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Brachial plexus surgery

The role of the surgical technique for improvement of the functional outcome

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ABSTRACT
Objective: The study aims to demonstrate the techniques employed in surgery of the brachial plexus that are associated to evidence-based improvement of the functional outcome of these patients. **Method:** A retrospective study of one hundred cases of traumatic brachial plexus injuries. Comparison between the postoperative outcomes associated to some different surgical techniques was demonstrated. **Results:** The technique of proximal nerve roots grafting was associated to good results in about 70% of the cases. Significantly better outcomes were associated to the Oberlin's procedure and the Sansak's procedure, while the improvement of outcomes associated to phrenic to musculocutaneous nerve and the accessory to suprascapular nerve transfer did not reach statistical significance. Reinnervation of the hand was observed in less than 30% of the cases. **Conclusion:** Brachial plexus surgery renders satisfactory results for reinnervation of the proximal musculature of the upper limb, however the same good outcomes are not usually associated to the reinnervation of the hand.
Key words: brachial plexus surgery, nerve grafting, nerve transfer, palsy.

Cirurgia do plexo braquial: o papel da técnica cirúrgica para a obtenção de melhores resultados funcionais

RESUMO
Objetivo: Análise de resultados das técnicas que comprovadamente melhoraram o prognóstico funcional de pacientes com lesões traumáticas do plexo braquial. **Método:** Estudo retrospectivo de cem casos de lesões traumáticas do plexo braquial. Foi realizada comparação dos resultados pós-operatórios obtidos com as diferentes técnicas utilizadas. **Resultados:** A técnica de enxertia a partir de raízes proximais resultou em bons graus de reinervação em 70% dos casos. Bons resultados ($p<0,05$) também foram relacionados à técnica de Oberlin e de Sansak, enquanto que a transferência frênico-musculocutâneo e acessório-suprascapular não resultaram em melhora que atingisse significância estatística. Reinervação motora da mão foi observada em menos de 30% dos casos. **Conclusão:** A cirurgia de reinervação do plexo braquial em geral resulta em boa recuperação da função proximal do membro, porém esses mesmos bons resultados não são observados em termos de reinervação da mão.
Palavras-chave: cirurgia de plexo braquial, enxertos nervosos, transferência de nervos, paralisia.

In an attempt to recover the function of the affected limb, a number of different techniques has been proposed for brachial plexus reconstruction, including neurolysis, nerve reconstruction (repair or grafting), nerve transfer, tendon transfer, free muscle transplantation, or nerve root reimplantation[1,2]. However, the types of lesion associated to trauma of the brachial plexus encompass a number of different clinical aspects, sustaining different degrees of severity[3,4]. To date, there is no

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standardized surgical protocol determining the best treatment to be offered to patients sustaining brachial plexus injuries, and the operative strategy is mainly based on the surgeon's own experience[5]. Nevertheless, despite the recent advancements on microsurgical techniques obtained on the last two decade, in most of the cases is difficult to provide patients and their families with expectations about the surgical results[6].

This study aims to demonstrate the surgical results of the first one hundred cases of traumatic brachial plexus injuries operated on by the author, focusing on those techniques associated to evidence-based improvement of the final functional outcome of these patients.

METHOD

During the period of 2004 to 2010, author performed 165 brachial plexus surgeries. Included are patients operated at the Hospital de Base do DF, and those cases derived from the author's private clinic. For this study, it was selected the first one hundred cases of traumatic injuries, including only those subjects who reached a minimal postoperative follow-up to assume that the final outcome was obtained (i.e., the muscle reached the maximal strength that could be obtained for each case, or the recovery of sensory protection was considered satisfactory). Exclusion criteria included cases that lost follow-up, and those patients in which surgery was not motivated by trauma (as tumors or compressive etiology). Written informed consent was obtained from each participant, and the study was carried out in accordance with the Declaration of Helsinki II. Our protocol of preoperative evaluation is described elsewhere[7].

