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The components of shoulder and elbow movements as goals of primary reconstructive operation in obstetric brachial plexus lesions

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ABSTRACT

Most of the cases of obstetric brachial plexus lesions (OBPL) show satisfactory improvement with conservative management, but in about 25% some surgical treatment is indicated. The present paper analyzes the effects of primary reconstructive surgeries in aspect of achieving delineated intraoperatively goals.

Children operated before the age of 18 months with follow-up period longer than 1 year were selected. Therapeutic goals established during the operation were identified by analysis of initial clinical status and operative protocols. The elementary movement components in shoulder and elbow joints were classified by assessing range of motion, score in Active Movement Scale and modified British Medical Research Council scale of muscle strength. The effect was considered satisfactory when some antigravity movement was possible, and good when strength exceeded M3 or antigravity movement exceeded half of range of passive movement.

In 13 of 19 patients most of established goals were achieved at good level, in 2 at satisfactory level. Remaining 4 patients showed improvement only in some aspects of extremity function. In 2 patients improvement in some movements was accompanied by worsening of other movements.

The analysis of results separated into individual components of movements showed that goals were achieved in most of the cases, simultaneously clearly indicating which damaged structures failed to provide satisfactory function despite being addressed intraoperatively.

The good results were obtained mainly by regeneration through grafts implanted after resection of neuroma in continuity, which proves that this technique is safe in spite of unavoidable temporary regression of function postoperatively.

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1. Introduction

Obstetric brachial plexus lesions (OBPL) always put parents in great distress and raise concerns about future function of the impaired limb. Its frequency, despite achievements of modern obstetrics, remains relatively stable in developed countries, lying between 0.2 and 5.1 per 1000 live births (in Poland it is estimated to be 0.4–2/1000) [1]. Even though this entity is known since long time – it was mentioned for the first time by Smellie in 1764, the treatment method still evolves. After discouraging results of first attempts of surgical treatment in the beginning of XX century the development of microsurgery in 70s improved the effects (Millesi, 1977; Narakas, 1978; Gilbert et al., 1980; Terzis et al., 1986) [2] and the struggle for optimization of surgical strategy began. In the same time the questions aroused whether complicated and invasive treatment of illness, which is not life-threatening and may cure by itself, is indicated at all.

Metaanalysis done by Pondaag [3] showed that in 70–90% of cases the injured limb regains proper function without surgical intervention. Restoration of antigravity movements before the end of second month of life is a good prognostic factor allowing limitation of therapeutic process to physiotherapy alone. In cases with absent antigravity function of biceps muscle by the end of third month of life and no surgery performed persistent paresis can be expected with serious functional impairment. Among the patients with serious injuries (Narakas' group 3, Table 1) the ratio of conservatively treated patients with satisfactory function decreases radically to 23%, and in Narakas' group 4 – to zero.

Contemporary publications show considerably better final results in groups of patients treated surgically than can be expected from conservative treatment as described above [4].

Despite improvements in radiological visualization methods (myelo-CT, MRI) and electrodiagnostic studies (EMG), physical examination remains the basis of the qualification for the surgery and can be repeated every few months to select the patients in the earliest moment when the expected final result of spontaneous recovery is less than satisfactory. The most commonly used criteria recommend early operation (about 3 months of age) in total injuries comprising all levels of the plexus, especially if root avulsions are suspected [6]. Lack of biceps function at 3 months of age is another widely used criterion [4]. In cases of upper brachial plexus lesion without balanced recovery of shoulder and elbow movements at the age of 3 months the physiotherapy can be continued for another 3 months, which should be enough time to reach at least good level of function, and if impairment persists surgical management yields better final result [7]. If proximal recovery is doubtful then coexisting weakness of hand function (usually extension of wrist or fingers) indicates the lesion wider than C5 and C6 roots and suggests the necessity of surgery. Profound impairment of external rotation of the arm with satisfactory improvement of other movements is frequently observed. It is an indication for neurotization of suprascapular nerve by distal part of accessory nerve, which can be performed relatively late – up to the age of 18 months [7].

The abundance of currently available and continuously developed surgical methods matches the complexity of brachial plexus injury problems. They can be divided in two groups: operations targeted at restoring of function of particular nerves and operations replacing the function of paralyzed muscle with another muscle. The operations regarding nerve function can further be classified as intraplexic reconstructions (mostly by autologous sural nerve grafts, anatomic – between proximal and distal stump of the same structure, and non-anatomic – grafts from the part of the plexus other than proximal stump of injured structure) and nerve transfers in order to supply the non-functioning nerve with regenerating axons from another, less important nerve (Fig. 1).

