotation was achieved in 51 (59%) of 86 children. This means that in 35 patients (41%) external rotation did not recover; that is functional infraspinatus muscle reinnervation did not occur. The results of SSN neurotization are disappointing and far less favorable than the restoration of biceps muscle force greater than MRC 3, in more than 90% of the same group. The disappointing results may be explained partly by the way we defined outcome. The present evaluation concept was adapted to the view of Narakas[25] who emphasized the importance of discrimination between true glenohumeral motion and the total range of motion, the latter also including thoracoscapular movement. Functional scores show much better results: 88% of the children reach their mouth and 75% reach their head. Although the outcome of true glenohumeral external rotation was found to be limited, successful SSN neurotization contributes to improved function. Indeed, we found a statistically significant effect of true glenohumeral external rotation on the ability to reach the head and mouth.

Comparison of our results with those of others proved difficult because of different methods of evaluation. In the literature, results on restoration of glenohumeral external rotation are not expressed in degrees of active range of motion. Nor did we come across articles calling attention to our effort taken during evaluation to eliminate the unintentional compensatory tricks to increase the functional external rotation range, such as thoracoscapular movements and curvature of the spine. Only recently, prevention of thoracoscapular movements was emphasized in the evaluation of passive glenohumeral movements in relation to shoulder deformities.[29]

The most commonly used scoring system is the Mallet score, which combines five movements of the shoulder in one score ranging from 1(flail shoulder) to 5 (normal shoulder).[26] Using this scoring method, the results of global shoulder function after nerve surgical repair are good.

Two modifications of the Mallet score have been proposed, but they have not found wide acceptance so far.[30,31]

Waters[32] 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 patients are provided after nerve grafting.

Another evaluation system is the Toronto Movement Scale. However, in most reports using this scale for the evaluation of outcome after surgery, a sum score for different movements is presented, and data on external rotation as an isolated movement are not provided.[13,33] In one meeting abstract, Marcus et al.[34] presented the results of a direct comparison between nerve grafting and transfer using the Toronto score. No difference was found between the two methods of repair, which is in accordance with our findings. However, details of the exact nature of the lesions (i.e., neurotmesis or root-avulsion) in groups are missing.

Results according to the MRC scale have been reported for only a limited number of patients.[16]

In the present series, there was no statistically significant difference between results of C5-SSN nerve grafting and XIN-SSN nerve transfer, although results from nerve grafting tended to be slightly better. Caution should be exercised in interpreting these data. Ideally, two identical patient groups should be compared, differing only in nerve repair technique used to neurotize the SSN. However, this was not the case in this study. For instance, in the XIN-SSN group, a significantly greater number of patients had root avulsions. Differences between patient populations may contribute to a difference in postoperative recovery potential.

The only significant factor related to the restoration of active true glenohumeral external rotation was the passive range of external rotation. This relationship, however, seems somewhat dualistic. On the one hand, active glenohumeral external rotation may be limited because of a decreased passive mobility of the joint, which in turn may be caused by a persisting paresis of the infraspinatus muscle. On the other hand, recovery of infraspinatus muscle function in turn may improve the passive movement range. We have noted that the passive range of motion in the C5-SSN grafting group was slightly smaller than in the XIN-SSN transfer group. Although not statistically significant, this finding may indicate that there was a slightly stronger tendency to develop an internal rotation contracture in the C5-SSN group as compared with the XIN-SSN group. We hypothesize that the type of OBPL lesion, or more specifically the number of root avulsions, is one of the factors that plays a role in internal rotation contracture formation.

We found no statistically significant influence of the well-known factors that affect the results of nerve repair in general, i.e. method of repair (grafting versus extraplexal neurotization), timing of repair and extent of the lesion.

Other factors might influence functional recovery following SSN neurotization. First, we have not routinely dissected the SSN up to the level of the suprascapular notch to exclude a two-level lesion. We believe that the OBPL trauma mechanism is unlikely to lead to SSN damage at the level of the notch. In our view, it is improbable that this factor accounts for the high percentage of our failures. Second, there may be some controversy about the optimal site for attaching the nerve graft onto the C5 stump to derive SSN fibers from it. As a rule, we have coapted the graft to the SSN at the rostroventral part of C5[35], which has not yet been proved to be the optimal site. Third, the quality of the proximal stumps is known to affect the result of nerve grafting.[24] All proximal stumps used were of good quality as judged by frozen-section examination. Only six stumps used as outlets contained 50% to 75% of the normal amount of myelinated fibers. Although indicative of a reduced regenerative capacity, the impact of this factor on the outcome of C5-SSN grafting may not have been serious.

A factor that might have influenced the outcome of the nerve transfer procedure is the location where the XIN was cut to obtain direct coaptation to the SSN. The number of axons in the XIN decreases from proximal to distal because of branching of terminal nerve to the different parts of the trapezius muscle. Therefore, the more distally the XIN is transected, the fewer the number of axons that become available for reinnervation of the infraspinatus muscle. This will have a negative effect on the result of the nerve transfer. As a rule, we cut the XIN distal to the branches to the upper part of the trapezius muscle. At this level, the XIN contains approximately 1700 to 2000 axons.[36] We have not evaluated the effect of partial denervation of the trapezius muscle on shoulder movement, an effect that is claimed to be negligible,[16,36,37] although detailed studies are lacking.

The question now arises: what is the optimal evaluation method for the results of nerve surgery in OBPL? If the goal of the analysis is the evaluation of a particular type of nerve repair, we believe a critical analysis of the reinnervated muscle – as used in this study – is indicated. An evaluation of the ability to perform daily tasks, however, will produce a better reflection of the handicap of patients with OBPL. We found a large discrepancy between the two types of evaluation. The degree of restoration of true glenohumeral external rotation after SSN neurotization was low, whereas functionally most patients seem to do well. We therefore conclude that patients with OBPL have a capacity to adapt functionally to minimize their handicap. The capacity to adapt may be based partially on the development of joint contractures resulting in a functional arthrodesis. In addition, the young age of these patients may explain the greater capacity to adapt successfully. Consequently, for the correct interpretation and comparison of surgical results in OBPL, we would prefer results to be presented as a true range of motion as well as from a functional point of view.

Conclusion

The result of neurotization of the SSN, whether by grafting from C5 or XIN transfer in OBPL, is disappointing when true glenohumeral external rotation is evaluated. Successful reinnervation of the infraspinatus muscle contributes to the functional outcome in these children, which remains limited in only a minority of the patients.

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