The surgical technique included a combined supra and infraclavicular approach in most of the patients. The supraclavicular region was explored via a transverse skin incision located two fingerbreadths over the clavicle, laterally to the sternocleidomastoid muscle. The phrenic nerve was mobilized over the surface of the *anterior scalenus* muscle and the spinal accessory nerve was isolated at the medial border of the *trapezius* muscle. C5, C6 or eventually C7 nerve roots were identified at the lateral border of the *anterior scalenus* muscle. The same route was employed for mobilization of the anterior and posterior division of the upper trunk, and the suprascapular nerve. The infraclavicular brachial plexus was explored via a deltopectoral incision, with section of the *pectoral minor* muscle. The divisions, cords and distal nerves of the brachial plexus (as musculocutaneous, axilary, median, radial and ulnar nerves), in addition to the axilary artery, were mobilized via this approach. Reconstruction using nerve grafts was performed for cases of extra-foraminal rupture, and nerve transfers were employed for cases nerve root avulsion. The strategy of surgery for open sharp injuries and gunshot wounds objected to restore the continuity of the injured nerve; for closed injuries associated to traction, the strategy included restoration of the following functions, in order of priority: [1] elbow flexion; [2] shoulder abduction; [3] elbow extension; [4] finger flexion; [5] protective sensory recovery on the fingers.

The British MRC (Medical Research Council) grading system[8] was used to graduate the power of each muscle that was targeted in surgery. Sensory recovery was graded according to the Louisiana State University Medical Center Grading System for Sensory Function[9] (0-5). For the purpose of comparing the observed outcomes associated to different cohorts, data were analyzed by determining the average of the final result of the surgery (AFRS). This method consisted in an average of all the results obtained for each function that was intended to recover with the surgery. Each motor function was graded according to the MRC system (0 to 5), and the sum of these scores was divided by the number of them. For example: a patient sustaining a C5 and C6 root injury in whom the suprascapular, axilary and musculocutaneous nerve were targeted, obtained a strength MRC M3 for shoulder abduction, M2 for external rotation and MRC M4 for elbow flexion. In these case, the calculation consisted in 3+2+4/3=3. Hence, the AFRS was 3. Other example: patient sustaining an infraclavicular open sharp wound with transection of the posterior cord, in which the axilary and the radial nerve were reinnervated. This patient recovered strength M4 for shoulder abduction, M4 for elbow extension, M3 for wrist extension, M2 for fingers extension, and M3 for thumb extension. The AFRS of this case was (4+4+3+2+3/5=3.2). Those cases in which the AFRS was equal or better than 3 were considered as a good outcome. Poor outcomes were considered cases in which AFRS was inferior to 3.

Data processing was performed using commercially available statistical software (SPSS, version 16.0 for Windows, SPSS, Inc. Chicago, IL). Comparison between two postoperative outcomes regarding the same cohort was carried out using the Mann-Whitney U test. The significance level was set at 0.05.

RESULTS

This retrospective study encompassed one hundred consecutive cases of traumatic injuries of the brachial plexus in adults, meeting the inclusion criteria described above. From the initial selected cohort, 18 patients were lost follow-up and were substituted by the following patients (meeting the inclusion criteria) of the total casuistic, aiming to analyze 100 consecutive cases. There were 71 males and 39 female, and the mean age of the group was 35 years old (ranging from 17-53 years old).

Table 1. Grafting proximal nerve roots: donors and recipient nerves.

	MCN	SSN	AXN	ADUT	PDUT	RN	MN	MCMN
C5	31	32	24	21	35	0	0	0
C6	19	9	0	0	0	0	0	0
C7	0	0	0	5	0	6	1	0
C8	0	0	0	0	0	0	0	2

MCN: musculocutaneous nerve; PDUT: posterior division of the upper trunk; SSN: suprascapular nerve; MN: median nerve; AXN: axilary nerve; MCMN: medial contribution of the median nerve; ADUT: anterior division of the upper trunk.

Fig 1. Grafting the proximal spinal nerves. From the left to the right side: C5, C6 and C7 nerve root.

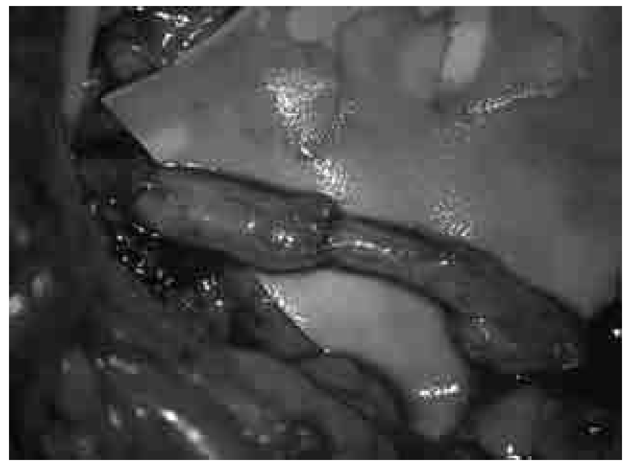

Fig 2. End-to-end suture between the accessory and suprascapular nerve.

