Chapter

Nerve Transfers for Restoring Elbow Flexion in Brachial Plexus Palsy

Teodor Stamate and Dan Cristian Moraru

Abstract

Nerve transfers (NT) consist in sectioning a donor nerve and connecting it to the distal stump of a recipient unrepairable nerve. For elbow flexion restoration in brachial plexus palsy (BPP) we used different NT: 1) GF motor Ulnar Nerve to Biceps nerve (Oberlin technique), 2) Double fascicular median/ulnar to biceps/brachialis nerve transfer (Mackinnon), 3) InterCostal Nerves (ICN) to MCN (+/− nerve graft), 4) Medial Pectoral Nerve (MPN) to MCN, 5) ThoracoDorsal Nerve (TDN) to MCN, 6) Spinal Accessory Nerve (SAN) to MCN transfer, 7) Phrenic Nerve (PhN) to MCN, 8) Cervical Plexus C3-C4 to MCN and 9) Contralateral C7 (CC7). I want to present my personal experience using the phrenic nerve (PhN), the intercostal nerves (ICN) and Oberlin's technique. The aim of this retrospective study is to evaluate the results of this procedure in BPP. NT is an important goal in BPP. ICN transfer into the nerve of biceps for elbow flexion recovery is a reliable procedure in BPP. ICN transfer for triceps offers a positive alternative (Carroll transposition). Oberlin technique is simple and offers better results in a shorter amount of time and is an effective and safe option.

Keywords: brachial plexus, nerve transfer, elbow flexion

1. Introduction

A complete functional recovery is the ultimate goal in the treatment of brachial plexus injury. However, in most of our patients, this goal cannot be achieved due to the severity of the injuries and the restriction of donor nerves.

The priorities of functional reconstruction in brachial plexus injury have been set as follows [1], in order: 1) elbow flexion; 2) shoulder abduction; 3) wrist and finger flexion and sensation in the median nerve distribution; 4) wrist and finger extension; 5) intrinsic muscle function.

2. Nerve transfers

Nerve transfers for elbow flexion are:

1. Motor fascicular groups (FG) Ulnar Nerve to Biceps nerve (Oberlin technique)

2. Double fascicular median/ulnar to biceps/brachialis nerve transfer (Mackinnon)

3. InterCostal Nerves (ICN) to Musculocutaneous nerve (MCN) (+/– nerve graft)

4. Medial Pectoral Nerve (MPN) to MCN

5. Thoraco Dorsal Nerve (TDN) to MCN

6. Spinal Accessory Nerve (SAN) to MCN transfer

7. Phrenic Nerve (PhN) to MCN

8. Cervical Plexus C3-C4 to MCN

9. Contralateral C7 (CC7)

2.1 Motor FG ulnar nerve to biceps nerve (Oberlin technique)

In 1990 – Oberlin proposed the transfer of motor FG's from the ulnar nerve to the biceps branch of the MCN without an intervening nerve graft; the motor branch from the musculocutaneous nerve to the biceps muscle and the ulnar nerve were found at the midarm level [2]. After performing a 2–3 cm longitudinal epineurotomy in the ulnar nerve, one or two fascicles are found and sutured end to end to the branch of the nerve to the biceps by 3 or 4 stitches of 10–0 nylon. 90% of the patients achieve better than MRC grade 4 elbow flexion with the Oberlin technique [3]. Intraoperative electrostimulation to identify motor FG's of the ulnar nerve is mandatory [4]. The contraindications for Oberlin technique are: lesion of C7-C8-T1 (electromyography (EMG) before surgery on the donor nerve – ulnar nerve – is mandatory); long delay between injury and surgery (**Figure 1**) [5].

2.2 Mackinnon technique

In 2005, MacKinnon proposed to modify the original Oberlin procedure to include reinnervation of the brachialis branch of the MCN using the motor FG's of the median nerve [6]. The ideal median nerve donor fascicle contains nerves to the flexor digitorum superficialis (FDS) and flexor carpi radialis (FCR) and intraoperative electrostimulation for motor fascicle of median nerve causes wrist flexion [7]. Several reports have been published comparing single and dual reinnervation, and despite the intuitive logic that more is better, the most recent prospective randomized trial did not demonstrate any difference in objective outcomes between the Oberlin procedure versus MacKinnon technique (**Figure 2**) [8].

