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Original Article

Brachial plexus exposure in 19 post-traumatic patients: A morphometric anatomic analysis

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ABSTRACT

Background: Traumatic brachial plexus injuries result in severe functional impairment, significantly affecting patients' quality of life. This study aims to evaluate the clinical outcomes of surgical interventions in 19 patients with brachial plexus injuries, emphasizing the effectiveness of linear incision techniques. Our surgical objectives included restoring shoulder control, elbow flexion, and elbow extension, alongside optimizing sensory recovery.

Methods: We performed morphometric analyses to standardize surgical approaches, utilizing topographic linear incisions for enhanced exposure and precision. This technique ensures critical advantages: short incisions with excellent nerve visualization, identification of consistent anatomical landmarks for safe dissection even amidst scar tissue, and facilitation of multiple neurotizations through single incisions. This approach is inspired by and builds on the principles outlined by Bertelli and Ghizoni, whose work highlighted the importance of precise anatomical dissection and efficient nerve exposure.

Results: We collected all morphometric measurements to standardize surgical approaches. Key findings demonstrated that linear incisions improved surgical efficiency and facilitated tension-free nerve anastomoses without the need for grafts in most cases.

Conclusion: Linear incision techniques, supported by the foundational principles established by Bertelli and Ghizoni, provide significant clinical benefits in brachial plexus surgery. This approach enhances both surgical precision and patient recovery while supporting the achievement of critical neurofunctional objectives.

Keywords: Brachial plexus injuries, Nerve grafting, Nerve transfer, Neurotization

INTRODUCTION

Traumatic brachial plexus injuries are increasingly frequent, causing significant physical and social disability due to the loss of upper limb strength, sensitivity, and hand function. These injuries are often associated with penetrating trauma, falls, or motor vehicle accidents, particularly involving high-speed motorcycles, and most commonly affect men aged 16–25 years.[20]

Management requires a multidisciplinary approach involving specialists in rehabilitation, neurology, physical and occupational therapy, and peripheral nerve surgery. The approach depends on the injury's mechanism, location, and whether it is "open" or "closed." Early surgical intervention is indicated for open injuries caused by sharp or penetrating trauma that transect nerves. For blunt or stretch injuries, electrodiagnostic studies are recommended at 6 weeks and

3 months, with surgical planning initiated if no improvement is observed.

Advances in peripheral nerve surgery have improved outcomes, but treatment combines evidence-based principles, feasibility, and surgeon expertise, with the primary goal being to restore motor and sensory neurological function.

Patients were considered eligible for surgical treatment if they met the following criteria:
1. Patients with avulsion injuries;
2. Patients with extensive neuromas;
3. Patients with axonotmesis damage without recovery after the observation period;
4. Patients with a combination of the above patterns.

We performed a morphometric analysis on 19 patients who met the criteria for surgical candidacy. The surgical techniques applied were based on descriptions in the literature, with reference to the works of Bertelli and Ghizoni.[1-10] This morphometric analysis is performed to achieve greater standardization of these approaches and meet the following surgical objectives through appropriately placed topographic incisions:
- Short incisions with excellent exposure of the nervous elements;
- Identification of fixed anatomical landmarks that ensure nerve isolation even in the presence of scar tissue;
- Selection of the most suitable donor nerves;
- Combination of multiple neurotizations with a single incision;
- Ipsilateral and synergistic neurotizations;
- Distal harvesting of donor nerves and nerve sutures as close as possible to the muscle targeted for reinnervation;
- Anastomoses performed without tension and grafts in most neurotizations;
- Facilitation and acceleration of surgical approaches.

MATERIALS AND METHODS

The study was conducted by obtaining morphometric measurements during the various surgical steps. During each step, a measurement table was completed for each approach.

The aims of our brachial plexus surgery on 19 patients included:
1. Shoulder control (abduction, external rotation, and scapular stabilization)
2. Elbow flexion
3. Elbow extension and restoration of sensation in the median nerve distribution whenever possible, or in cases of multilevel avulsion injuries associated with neuropathic pain.[12]

All procedures were performed with neurophysiological monitoring.

Shoulder control

In cases of non-avulsion injuries, the first step of surgery involves achieving shoulder control, specifically, abduction, external rotation, and scapular stabilization, by exposing the C5 and C6 nerve roots. The procedure also includes exposing the XI cranial nerve and the suprascapular nerve, as outlined below.