The progress in understanding of the impact of particular muscle groups, comprising the functional elements of the extremity, on global limb function led to development of therapeutic priorities in the management of paresis [2,7], which are summarized in Table 2 and provide useful guidance in frequently encountered insufficiency of sources of regenerating axons (for example in avulsion injuries, but also in cases of unbalanced recovery when improvement of some function would endanger already regained function of other injured structure). Applying this knowledge enables us to redirect the axons from the best available sources to the targets of the highest priority, independently from anatomic location, e.g. when lower roots are avulsed the restoration of hand function is of highest priority and can be achieved by grafting from the upper roots with preserved regeneration potential to the lower trunk of the plexus (Fig. 1).

This paper analyses the degree of achievement of therapeutic goals established according to the above described priorities.

2. Patients and methods

In July 2010 the whole spectrum of microsurgical reconstructive methods for brachial plexus injury was introduced to our hospital. Until October 2015 we performed 43 operations (36 in patients with OBPL and 7 operations in 6 patients with brachial plexus injury in later age). 30 patients with OBPL had primary

Table 1 – Classification of obstetric brachial plexus injuries according to Narakas.

Group	Range	Clinical presentation
I	C5–C6	Paralysis of shoulder and biceps
II	C5–C7	Paralysis of shoulder, biceps and forearm extensors, function of long flexors at the forearm is preserved
III	C5–Th1	Complete paralysis of limb (a trace of finger flexion may be present)
IV	C5–Th1 + Horner sign	As above with Horner sign (root avulsions probable)

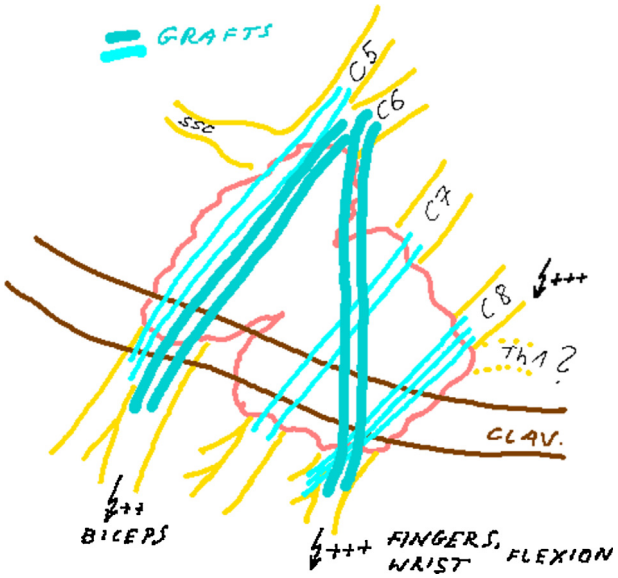

Fig. 1 – Schematic drawing of the lesion and performed reconstruction. Intraoperative findings included: a neuroma involving all levels of the plexus, Th1 root avulsed, C8 root suitable for reconstruction. Due to total lesion restoration of finger and wrist flexion was the highest priority, together with elbow flexion. Relevant structures (anterior division of upper trunk and anterior division of lower trunk) were targeted by grafts supplied from C6 root, which was assessed as the best one. Remaining parts of the trunks were addressed in typical manner using remaining material from both sural nerves for grafts. Suprascapular nerve was subsequently targeted by transfer of distal part of spinal accessory nerve.

reconstruction of the injured plexus performed before the age of 18 months. For the detailed analysis we selected 19 of them with available data from follow-up visit after at least 1 year after operation. In two of them, who had secondary operations, we used the last data obtained more than one year after primary intervention but before secondary operation. In one case the primary reconstruction was performed in two stages, with 3 months interval between them, and they are treated as one treatment. The degree of injury according to Narakas scale is shown in Table 6. Due to selected follow-up period of one year only the recovery of proximal part of the extremity (shoulder and elbow movements) were analyzed, as recovery of distal function cannot be considered final yet.

Table 2 – Priorities in management of obstetric brachial plexus lesions.