2.3 Intercostal nerves (ICN)

In 1968, Tsuyama and Hara suggested the transfer of two or more intercostal nerves (ICN) to the Musculo Cutaneous Nerve (MCN) [9]. In 1978, Celli neurotized torn roots of the brachial plexus (preliminary note on the surgical technique) [10]. In 1984, Dolenec performed various neurotizations using the ICN into MCN, radial, axilar or motor FG of ulnar nerve (sural nerve graft interposition) [11]. In 2003, Oberlin used an intercostal nerve transfer to neurotized triceps [12]. The transfer of ICN to MCN or to Radial nerve (long portion of triceps) are the 4-th choice. Each ICN presents approximately 1200 axons but we must not forget that: ICN 1 participates to the BP formation; ICN 2 is very small and with *no motor fibers*; ICN7 – ICN12 have very few motor axons - only up to 20%; ICN-3 to ICN-6 are used for neurotization of MCN;

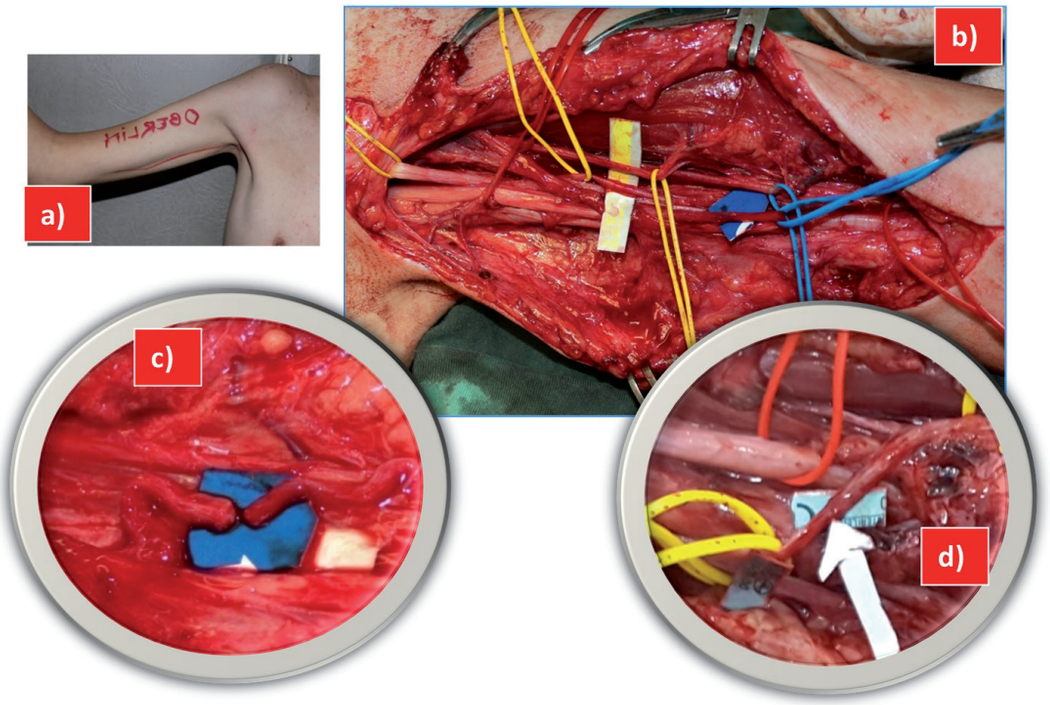

Figure 1.
Oberlin technique: a) 8–10 cm incision, internal bicipital groove; b) MCN motor branch identification destined to the biceps, longitudinal epineurotomy 3–4 cm on the cubital nerve with the identification by electrostimulation of motor 2-FG; c) by internal neurolysis in the MCN trunk, the FG destined to the biceps are separated, sectioned at 3–4 cm proximally, the ends being transcended towards the ulnar nerve; the same procedure is done for the ulnar nerve FG, which are sectioned at 3–4 cm distally, so that the proximal transcended ends come in contact with the MCN FG ends; neuroraphy, motor FG from the UN to the MCN FG destined to the biceps, done without tension, with 3–4 points, nylon 9.0 or 10.0.

