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Preganglionic injuries in perinatal brachial plexus palsies – results of surgical treatment

Uszkodzenia przedzwojowe w okołoporodowych porażeniach splotu ramiennego – wyniki leczenia operacyjnego

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Abstract

Background and purpose: The authors report their experience in surgical treatment of preganglionic injuries in perinatal brachial plexus palsies.
Material and methods: Clinical material consisted of 16 children, of both sexes, aged from 2.5 to 33 months (mean 6.2 months), treated surgically between 1994 and 2006. The clinical view of the injury and location of preganglionic lesions was analysed and the description of the performed microsurgical techniques is provided. Control clinical examinations included a group of 14 children. The shortest postoperative observation period was 3 years. The currently accepted scales of evaluation of function of particular joints of the upper limb were used.
Results: The following outcome was noted after surgical treatment of perinatal brachial plexus palsies with signs of pre- and postganglionic injuries: good shoulder function in 6 cases, and average in 2 others; good elbow function in 4 cases, and average in 7 patients; functional position of the forearm in 9 cases, and good range of pronation and supination in 1 patient; useful function of wrist (flexion/extension) in 4 cases; good motor hand function in 3 cases, and fair in 6 patients.
Conclusions: In preganglionic perinatal brachial plexus injuries located in the upper-middle part, spinal nerve C7 roots avulsion is the most frequently observed, and in the lower

Streszczenie

Wstęp i cel pracy: W pracy przedstawiono własne doświadczenia w leczeniu operacyjnym uszkodzeń przedzwojowych w okołoporodowych porażeniach splotu ramiennego.
Materiał i metody: Materiał kliniczny stanowiło 16 dzieci, obojga płci, w wieku od 2,5 do 33 miesięcy (średni wiek: 6,2 miesiąca) leczonych operacyjnie w latach 1994–2006. Analizie poddano obraz kliniczny uszkodzenia i lokalizację uszkodzeń przedzwojowych oraz przedstawiono opis zastosowanych technik mikrochirurgicznych. Kontrolne badania kliniczne objęły grupę 14 dzieci. Najkrótszy okres obserwacji pooperacyjnej wynosił 3 lata. Zastosowano powszechnie przyjęte skale oceny funkcji poszczególnych stawów kończyny górnej.
Wyniki: W wyniku leczenia operacyjnego okołoporodowych obrażeń splotu ramiennego łączących w sobie cechy uszkodzeń przed- i pozazwojowych uzyskano: dobrą funkcję stawu ramiennego w 6, średnią w 2 przypadkach; dobrą funkcję stawu łokciowego w 4, średnią w 7 przypadkach; funkcjonalne ustawienie przedramienia u 9 , a dobry zakres ruchu nawracania i odwracania u 1 pacjenta; użyteczną funkcję nadgarstka w zakresie zginania i prostowania w 4 przypadkach; dobrą funkcję ruchową ręki u 3, a zadowalającą u 6 pacjentów.
Wnioski: W przedzwojowych okołoporodowych uszkodzeniach splotu ramiennego w zakresie części górno-środkowej

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part of the brachial plexus, spinal nerve C8 roots avulsion is the most frequently observed. In preganglionic injuries of the brachial plexus, the number of avulsed spinal nerves has an influence on technical possibilities of performing reconstruction procedures, and then the results of the surgical treatment.

Key words: preganglionic injuries, spinal nerve roots avulsion, perinatal brachial plexus palsy, extra-anatomical extraplexus reconstructions, extra-anatomical intraplexus reconstructions.

najczęściej obserwuje się wyrwanie korzeni nerwu rdzeniowego C7, a w zakresie dolnej części splotu ramiennego wyrwanie korzeni nerwu rdzeniowego C8. W uszkodzeniach przedzwojowych splotu ramiennego liczba wyrwanych nerwów rdzeniowych wpływa na techniczne możliwości wykonania zabiegów rekonstrukcyjnych, a co za tym idzie – na wyniki leczenia operacyjnego.

Słowa kluczowe: uszkodzenia przedzwojowe, wyrwanie korzeni nerwów rdzeniowych, okołoporodowe uszkodzenia splotu ramiennego, rekonstrukcje pozaanatomiczne pozasplotowe, rekonstrukcje pozaanatomiczne wewnątrzsplotowe.

Introduction

Brachial plexus palsies with complete disruption of continuity may present as pre- and postganglionic injuries [1-3]. Preganglionic injuries involve spinal root avulsions (Fig. 1) with spinal ganglion cell preservation without peripheral degeneration of sensory fibres [4]. A classic reconstructive operation in cases with preganglionic injury is unfeasible. For functional restoration of the avulsed neural element, a source of regenerating axons is essential [4,5]. Partial or complete sacrifice of function of a donor nerve is then necessary to achieve it.