The initial incision described is a linear oblique one, allowing for root exposure slightly lateral to Chassaignac's tubercle [Figure 1]. This incision provides access for a comfortable dissection behind the sternocleidomastoid muscle and into the deeper planes, reaching the nerve roots as they exit the intervertebral foramina.[7] The non-avulsed C5 and C6 roots are inspected and stimulated intraoperatively to assess their residual function. In cases of complete damage, sural nerve grafts are used to connect the proximal stump of the C5 root to the posterior division and the proximal stump of the C6 root to the anterior division [Figure 2], exposed through the following second incision.

Figure 1: Linear oblique incision for the exposure of the brachial plexus roots.

Figure 2: Brachial plexus roots (axonometric damage).

Figure 3: Linear oblique supraclavicular skin incision starting at the junction between the medial and middle thirds of the clavicle and extending posteriorly toward the trapezius muscle.

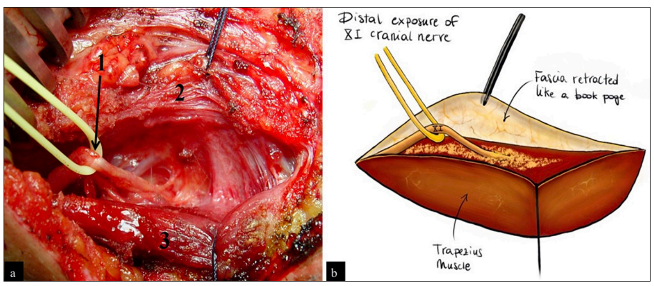

Figure 4: Distal exposure of the XI cranial nerve (1) according to Bertelli and Ghizoni's surgical technique. (a) The fascia (2) is retracted from the trapezius border (3) like a book page – right side. (b) Anatomic illustration.

The second incision is an oblique supraclavicular one, starting at the junction between the medial and middle thirds of the clavicle[8] and extending posteriorly toward the trapezius muscle [Figure 3].

This posterior portion of the incision, located at the anterior edge of the trapezius muscle, facilitates exposure of the XI cranial nerve using the "book-opening" technique described by Bertelli and Ghizoni. The subcutaneous tissue is dissected, and the XI cranial nerve is isolated at the anterior border of the trapezius muscle, approximately 4 cm from the clavicle, with the aid of an intraoperative microscope. Specifically, the spinal accessory nerve is identified within the fat between the trapezius muscle and its fascia, which is retracted like a book page, in an avascular plane, as described by Bertelli and Ghizoni [Figure 4].[4]

On the other hand, the anterior portion of the same second incision allows access to the omohyoid muscle, which can be retracted anteriorly and serves as a landmark for exposing the suprascapular nerve, originating from the superior trunk of the brachial plexus. The nerve is identified at a deeper plane beneath the omohyoid muscle [Figure 5].

In summary, moving in a distal-to-proximal direction, the following anatomical structures are identified: the retracted omohyoid muscle, the posterior division, the anterior division, the suprascapular nerve, and the spinal accessory nerve at the posterior aspect of the second incision [Figure 5]. Neurotization of the spinal accessory nerve to the suprascapular nerve is a critical step in the treatment of severe axonotmesis and avulsion injuries of the upper brachial plexus.

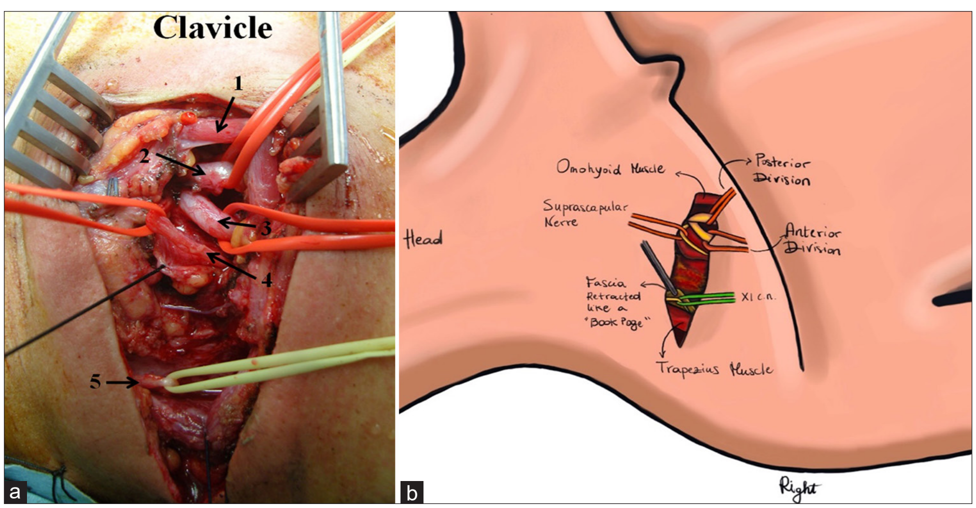

Figure 5: (a) Linear incision in the supraclavicular region. It begins at the junction between the medial third and the lateral two-thirds of the clavicle and extends toward the trapezius muscle. In a disto-proximal direction, the following anatomical structures are visible: the retracted omohyoid muscle (1), the posterior division (2), the anterior division (3), the suprascapular nerve (4), and the spinal accessory nerve (XI cranial nerve, 5) - right side. (b) Anatomic illustration.