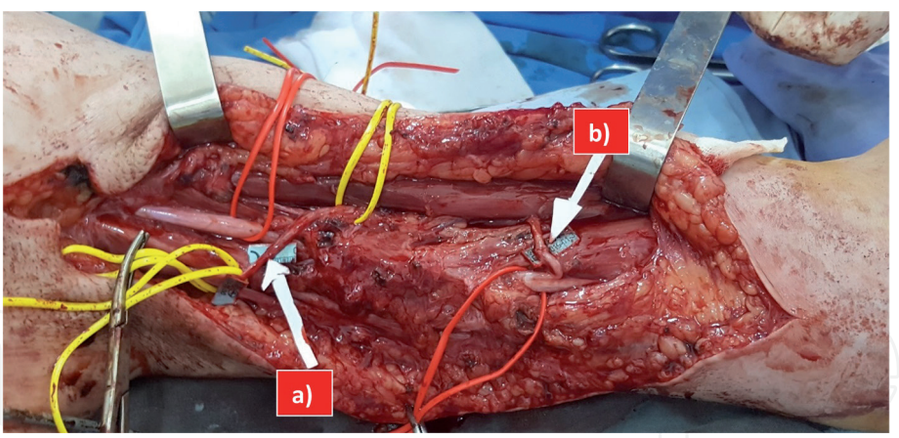

Figure 2.
Mackinnon technique: a) Oberlin technique; b) FG isolated from the median nerve is connected to the MCN motor branch destined to the anterior brachial muscle [6].

30–45% motor axons lose 10% of motor fibers to every 10 cm from the axillary line [4]. We prefer the surgical approach to harvest the ICN proposed by Hanno Millesi also used by David Chuang (**Figure 3**) [13]. ICN harvest is a technique requiring meticulous approach and careful dissection with proper hemostasis, preserving the serratus anterior muscle insertion [14]. We prefer the Oberlin technique because IC vasculo-nervous bundle is harvested without dissecting it, avoiding excessive bleeding (**Figure 4**) [15]. Minimal invasive robotic surgery has become possible today in centers equipped with surgical robot system - Da Vinci [16]. The ICN are connected to MCN by sural nerve graft (**Figure 5**). The indication of the NT with ICN are: 1) restoration of

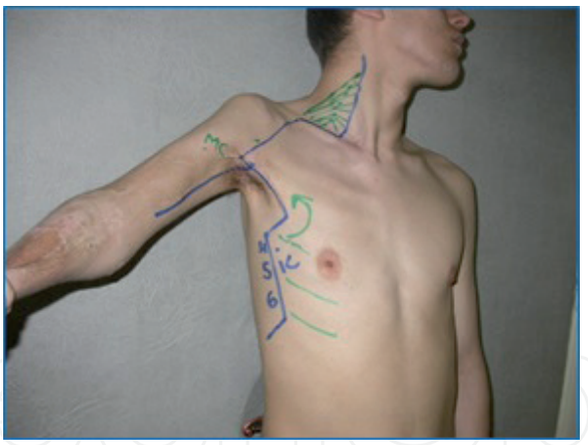

Figure 3.
Intercostal nerves: Meticulous preoperative planning for the surgical approach.

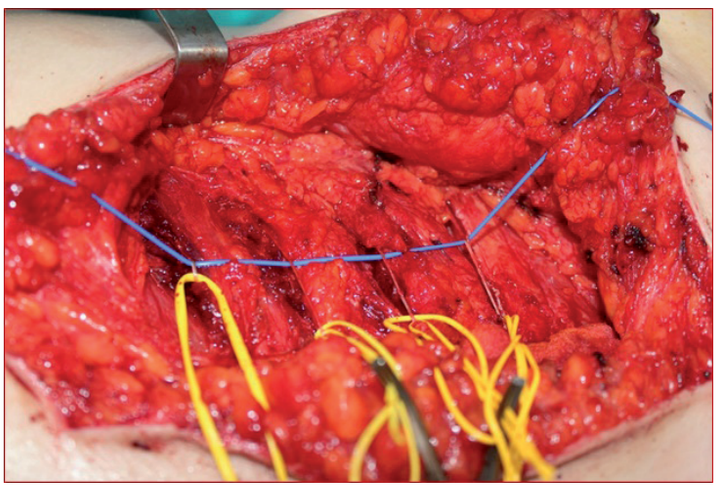

Figure 4.
The intercostal nerves – Harvesting ICN technique: The dissection is difficult and with important bleeding; the Oberlin technique allows for the ICN isolation without major bleeding.