Anastomosis of an extraplexus nerve with avulsed plexus element is termed an extra-anatomical extraplexus reconstruction (or extraplexus neurotization) [4]. Conversely, when an interrupted element of the brachial plexus is being used, an extra-anatomical intraplexus reconstruction is performed [4].

The most commonly used extraplexus innervation donor sites include: accessory nerve [6-9], intercostal nerves [10-12], phrenic nerve [13,14], hypoglossal nerve [15,16], sensory and motor branches of cervical plexus [17-19], and ventral root of the contralateral C7 spinal nerve [20,21]. In selected situations that involve a spinal nerve roots avulsion with its dislocation outside the foramen and concomitant visualization of the ventral root and spinal ganglion of the dorsal root (Fig. 2), a selective neurotization is feasible, i.e. an anastomosis of a ventral root of an avulsed spinal nerve with motor branches and dorsal root with sensory branches from the cervical plexus [22]. A short distance between both plexuses often facilitates such an anastomosis without sural nerve grafts [18]. All the other clinical scenarios require spinal ganglion dissection with subsequent anastomosis with a regenerating axon donor that originates either from the brachial plexus or outside of it [18].

The aim of our study was to present our own experience in the surgical treatment of preganglionic injuries in patients with perinatal brachial plexus palsies with specific attention to the most common locations of avulsion injuries, the analysis of surgical techniques implemented and the evaluation of surgical outcomes achieved.

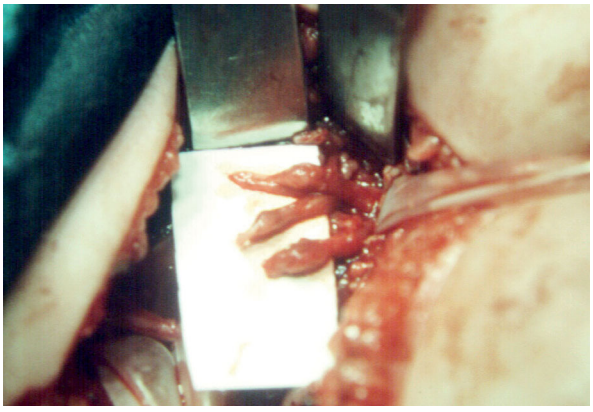

Fig. 1. Intraoperative view: status after avulsion of the spinal nerves roots from the spinal cord

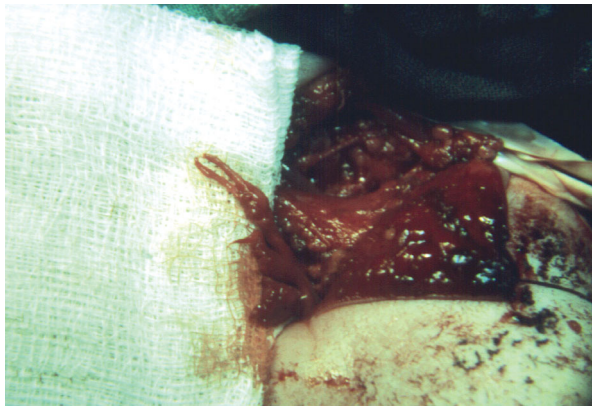

Fig. 2. Intraoperative view: status after avulsion of the roots of the single spinal nerve. Dorsal root with spinal ganglion and ventral root are visible

Material and methods

A retrospective analysis of 16 children of both sexes, aged 2.5 to 33 months (mean age 6.2 months), who underwent surgical treatment for preganglionic brachial plexus injury between 1994 and 2006 was performed. Our cases were selected from a group of 80 surgically treated children among whom 64 presented with signs of isolated postganglionic injury and 16 with signs of preganglionic (avulsive) injury.

Clinical signs and symptoms of the injury, preganglionic injury location and a detailed description of microsurgical techniques (extra-anatomical intra- or extraplexus reconstruction) are summarized in Tables 1 and 2.

Follow-up and outcome were assessed in 14 children. The shortest follow-up period was 3 years. The following scales of evaluation were used:

1. Gilbert's scale for evaluation of shoulder function [23]:
   Stage 0 = complete shoulder flail
   Stage I = abduction or flexion to 45°, no active external rotation
   Stage II = abduction < 90°, external rotation to neutral
   Stage III = abduction = 90°, weak external rotation
   Stage IV = abduction < 120°, incomplete external rotation
   Stage V = abduction > 120°, active external rotation
   Evaluation: stage V – very good result, stage IV – good result, stage III – average result, stage II – poor result.