The mean time interval from injury to surgery was 6.5 months (range 3 to 11 months) and the mean postoperative follow-up time was 32.5 months (ranging from 15 to 55 months). The mean time interval from injury to surgery was 225 days (ranging from 0 to 450 days) and the mode of the postoperative follow-up time was 21 months (ranging from 18 to 55 months).

There were 56 cases in which the proximal spinal nerves were employed for reconstruction (Fig 1). C5 was employed in 47 cases, C6 in 28, C7 in 12 patients and C8 in only two cases. Table 1 summarizes the recipient nerves of these nerve roots. C5 and C6 were mostly employed for reinnervation of the proximal muscles of the upper limb (biceps and shoulder abductors); C7 targeted specially the radial nerve; and C8 targeted the medial cord in two subjects, aiming to restore finger flexion function.

End-to-end sutures were employed in 127 nerves cooptation (Fig 2); grafts were employed to connect 156 nerves; and end-to-side suture in one case (these results encompass the techniques of nerve repair and nerve transfer for each group). Grafts were employed in 82% of the subjects, and the sural nerve was the most frequently harvested nerve, employed in 80%. Other nerves used for grafting included the medial cutaneous nerve of the forearm in 18 cases, the superficial sensory branch of the radial nerve in 12 patients, and the ulnar nerve in two cases (for contra-lateral C7 nerve root transfer technique).

Fig 3. The Oberlin's technique: the motor branch from the musculocutaneous nerve destined to the biceps was proximally transected and its distal stump was rotated medially. One motor fascicle from the ulnar nerve was sectioned, and its proximal stump was sutured to the nerve to the biceps.

Table 2 summarizes the outcomes obtained from the different techniques employed. A univariate analysis was employed to compare the outcomes associated to each

Table 2. Outcomes associated to surgical techniques in one hundred brachial plexus surgeries, according to the average of the final result of the surgery.

	n	Outcome		p
		Good	Poor	
Type of technique				
Neurolysis only	6	5 (80%)	1 (20%)	0.0031*
Repair only	32	23 (71%)	9 (29%)	0.0046*
Nerve transfer only	21	11 (52%)	10 (48%)	0.0071
Reconstruction and nerve transfer	41	32 (78%)	9 (22%)	0.0026*
Nerve transfer technique				
XI-SSN	74	35 (47%)	39 (53%)	0.0914
PhN-MC	28	15 (52%)	13 (48%)	0.0932
Oberlin	41	31 (75%)	10 (25%)	0.0027*
Sansak	13	9 (70%)	4 (30%)	0.0043*
Direct repair				
Median	15	5 (33%)	10 (66%)	0.0037*
Upper trunk	11	8 (72%)	3 (28%)	0.0025*
Ulnar	7	0 (0%)	7 (100%)	<0.001*
Musculocutaneous	4	4 (100%)	0 (0%)	<0.001*
Radial	4	2 (50%)	2 (50%)	–
Suprascapular	4	3 (75%)	1 (25%)	–
Axilary	3	2 (66%)	1 (33%)	–
Recipient nerve in closed injuries				
Suprascapular	81	51 (62%)	40 (38%)	0.0056*
Musculocutaneous	56	38 (68%)	18 (32%)	0.0043*
Nerve to biceps	41	31 (75%)	10 (25%)	0.0027*
PDUT	27	16 (60%)	9 (40%)	0.0058
Axilary	21	11 (52%)	10 (48%)	0.0107
RN or BLHT	19	13 (68%)	6 (32%)	0.0041*
ADUT	18	14 (77%)	4 (23%)	0.0027*
MCMN	12	4 (33%)	8 (66%)	0.0040*
Median	5	1 (20%)	4 (80%)	0.0013*
Donor roots				
C5	47	32 (68%)	15 (32%)	0.0041*
C6	28	20 (71%)	8 (29%)	0.0036*
C7	12	9 (75%)	3 (25%)	0.0027*

*Man-Whitney U test. Difference considered significant (p<0.05). XI-SSN: accessory to suprascapular nerve transfer; PhN-MC: phrenic to musculocutaneous nerve transfer; PDUT: posterior division of the upper trunk; ADUT: anterior division of the upper trunk; RN: radial nerve; BLHT: branch to the long head of the triceps; MCMN: medial contribution to the median nerve.

cohort. Regarding the type of the technique, the results demonstrated that the possibility of using some of the intra-plexual nerve structures for the reconstruction improved significantly the outcomes associated to surgery, whereas the difference favoring good outcomes in those cases who underwent solely nerve transfers did not reach statistical significance. The technique of proximal nerve root grafting was associated to good results in about 70% of the cases, regardless the root employed for the reconstruction (C5, C6 or C7).