elbow flexion is the first goal in brachial plexus injuries [17]; 2) ICN to the long head of the triceps nerve - for the restoration of elbow extension without nerve graft and afterwards, the reinnervated triceps can be transferred to the biceps (Carroll Technique); 3) gracilis free muscle transfer reinnerverted with ICN for elbow flexion [18]. We prefer to associate ICN transfer to MCN with Direct Neuro Muscular Neurotization (DNMN) to the denervated biceps and we consider that this improves the results (**Figure 6**).

The contraindications for ICN transfers are: ipsilateral phrenic nerve palsy, Serratus anterior muscle palsy or rib fractures [19]. The complications to use ICN are: 1) a variable degree of ipsilateral pulmonary atelectasis in infants [20]; 2) pleural rupture is in the opinion of some authors the most frequent complication [21].

2.4 Medial pectoral nerve (MPN)

MPN are 73% composed of fibers from C8 and T1, contains approximately 1,100 to 2,100 motor fibers, its surgically obtainable length is of up to 78 mm and has a mean diameter ranging between 1.4 and 2.7 mm [22]. The pectoral nerves - namely the lateral pectoral nerve (LPN) and the medial pectoral nerve (MPN) - are joined together by the pectoral loop. MPN innervates the lower pectoralis major and pectoralis minor muscle and may have connections to the intercostal

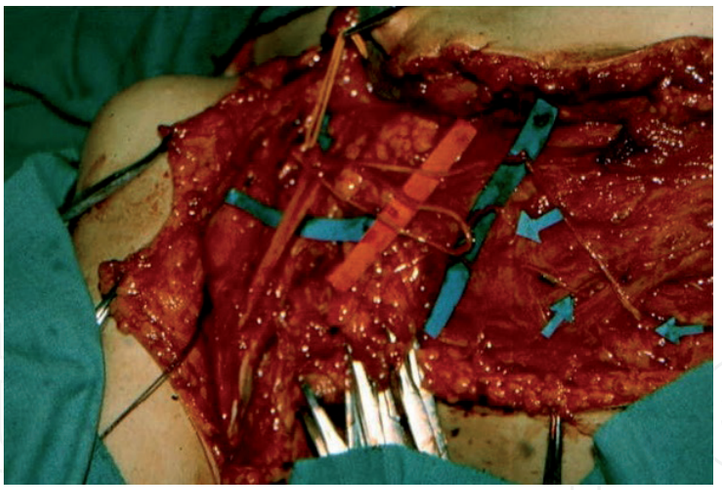

Figure 5.
The intercostal nerves – connected to sural nerve graft: depending on the quality and length of the harvested sural nerve, 2 ICN may be connected or even one ICN to a sural nerve segment.