1.	Motor and sensory reinnervation of a hand
2.	Elbow flexion
3.	Shoulder flexion/abduction
4.	Elbow extension
5.	Shoulder external rotation
6.	Wrist stability
7.	Forearm pronation/supination

Table 3 – Active Movement Scale.

Description	Grade
Gravity eliminated	
No contraction	0
Contraction, no motion	1
Motion ≤ 1/2 range	2
Motion > 1/2 range	3
Full motion	4
Against gravity	
Motion ≤ 1/2 range	5
Motion > 1/2 range	6
Full motion	7

Three methods of assessment of extremity function, applicable both in infant period and later, were chosen from various methods used during follow-up visits: Active Movement Scale (Table 3), simplified British Medical Research Council scale for strength, without assessment of movement against resistance, and range of active movement expressed in degrees.

The physical examination before surgery served as a basis for establishing groups of muscles responsible for particular movements as the targets for reinnervation. As a rule, reaching all identified targets was attempted intraoperatively, but the strategy was verified during the operation and in cases when achieving all goals was not possible they were limited according to accepted priorities and secondary surgeries using other techniques at the appropriate time were suggested. Nerve structures serving as primary supply for particular movements and considered as potential reinnervation targets are shown in Table 4.

Functional approach enables flexible choice and optimization of surgical techniques according to availability of the sources of regenerating axons. For example regaining of elbow flexion is usually possible by grafting from one of C5 or C6 roots to anterior division of upper trunk, but if these roots are not available, e.g. due to avulsion, the same goal can be achieved by transfer of ulnar nerve fascicle to the branch of musculocutaneous nerve supplying biceps muscle (Oberlin transfer), despite the anatomical structure of the plexus is not restored. We analyze in this paper the achievement of established goals regardless of the method chosen intraoperatively.

The therapeutic effect was classified using following rules (Table 5):

- good when regained strength allowed movement against resistance or active movement against gravity with the range greater than a half of passive range of motion;
- satisfactory when strength was sufficient for antigravity function, as this allows voluntary placement of the extremity in the space and makes other preserved or recovered movements usable;
- unsatisfactory when final status was better then initial (e.g. increased active range of motion) but the strength was insufficient for antigravity function;
- unchanged when scores/degree assigned to the function were the same as initial ones (including cases when neuroma was resected and grafting was performed, and after initial paralysis the recovery of function as a result of reinnervation did not exceed the initial level);

Table 4 – Nerve structures being possible targets for reconstruction and primary movement related to them.

Structure	Movement
Anterior division of upper trunk, musculocutaneous nerve	Elbow flexion
Posterior division of upper trunk, axillary nerve	Shoulder abduction and flexion
Suprascapular nerve	Shoulder external rotation
Middle trunk, radial nerve	(Elbow extension), wrist extension, (fingers extension)
Anterior division of lower trunk	Wrist and fingers flexion
Posterior division of lower trunk	Wrist and fingers extension

Table 5 – Rules for classification of the effect of reconstruction used in present paper.

Classification		Criteria during clinical examination
Good	G	Strength sufficient for movement against resistance (>M3 according to BMRC) or movement against gravity exceeding half of passive range of motion (AMS 6)
Satisfactory	S	Strength sufficient for antigravity movements (M3, AMS 5)
Unsatisfactory improvement	U	Better then initial state (e.g. larger range of motion) but the strength insufficient for antigravity movement
No improvement	N	The same grade/score as initially
Deterioration	D	Grading in any of the scales or range of active movement expressed in degrees are lower then initially

- worse when any score or range of movement expressed in degrees was lower then initial, even in cases where initial status was functionally useless.

3. Results

The results in particular patients are shown in Table 6. All intraoperative targets are included, together with distal ones, in which the follow-up period is too short to consider the results final and further improvement is possible.

After analysis of the global results regarding function of proximal part of the extremity it is possible to state that 58% of established goals were achieved on good level, and 12% on satisfactory level (Fig. 2). In 4 patients (number 10, 11, 12, 19) the goals were not achieved. In one of these cases (no. 12) improvement of shoulder external rotation was the only goal and after the operation this movement did improved, but insufficiently to be classified as the goal. In 3 other cases at least one root was found to be avulsed, which limited the available sources of axons for reconstruction, especially in case 12, where avulsion of 2 roots and good function of the remaining 3 made grafting impossible and forced to perform only nerve transfers, which resulted in good elbow flexion (higher priority) and week shoulder function. The presence of avulsion injury did not always make the established goals impossible, as in three patients (no. 9, 13, 14) the therapeutic

Table 6 – Outcome in individual patients separated into distinctive operative goals.