The most frequently used techniques of nerve transfer are demonstrated in Table 2. Some other techniques were also employed in few cases, such as: phrenic to radial nerve transfer (6 cases); intercostals T3, T4 and T5 to musculocutaneous nerve transfer (3 cases) or to the branch of the long head of triceps (3 cases); contralateral C7 root to median nerve transfer (2 cases), and C2 nerve root to accessory nerve transfer (1 case). Significantly better outcomes were associated to the Oberlin's procedure (transfer of a motor fascicle from the ulnar nerve to the nerve of the biceps)[10] (Fig 3) and the Sansak's procedure (transfer of a motor branch from the radial nerve to the posterior division of the axilary nerve)[11]. The techniques of phrenic to musculocutaneous nerve and accessory to suprascapular nerve transfer did not reach statistical significance regarding good outcomes.

Direct nerve repair were associated to good outcomes only for those nerves supplying the proximal musculature (as upper trunk, musculocutaneous nerve, etc), whereas the repair of the nerves that targeted the hand (as the median and the ulnar nerve) usually resulted in poor outcomes. Radial, suprascapular and axilary nerves were also repaired, however no statistical analysis was possible for these nerves due the low number of cases enclosed in each group (Table 2).

The analysis of the outcomes associated to reinnervation of different recipient nerves associated to closed injuries is also demonstrated in Table 2. The brachial plexus surgery resulted in statistically significant better outcomes for the following nerves: suprascapular nerve, musculocutaneous nerve, the branch from the musculocutaneous nerve destined to the biceps, techniques for reinnervation of the triceps (radial nerve or the branch to the long head of the triceps), and the anterior division of the upper trunk. On the other hand, level of statistical significance was also reached for the opposite: surgery to reanimate the median nerve or the medial contribution of the median nerve demonstrated poor outcomes in most of the cases. The good results associated to reanimation of the posterior division of the upper trunk and the axilary nerve did not reach statistical significance.

Beside techniques of reinnervation, some patients from this series were also submitted to tendon transfer surgery. One patient sustaining wrist and finger flexion palsy and who recovered full wrist extension following a brachial plexus surgery underwent a transfer of the *extensor carpi radialis longi* to the *flexoris digiti profundi*; two patient sustaining infraclavicular injuries of the ulnar nerve underwent a Lasso's surgery; one patient, previously submitted to reconstruction of the posterior cord, underwent a *pronator teres* to *extensor carpi radialis brevis* transfer, *flexor carpi ulnaris* to *extensor digitorium* transfer and a *palmaris longus* to *extensor policis longi* transfer; one patient who recovered strength M2 for biceps following a Oberlin's procedure was submitted to a Steindler's procedure; and one case of C7, C8 and T1 root avulsion were submitted to transfer of the *brachioradialis* to the tendons of the *flexor digitorium profundi*.

DISCUSSION

Brachial plexus surgery is a complex surgery. The number of currently available techniques only expresses the number of uncertainties about this issue. There were great advancements on the last two decades, however the ideal goal that every patient who underwent surgery will certainly obtain full recovery is still far away from nowadays. A number of hypothesis can be postulate to explain the fair results observed in some cases, but maybe it is time to considerer that the original ideas regarding brachial plexus surgery[12,13] - developed by the pioneers on the decade of the 60's - has already reached their limits, and novel approaches should and must be developed. In this study we described the surgical results obtained from the first one hundred cases of our series, and most of the employed techniques can be considered as conventional techniques.