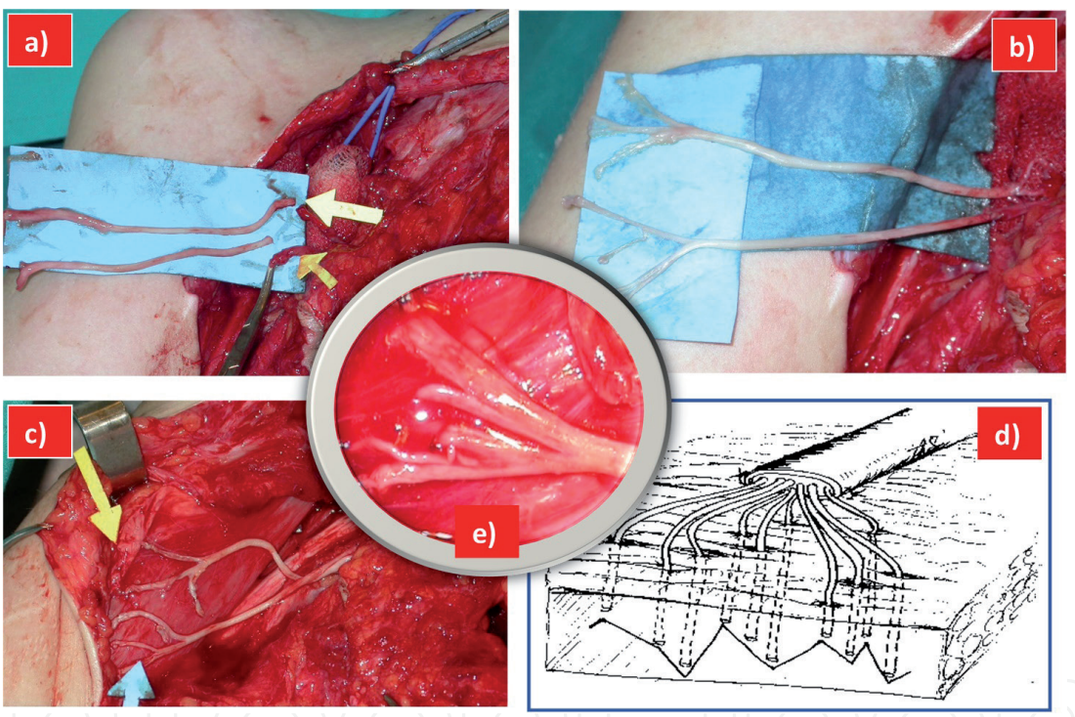

Figure 6.
The intercostal nerves – direct neuro muscular neurotisation – giorgio Brunelli technique: (a) each ICN is connected to a sural nerve graft; b) the biceps extremity of each graft is opened wide c) the grafts must be long enough to allow arm abduction; d) the nerve fibers from each graft are inserted at different depths in the biceps muscle; e) a nylon 10.0 point is placed at the level between the perimysium and the epinerv to ensure stability.

nerves [23]. The redundant innervation of the pectoralis major by the medial and lateral pectoral nerves allows for a continued pectoralis function after MPN transfer [7]. The MPN harvesting technique is relatively simple by a deltopectoral incision that highlights the infraclavicular plexus and the medial pectoral nerve is identified by electrostimulation; the branches of the medial pectoral nerve are sutured to the distal end of the branch from the biceps directly, without the interposition of a nerve graft. The MPN is dissected to obtain a sufficient length and is then sectioned; the MCN branch destined to the biceps is isolated on a sufficient length to allow a no tension neuroraphy with the MPN [24]. This transfer is indicated in patients with C 5,6 or C 5,6,7 lesions but with a good strength in the pectoralis major (**Figure 7**).