Patient's number		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Severity of lesion according to Narakas		1	1	1	1	1	2	2	2	2	2	2	2	3	3	3	3	3	4	4
Type of surgery		Gr	Gr	T	T	T	Gr	Gr	Gr	Gr	T	Gr	T	Gr	Gr	Gr	Gr	Gr	Gr	Gr
SSc	Shoulder ext. rotation	–	G	G	G	G		G	G	G	S	N	U	G	G	U	G	–	U	–
PDUT	Shoulder flexion	G						G	G	G	U	U		G	G	G	G	S	S	U
	Shoulder abduction	–						S	G	G	N	U		G	G	G	G	S	–	–
ADUT or MCN	Elbow flexion	G	G				G	G	G	G	G	S		G		G	G	G	S	D
MT	Elbow extension									G		S			G	G	G	D	–	D
	Wrist extension									N		N			S	G	G	N	–	N
MT/PDLT	Finger extension									U		D			G	G	G	D	–	–
ADLT	Wrist flexion													U				D	U	U
	Finger flexion													G				N	U	U

Abbreviations:
Type of surgery: Gr – grafts (with nerve transfers if necessary), T – only nerve transfers.
"–" (dash) – data not available (note – empty space indicates that given movement was not a target during the operation), G, S, U, N, D – as in Table 5.
ADUT/PDUT – anterior/posterior division of upper trunk, SSc – suprascapular nerve, MCN – musculocutaneous nerve, MT – middle trunk, ADLT/PDLT – anterior/posterior division of lower trunk.

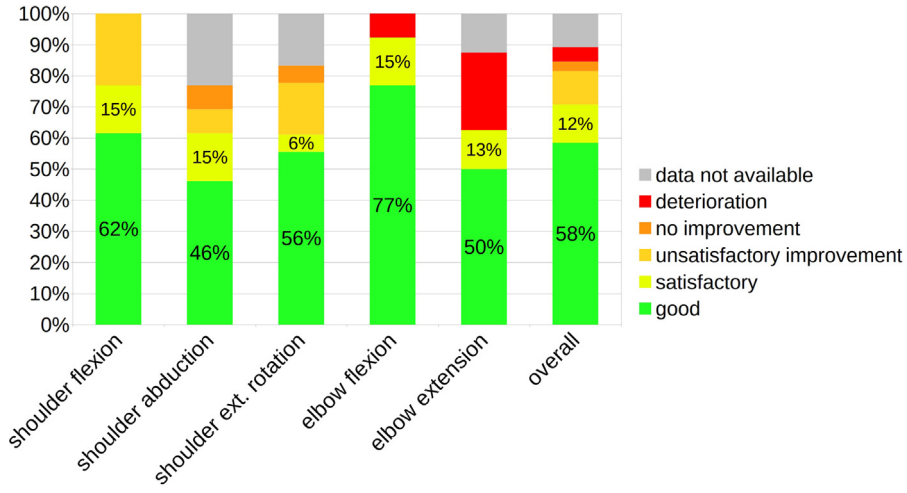

Fig. 2 – Goals separated into individual movement and percentage of their achievement.

result was good and in two (no. 17, 18) – satisfactory. In two patients improvement of some functions was accompanied by deterioration of another. It was related to severe injury and the necessity to include restoration of hand function in the therapeutic plan, which has higher priority than elbow extension. The regress of elbow function in the patient no.19 regarded aggravation of initial profound paresis already making the movement functionally insufficient.

After combining the information about achievement of established goals with the type of performed operation it is noticeable that in 10 of 13 patients with majority of the goals achieved the reconstruction was performed by grafting. After such an operation temporary total paralysis of the muscles supplied by the target nerve is a natural consequence, the result develops after many months and is totally dependent on the quality of regeneration across the grafts. In patients treated by only nerve transfers the applied techniques do not carry the risk of such important deterioration and we did not observed clinically noticeable deterioration of function related to donor nerve in analyzed patients.