Recently, some groups advocate that reinervation of the brachial plexus shall be restricted to nerve transfer surgery, avoiding proximal spinal nerve grafting[14]. Our results suggested the opposite: cases submitted to reconstruction solely and those who underwent nerve transfer associated to reconstruction demonstrated statistically significant better results than those in which nerve transfer solely was chosen as surgical strategy. However, some concerns must be discussed to explain such results: [A] cases of open sharp injuries, which demonstrated to reach better outcomes than closed injuries, were included in the group submitted to reconstruction only; [B] most of the cases included in nerve transfer solely group included patients sustaining a flail arm, which is admittedly a factor of poor prognosis[15]. On the other hand, patients sustaining upper root palsy submitted to a triple nerve transfer (i.e., accessory to suprascapular nerve transfer, Oberlin's procedure and Sansak's procedure) demonstrated excellent outcomes (M4 in 80% of the cases). Hence, it is our opinion that the problem is not whereas the selected strategy is to reconstruct or to transfer: the most important issue for obtaining better surgical results seems to be the potential of a given nerve as a source of motor axons. Most of our patients underwent nerve transfers associated to nerve grafting, since in most of them at least one viable nerve root was identified. These cases obtained the best outcomes of this cohort because, by using the best of both techniques, the most powerful sources of axons were selected. Moreover, considering that good outcomes were frequently associated to grafting of the proximal spinal nerves and fair results of were observed regarding some techniques of nerve transfer that included grafts as part of the technique (as phrenic to musculocutaneous nerve transfer), we can conclude that the use of grafts or even their length did not interfere in obtained better outcomes, favoring again the potential of the donor nerve as an important predictor for functional recovery in brachial plexus surgery.

Regarding nerve transfers, our initial protocol has been changed over the years. On the first early cases, the use the phrenic to musculocutaneous and accessory to suprascapular nerve transfer was frequent, especially for cases associated to total palsies. However, our clinical observations during this period were eventually proven by the statistical data: these techniques did not demonstrate to be reliable, and the difference favoring good outcomes obtained with both did not reach level of significance. On the other hand, our study replicated the good results obtained with the Oberlin's procedure for elbow flexion recovery observed in the literature, and currently this is the most frequently employed technique for biceps reinnervation in our Department. We are using increasingly less the phrenic nerve for elbow flexion restoration, replaced by aiming most of the grafts from some proximal root (as C5 or C6) to the musculocutaneous nerve or the anterior division of the upper trunk, in cases of total palsies; or routinely using the Oberlin's procedure for cases in which the hand function is preserved. The phrenic nerve is currently only used in cases of total root avulsion (C5 to T1), or for reinnervation of a second line recipient nerve (as radial or axilary nerves).

The frequent use of the phrenic nerve as donor for cases of flail arm could explain the fair results associated to the technique, however the same explanation cannot substantiate some of the poor outcomes associated to the accessory nerve. The transfer of the accessory to suprascapular nerve for restoration of shoulder abduction were also used very frequently in cases of partial injuries, and this technique has proved to be unreliable for restoration of functional abduction of the arm, if used as the solely transfer. On the other hand, the Sansak's procedure demonstrated good outcomes in 70% of the cases, and it important to note that this technique is usually associated to accessory-to-suprascapular nerve transfer in cases of upper roots injuries. Hence, the good outcomes associated to the Sansak's procedure could be partially justified due its association to the reanimation of the suprascapular nerve, and to date we considerer that it is only possible to obtain functional shoulder's recovery if both suprascapular and axilary nerve are reinnervated.

The outcomes associated to motor reinnervation of the distal upper limb (as wrist and finger function) were very poor, regardless the type of injury or the type of technique employed for reinnervation. The cases of direct repair (usually associated to open sharp injuries or gunshot wounds) of the infraclavicular long nerves (and in special the median and ulnar nerves), and the cases of flail arm in which the median nerve or the medial contribution to the median nerve were targeted, demonstrated statistical significance against nerve surgery. Most of our cases of tendon transfer surgery were indicated for rehabilitation of the hand function in subjects sustaining very proximal injuries of the median, radial and ulnar nerves. Hence, based in this study, we discourage direct microsurgical reconstruction of these nerves or as a target for some proximal nerve root, except if the surgical objective is to obtain sensory recovery of the hand. Alternatives for hand reinnervation include the use of the contra-lateral C7 nerve root[16] or techniques of distal nerve transfer (as the transfer of the anterior interosseous nerve to the deep ulnar nerve for cases of infraclavicular ulnar nerve injury[17]). Nevertheless, a combined approach (nerve and tendon surgery) can improves the final outcomes of these patients, and tendon transfer should be considered by neurosurgeons as an important step of the surgical planning.

In conclusion, neurosurgical treatment of brachial plexus injuries renders satisfactory results for reinnervation of the proximal musculature of the upper limb; however the same good outcomes are not usually observed regarding the reinnervation of the hand. Good outcomes are frequently associated to techniques of spinal nerve grafting. Nerve transfer is very useful for reinnervation of the brachial plexus, however careful selection of the donor and the recipient nerve is imperative in order to obtain good outcomes. The association of nerve transfer, nerve repair and tendon transfer is the best alternative to increase the rank of recovered functions of a paralyzed arm.

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