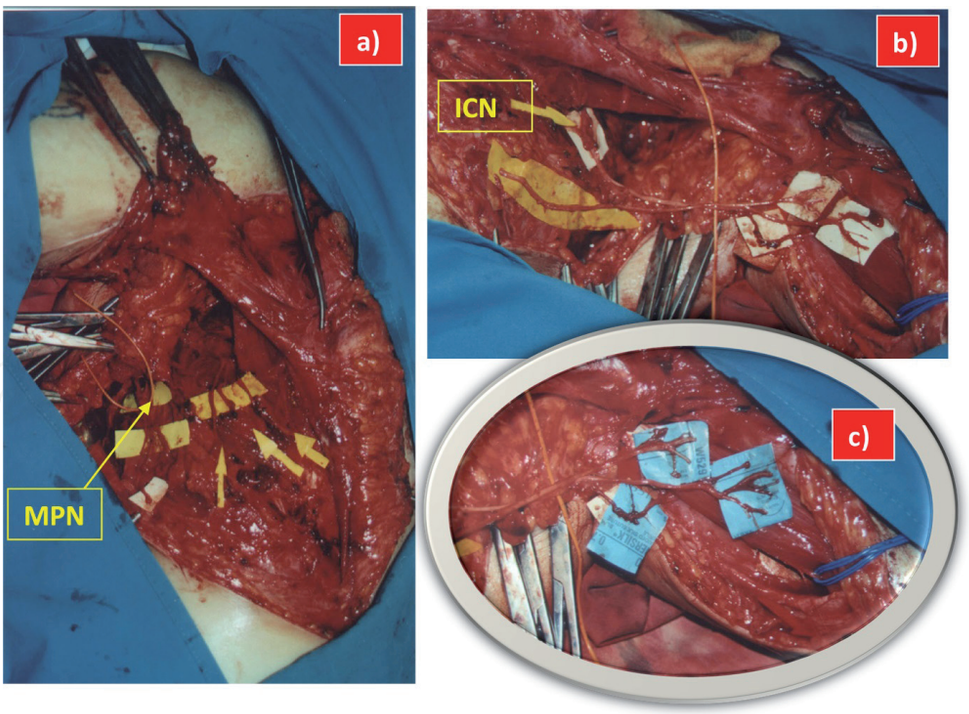

Figure 7.
Medial pectoral nerve (MPN) to musculocutaneous nerve: a) MPN dissection and isolation to 2 ICN; b) connecting the sural nerve grafts between the MPN and the biceps branch from the MCN and each ICN with a graft which has been widened at the biceps extremity also for the DNMN Brunelli technique; c) double neurotization: MPN to MCN + ICN to biceps (DNMN).

2.5 Thoracodorsal nerve (TDN)

The TDN is a motor nerve that originates from the posterior cord C7, C8 and less frequently C6-C8 [25]. The length of the TDN is 12.3 cm, the diameter ranges from 2.1 to 3.0 mm and the myelinated fibers range from 1530 to 2470.

TDN is a motor donor nerve useful in recovering elbow flexion without nerve grafting [26]. The TDN harvesting technique is made through an incision oriented at the level of the lateral border of the latissimus dorsi muscle with the upper limb

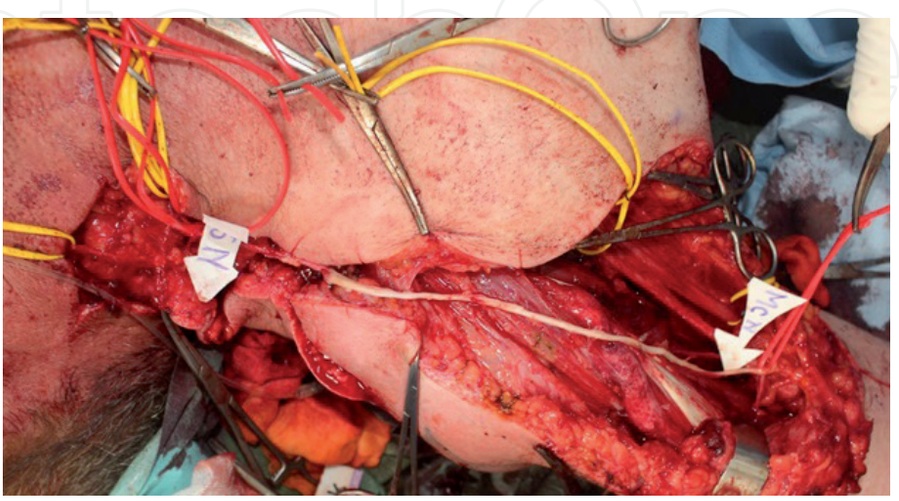

Figure 8.
Spinal accessory nerve (SAN) to MCN: Motor FG from the SAN identified through electrostimulation were connected to a sural nerve graft which allows the connection to the biceps branch from the MCN avoiding retroclavicular dissection through scar tissue.

at 90° abduction. After a distal to proximal MCN intraneural dissection, the TDN is connected to the FG of the MCN for the biceps muscle and to the FG for the brachialis muscle. TDN transfer to the MCN provides recovery of elbow flexion in 90% of cases [27]. TDN can be useful for neurotization of other nerves: axillary, suprascapular, spinal or anterior serratus [28].

2.6 Spinal accessory nerve (SAN)

The SAN contains approximately 1500 motor axons (C1 to C6) and was first used for MCN neurotization in 1980 by Marcelo Rosa de Rezende [29]. The SAN is harvested by an anterior approach for transfer to the MCN connected with a nerve graft (**Figure 8**) [30]. The posterior approach is used for transfer to the supra-scapular nerve (SSN) or associated with the triceps branch transfer to the axillary nerve [31]. Evaluating elbow flexion after SAN to MCN transfers have established MRC = M3 or better in 65–83% of patients [7].