4. Discussion

The complexity of movements of human upper extremity and dependence of overall use of the extremity on the cooperation of different elements led to development of assessment scales combining different parameters. One of the most frequently used scales for describing of shoulder function is the Mallet's scale [8], based on assessment of abduction, external rotation and complex movements required to reach the mouth, the neck and the back. Gilbert's scale for shoulder movements [9] assesses simultaneously abduction and external rotation. Global elbow function can be described by Gilbert-Raimondi scale [9] combining flexion, extension and the range of motion. These scales are based on many years of experience and are very useful in describing the long-term results of treatment, when the child can understand and obey commands, but for planning of surgical strategy more detailed approach is necessary, taking into account anatomy of the lesion and the chances of restoring the function of particular muscle groups by directing regenerating axons to individual nerve structures within the plexus or peripheral nerves. Restoration of globally good shoulder function requires both abduction, which recovers mostly by posterior division of upper trunk and external rotation, which depends mostly on suprascapular nerve. General elbow function comprises of flexion, which can be achieved by reconstruction of anterior division of upper trunk or directly branches of musculocutaneous nerve to biceps muscle, and extension which is related to posterior divisions of upper and middle trunks. Assessment of therapeutic results from the perspective of isolated movement components allows direct evaluation of management of particular targets selected for reconstruction and identification of targets without satisfactory result. This can serve as a basis for further analysis of global results and give useful guidance when secondary operations are considered.

In severe cases the necessity of surgical treatment is indisputable [4–6], but obtaining good results is not always possible. Too low number of sources of axons with regeneration potential can limit the chance for good result regardless of applied reconstruction strategy. The results of long-term follow-up published by Gilbert [4] show that good or very good shoulder function in lesions consisting of C5, C6 and C7 roots can be achieved in 61% of cases, and in total lesions average, good or very good result was achieved in 77% of cases. At least good function of elbow in patients with total lesions was achieved in 81% of cases. Yet, these results incorporate also secondary operations.

The rules of management of upper and middle parts of the plexus are not so unequivocal. Appreciating the role of time in making therapeutic decisions, which can be either positive, allowing to observe spontaneous improvement, or negative, delaying the required surgical treatment, the first author prefers to qualify for operation all patients, in whom the low speed of spontaneous recovery raises doubts. This attitude prevents the situation when physiotherapy alone is carried out for many months, the function of the extremity remains

unsatisfactory, but the optimal period for operation (usually defined as first 12–18 months of life) has passed and chances for improvement become severely limited. Such cases have been encountered by one of the authors. Naturally, it can lead to qualification of single patients, who might reach satisfactory outcome even without surgical intervention, but knowing good results of surgical treatment (show in this and other papers) we dare say that even in these cases the operation has no negative impact on final function of the extremity and gives the best chance for improvement.

Intraoperative strategy comprised of the resection of a neuroma in continuity involving the structures responsible for missing function and reconstruction of the gap by autografts is commonly regarded as a primary management method. Still, some authors prefer to restrict the intervention to neurolysis in case of finding of neuroma in continuity, even in total plexus lesions [10], despite such behavior since long is considered ineffective. The authors from Hospital for Sick Children in Toronto, who published the most frequently cited paper regarding this dilemma [11], reviewed their guidelines again in 2009, finding out that in long-term assessment the operations restricted to neurolysis alone are not justified also in lesions limited to upper part of the plexus [12]. In newer publications some authors attempt to support the decision of resection or neurolysis by intraoperative electrophysiological assessment [13], in spite of the failure of earlier investigations in that field [14]. Considering the natural course in patients with OBPL, when in the moment of qualification to operation we most frequently observe continuous but slow improvement and not total absence of function, preserved conduction through the neuroma should not be surprising. The anxiousness about the period of paralysis after resection of the neuroma is understandable, nevertheless, taking into account the repeatedly good results of reconstruction using grafts, limiting the management of neuroma in continuity to neurolysis should be considered an exception rather than a rule [2]. Unless clear prognostic criteria are developed allowing correct prediction of the effect of neurolysis during the operation, the unsatisfactory recovery of function related to the structure producing the neuroma in preoperative assessment remains the main indication for resection of the neuroma.

5. Conclusions

The analysis of short term results of neurosurgical operations separated into individual components of movements showed that goals were achieved in most of the cases, simultaneously clearly indicating which damaged structures failed to provide satisfactory function despite being addressed intraoperatively.

The great deal of good results was obtained by regeneration through grafts implanted after resection of neuroma in continuity, what is consistent with current management strategy and proves the safety of this technique despite unavoidable regression period immediately after the operation.

Conflict of interest

None declared.

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