2. Gilbert's and Raimondi's scale for evaluation of elbow function [23]:
   A. Elbow flexion:
   Nil or some contraction = 0 points
   Incomplete flexion = 2 points
   Complete flexion =3 points
   B. Elbow extension:
   No extension = 0 points
   Weak extension = 1 point
   Good extension = 2 points
   C. Extension deficit:
   0-30° = 0 points
   30-50° = –1 point
   More than 50° = –2 points
   Evaluation: grade I – poor recovery (0-1 points), grade II – average recovery (2-3 points), grade III – good recovery (4-5 points).

3. Al-Qattan's scale for evaluation of forearm rotation moves [24]:
   1 = pronated forearm causing a functional or cosmetic disability
   2 = supinated forearm causing a functional or cosmetic disability

Table 1. Extra-anatomical intraplexus reconstructions in injuries with complete disruption of continuity and spinal nerve avulsion

No.	Clinical presentation	Age (months)	Intraoperative view	Surgical technique
1.	Complete	5	Upper trunk rupture + C7, C8 spinal nerve roots avulsions + Th1 ventral branch compression	Upper trunk reconstruction with grafts (4 × 1.5 cm) + extra-anatomical reconstruction of C7 with anastomosis to proximal stump of the upper trunk + Th1 ventral branch neurolysis
2.	Complete	4	C5, C6 ventral branch ruptures + C7, C8, Th1 spinal nerve roots avulsions	C5 ventral branch reconstruction with upper trunk anastomosis with grafts (3 × 1.5 cm) + extra-anatomical reconstruction of C6 ventral branch with anastomoses with grafts (5 × 2 cm) C7, C8, Th1
3.	Complete	2.5	C5, C6 ventral branch rupture + C7 spinal nerve roots avulsion + lower trunk compression	C5, C6 ventral branch reconstructions with upper trunk anastomosis with grafts (4 × 1.5 cm) + C7 extra-anatomical reconstruction with C6 ventral branch anastomosis + lower trunk neurolysis
4.	Complete	7	C5 ventral branch rupture + C6, C7 spinal nerve roots avulsions+ lower trunk compression	C5 ventral branch reconstruction with direct anastomosis to upper trunk and C6, C7 spinal nerves + lower trunk neurolysis
5.	Complete	4	C5, C6 ventral branch ruptures + C7 spinal nerve roots avulsion + lower trunk compression	C5 ventral branch reconstruction with direct anastomosis to upper trunk and C6 ventral branch with direct anastomosis to C7 spinal nerve + lower trunk neurolysis

Table 2. Extra-anatomical extraplexus reconstructions in injuries with total rupture of continuity and spinal nerve avulsion