2.7 Phrenic nerve (PhN)

In 1990, Chinese surgeons performed the first phrenic nerve transfers to the MCN to recover elbow flexion [32]. To avoid dissection through retroclavicular scar tissue we prefer in the transfer of the phrenic nerve to MCN a long bypass nerve graft of maximum 10 cm (**Figure 9**). PhN contains 800 myelinated motor axons (C3, C4, C5) and is a good donor nerve but we should not forget its contribution in the respiratory function [33]. Phrenic nerve (PhN) transfer to the MCN is not recommended in patients with previous pulmonary diseases or for children under the age of two years [29].

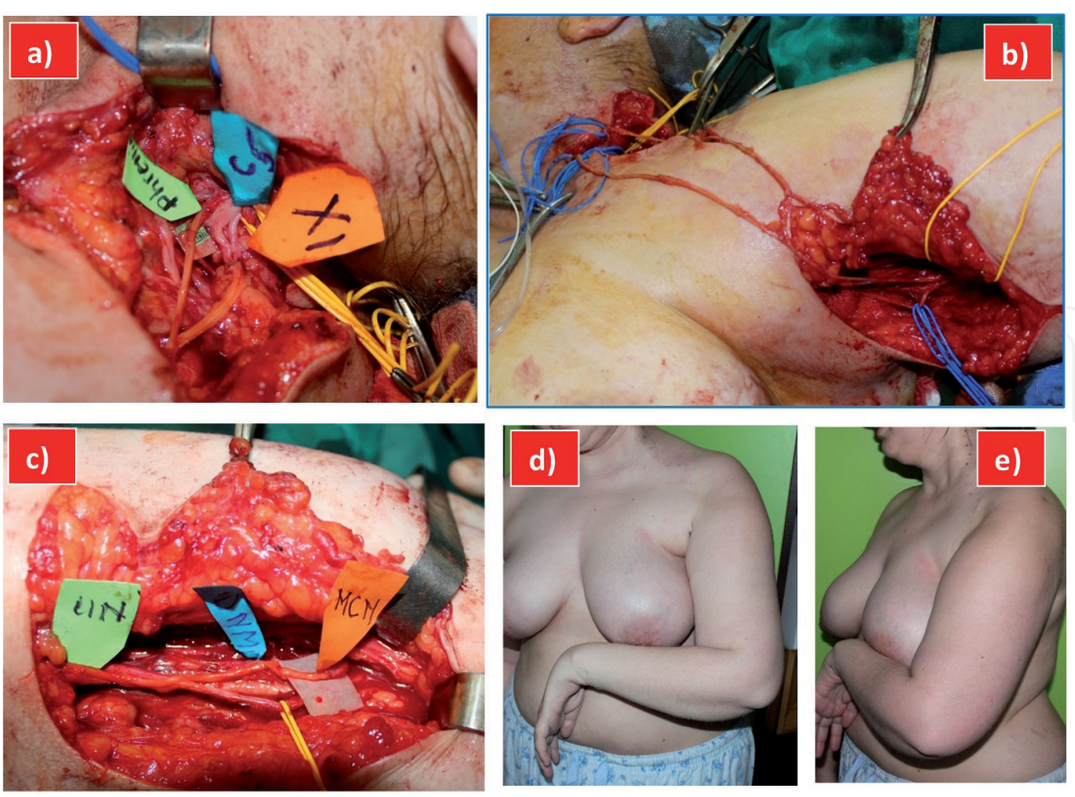

Figure 9.
*Phrenic nerve (***PhN***) to MCN: a) PhN, C5 root and ASN evidentiation; b) to avoid retroclavicular scar tissue area, we performed a long nerve grafts bypass; c) connecting the nerve grafts: PhN to MCN, C5 and ASN to MN and UN; d) and e) recovery of elbow flexion after 9 month.*