No.	Clinical presentation	Age (months)	Intraoperative view	Surgical technique
1.	Upper-middle	9	Upper trunk compression + C7 spinal nerve roots avulsion	Selective, extra-anatomical reconstruction of C7 spinal nerve with direct anastomoses to sensory and motor branches of cervical plexus + external and partial internal neurolysis of the upper trunk
2.	Complete	5	C5, C6, C7 spinal nerve roots avulsions + lower trunk compression	C5, C6, C7 spinal nerves' selective, extra-anatomical reconstruction with direct anastomoses to sensory and motor branches of cervical plexus + lower trunk neurolysis
3.	Complete	5	C5, C6, C7, C8, Th1 spinal nerve roots avulsions	C5, C6 spinal nerves' selective, extra-anatomical reconstruction with direct anastomoses to sensory and motor branches of cervical plexus
4.	Complete	6	C5, C6, C7 spinal nerve roots avulsions + lower trunk compression	C5, C6 spinal nerves extra-anatomical reconstruction with direct anastomoses to motor branches of trapezius muscle and C7 spinal nerve with direct anastomoses to sensory branches of cervical plexus + lower trunk neurolysis
5.	Complete	4.5	C5, C7 ventral branch ruptures + C6 spinal nerve roots avulsion + lower trunk compression	Extra-anatomical reconstruction with direct anastomosis of the proximal part of the ventral branch of C5 with distal part of the ventral branch of C6 and of a distal part of the ventral branch of C5 with cervical plexus branches + direct suture of the C7 ventral branch + lower trunk neurolysis
6.	Complete	3.5	Upper trunk rupture + C7 spinal nerve roots avulsion + lower trunk compression	Upper trunk reconstruction with grafts (3 × 2 cm) + selective, extra-anatomical reconstruction of C7 spinal nerve with direct anastomoses to sensory and motor branches of cervical plexus + lower trunk neurolysis
7.	Complete	33	C5 ventral branch rupture + C6, C7, C8 spinal nerve roots avulsions + Th1 ventral branch compression	Direct suture reconstruction of the C5 ventral branch + extra-anatomical reconstruction of C6 spinal nerve with direct anastomoses to motor branches of trapezius muscle and C7, C8 spinal nerves with sensory branches of cervical plexus + Th1 ventral branch neurolysis
8.	Complete	3	Upper trunk rupture + C7, C8 spinal nerve roots avulsions + Th1 ventral branch compression	Direct suture reconstruction of the upper trunk + extra-anatomical, intraplexus reconstruction with direct anastomosis of C8 with proximal part of upper trunk + extra-anatomical extraplexus reconstruction of C7 with direct anastomosis with sensory branches of cervical plexus + Th1 ventral branch neurolysis
9.	Complete	3	Partial rupture of the upper trunk with neuroma-in-continuity formation + C7 spinal nerve roots avulsion + lower trunk compression	Extra-anatomical reconstruction with direct anastomosis of C7 spinal nerve with cervical plexus branches + upper and lower trunk neurolysis
10.	Complete	3	C5 ventral branch rupture + C6, C7, C8 spinal nerve roots avulsions + Th1 ventral branch compression	C5 ventral branch reconstruction with anastomoses to upper trunk and C6 spinal nerve with grafts (4 × 1.5 cm) + C8 extra-anatomical reconstruction with direct anastomoses with motor branches of trapezius muscle and C7 spinal nerve with sensory branches of cervical plexus + Th1 ventral branch neurolysis
11.	Complete	2.5	C5, C6, C7, C8, Th1 spinal nerve roots avulsions	Extra-anatomical reconstruction of C5, C6 spinal nerves with direct anastomoses to motor branches to trapezius muscle and C7 spinal nerve with anastomoses to sensory branches of the cervical plexus

3 = functional forearm position (mid pronation-supination or slight pronation) with no or minimal active motion
4 = same as 3 but with good active pronation and supination
5 = normal power and range of motion
Evaluation: operative correction is necessary in grade 1 and 2.

4. Al-Qattan's scale for evaluation of wrist function [24]:
0 = no contraction or flicker of contraction
1 = active movement with gravity eliminated
2 = active movement against gravity only
3 = active movement against resistance with motion reaching ≤ 1/2 normal range
4 = active movement against resistance with motion reaching > 1/2 normal range
5 = normal power and range of motion
Evaluation: functional useful is grade 3 and 4 both to flexion and extension function (F/E).

5. Al-Qattan's scale for evaluation of hand motor function [24]:
0 = useless hand – complete paralysis or slight finger motion of no use, useless thumb
1 = poor function – only very weak grip possible
2 = fair function – there is some active flexion and/or extension of the fingers and some thumb mobility but the hand posture is intrinsic minus
3 = good function – some as 2 but there is no intrinsic minus posture (intrinsic balance)
4 = excellent function – near normal active finger flexion/extension and thumb mobility, with some active intrinsic function
5 = normal function
Evaluation functional useful is grade 3 and 4.

6. BMRC scale modified by Omer and Dellon for evaluation of hand sensory function [25,26].

Results

Surgical outcomes are summarized in Tables 3 and 4. The effect of additional tendon transfer (marked with 'T' in Tables 3 and 4) was also taken into consideration in the outcome evaluation.

Surgical treatment of perinatal brachial plexus palsies with combined pre- and postganglionic injuries resulted in: good shoulder function in 6 cases and average in 2 patients; good elbow function in 4 cases and average in 7 patients; functional forearm position in 9 cases and good movement range for pronation and supination in 1 patient; serviceable wrist flexion and extension in 4 cases; good motor hand function in 3 cases and fair in 6 patients.

Discussion

It is well recognized that vertex delivery might result in lower spinal nerve (C8-Th1) roots avulsions (preganglionic injury) while upper parts of the brachial plexus usually rupture (postganglionic injury) [27]. Certain anatomical conditions favour such a combination [5,28,29]. However, a thorough analysis of the literature provides clear evidence that intraoperatively various combinations of injuries are present. C5 and C6 roots avulsions with rupture or stretching of lower parts of the plexus [14,15,30] or even rare cases of root avulsions of all the spinal nerves that form the brachial plexus [23] have been described. C8 spinal nerve avulsions with concomitant stretching or even fully sustained function of the Th1 nerve or Th1 nerve avulsions with complete rupture or only stretching of the C8 spinal nerve have been found as well [14,31].

In our cohort we have found 4 cases of evident C5 spinal nerve root avulsions, 8 cases of C6 roots avulsions and 15 cases of C7 roots avulsions. In the lower part of the brachial plexus C8 spinal nerve roots avulsions were

Table 3. Results of surgical treatment after extra-anatomical intraplexus reconstructions (see text for details of grading)

No.	Evaluated function				
	Hand	Wrist flexion/extension	Forearm	Elbow	Shoulder
1.	2-S1*	4/4	1	3	IV (T)
2.	0-S3*	2/1	3	2	IV (T)
3.	2-S2*	3/3	3	2	I
4.	4-S4*	4/3	4	3	IV
5.	2-S2*	3/3	3	1	II

**Sensory level in all examined areas (thumb, index finger, fifth finger), T – additional tendon transfer*

Table 4. Results of surgical treatment after extra-anatomical extraplexus reconstructions (see text for details of grading)

No.	Evaluated function				
	Hand	Wrist flexion/extension	Forearm	Elbow	Shoulder
1.	4-S5	5/1	1	5	IV
2.	NDA	NDA	NDA	NDA	NDA
3.	0-S2**/S0***	1/2	3	4	III
4.	3-S2**/S4***	3/1	3	2	I
5.	NDA	NDA	NDA	NDA	NDA
6.	1-S2*	1/1	3	3	II
7.	2-S3*	3/1	2	5	IV
8.	3-S3+*	4/1	3 (T)	0	III
9.	2-S3+**/S2***	1/1	2	4	IV (T)
10.	2-S1*	3/1	3	0	I (T)
11.	0-S1*	2/1	3 (T)	2	0

**Sensory level in all examined areas*
***Sensory level in thumb and index finger*
****Sensory level in fifth finger*
NDA – no data available, , T – additional tendon transfer

more common (7 cases), while Th1 roots avulsions were present more rarely (3 cases). Anand reported similar findings in his cohort of 19 children where he found C8 spinal nerve root avulsions to be the most common in the lower part and C7 spinal nerve root avulsions in the upper part of the brachial plexus [31].

Reinnervation of avulsed spinal nerves in preganglionic brachial plexus injuries is feasible only upon their connection with another neural element that can serve as a source of regenerating axons. Attempts have been made to engraft avulsed roots of the spinal nerve into the spinal cord [32], but they raise many controversies. An increased risk of spinal cord injury or cervical spine instability has been brought to attention [3,33]. For the time being extra-anatomical reconstructions, also called neurotizations or nerve transpositions, remain the main line of treatment in avulsion injuries [3-5,33].

Selected cases of brachial plexus palsies with extensive preganglionic injuries force the surgeon to establish reconstructive priorities owing to the limited number of donors. Some authors emphasize the importance of restoration of adduction and external rotation of the arm along with elbow flexion as particularly important [5,30,34] while others accentuate that the reinnervation should be directed toward the improvement of hand function [23,33,35]. While performing reconstructive surgery in our group we have used ruptured elements of the brachial plexus (Table 1) or sensory and motor branches of the cervical plexus (Table 2) for anastomoses. Primarily we attempted to restore shoulder and elbow functions and subsequently, if possible, hand function. Nonetheless, muscles in the vicinity of the injured site have higher chances for functional recovery due to slow neural regeneration [36]. The aptitude of the cervical plexus for reconstructive purposes arises primarily from its proximity to the brachial plexus and from the availability of motor and sensory branches. On the other hand, limitations of the jugular plexus relate to the relatively small number of neural fibres. Still, efficient muscle reinnervation is sometimes possible even with the limited number of them [18].

Preganglionic brachial plexus injuries are among the most severe neural tissue lesions and have an unfavourable prognosis [37,38]. They usually appear as complete brachial plexus palsies; similar regularity was noticed in our series (15 complete injuries and 1 upper-middle one). Surgical outcomes in avulsion injuries are still unsatisfactory for both patients and surgeons. Nerves used for neurotization physiologically innervate muscles with different functions than those that are enervated subsequent to surgery. In order to achieve voluntary movements of the upper limb neuronal reorganization within the cerebral structures is necessary. Hence, the final motor outcome depends on the adaptive capabilities of the central nervous system [39].

Conclusions

1. Preganglionic, perinatal brachial plexus palsies most frequently encompass C7 spinal nerve roots avulsion in the upper-middle part and C8 spinal nerve roots avulsion in the lower part of the brachial plexus.
2. In preganglionic brachial plexus palsies, the number of avulsed spinal nerves influences the technical prospects of reconstructive surgery and subsequently the surgical outcome.

Disclosure

Authors report no conflict of interest.

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