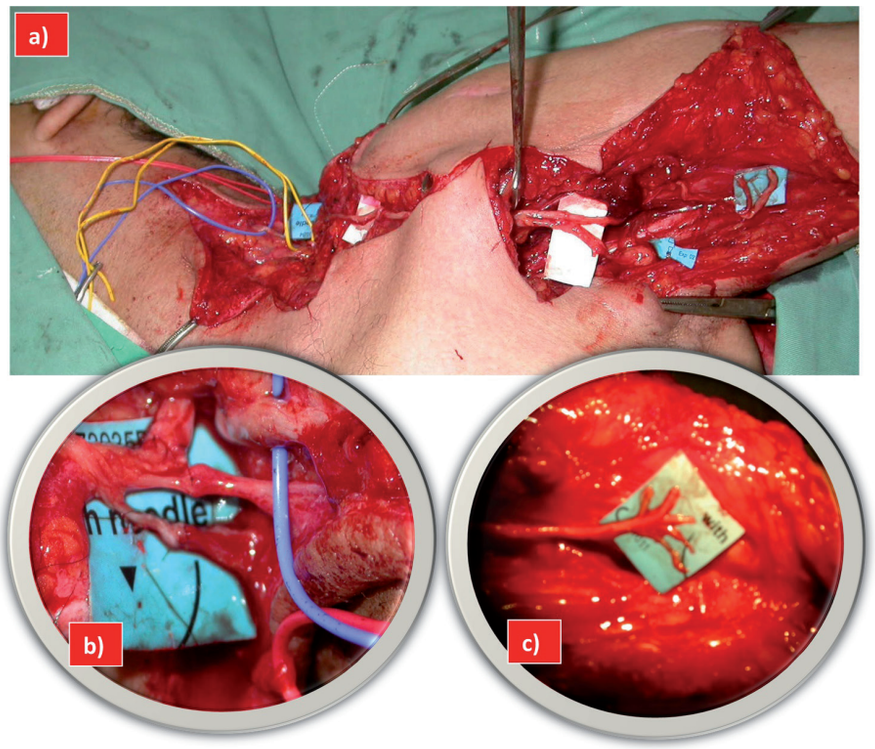

Figure 10.
Cervical plexus + spinal accessory to MCN transfer; combined neurotisation (NNN + DNMN) by nerve graft C3 + C4 + SAN to MCN + biceps - a) dissection of the C3 and C4 anterior rami of the cervical plexus; b) proximal neuroraphy; c) DNMN associated.

2.8 Cervical plexus C3-C4 to MCN

In 1984, Georgio Brunelli and Monini L. proposed to use the anterior motor branches of the cervical plexus. The anterior branches of the cervical plexus have approximately 14 000 myelinated axons but the distance of coaptation of the C3 and C4 anterior branches to the target (MCN) requires an intervening nerve graft [34]. We prefer to associate the transfer of anterior branches of cervical plexus with SAN and DNMN to MCN (**Figure 10**).

2.9 Contralateral C7 (CoC7) transfer to MCN

In 1992, a group of Chinese authors published the use of CoC7 and obtained good functional results considering that the procedure opens new perspectives in total brachial plexus paralysis [35]. In 1993, David Chuang used CoC7 as a source of neurotization, which he connected to the PB via a long graft from the sural nerve. After one year, in the second operative time, axonal growth was verified in the sural graft and neuroraphy was performed at MCN [36]. There are three different ways to harvest CoC7, including the whole root, 3/4 of the root and half (1/2) of the C7 root, respectively, and the functional recovery is much better in the whole root CoC7 transfer group - which provides a large number of donor nerve fibers - than that for the group with partial transfer [37]. CoC7 nerve transfer via a modified prespinal route and direct coaptation is not suitable because of the high complication rate: severe bleeding due to vertebral arterial injury during the procedure, temporary recurrent laryngeal nerve palsy, pain and numbness in the donor site during swallowing and dyspnea [38]. Because of the donor site morbidity after the (CoC7) transfer was relatively high, of over 20%, although the C7 has a large number of fibers (8467 ± 1019), it remains the last option [39].

3. Conclusions

Nerve transfer in elbow flexion recovery provides results. The choice of techniques in nervous surgery depends on: the type of lesion, the presence of the roots that can be grafted, the time between the accident and the intervention [4]. The association of the 3 methods: 1) neuro-neuronal neurotisation (NNN) = NT with 2) direct neuro-muscular neurotisation (DNMN) proposed by Georgio Brunelli to insert the nerve fibers at different levels in the muscle [40] and 3) teno-muscular transfer (TMT) improved the results in BPP [41].

Conflict of interest

The authors declare no conflict of interest.

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