The third supraclavicular incision is linear, with a lateral extension toward the acromion in a zigzag pattern [Figure 6]. This incision is employed in cases where double crush syndrome of the suprascapular nerve is suspected or when the nerve is difficult to expose proximally due to post-traumatic scarring or extensive neuroma. In such cases, the nerve is exposed more distally at the notch, following the technique described by Bertelli and Ghizoni.[8] This approach offers the advantage of enabling the surgeon to expose the distal portion of the suprascapular nerve while keeping the patient supine with the thorax elevated at 45°.

The deep fascia over the trapezius muscle is dissected, and the muscle is detached from the clavicle and acromion. The coracoid process, located beneath the clavicle within the fat tissue, is identified by palpation. The final step involves exposing the ligament under magnification [Figures 7 and 8] and then sectioning it. This enables the identification of the suprascapular nerve and its branches in a deeper plane beneath the clavicle. After transecting the ligament, the suprascapular nerve is mobilized and advanced toward the clavicle, allowing approximately 11 cm of nerve exposure from its origin [Figure 9]. The transfer and coaptation of the XI cranial nerve to the suprascapular nerve are then performed tension-free using 9-0 nylon sutures [Figure 10].

In addition, we routinely expose the motor branch of the platysma as described by Bertelli[1] to augment the previous connections. This is done through a 3 cm linear incision made one finger's breadth below the mandible. The nerve, which emerges just beneath the platysma muscle, is isolated using intraoperative nerve stimulation [Figures 11-13]. This branch is then connected to the medial pectoral nerve or the anterior division using a sural nerve graft.

Figure 6: Linear supraclavicular incision with the zigzag extension toward the acromion to expose the notch.

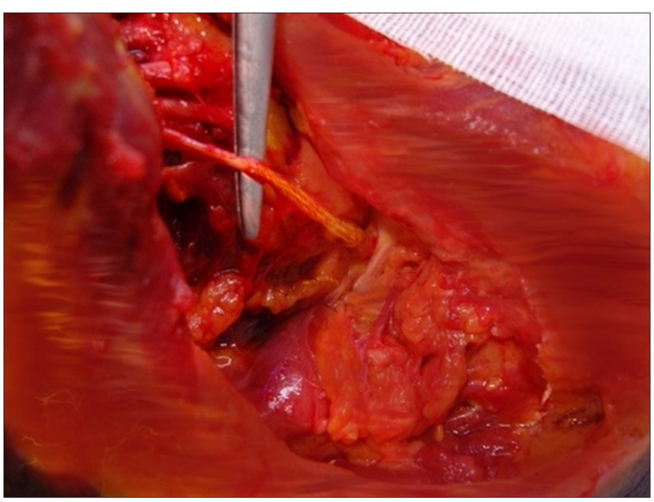

Figure 7: Exposure of the suprascapular nerve up to the notch.

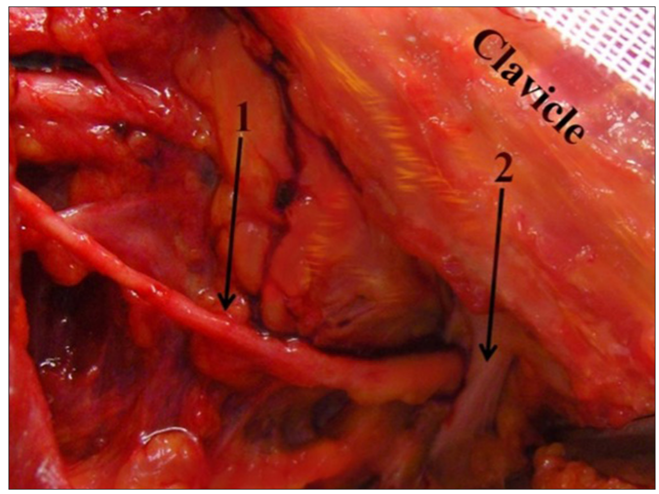

Figure 8: Exposure of the suprascapular nerve (1) up to the notch. The suprascapular ligament is visible (2) – right side.

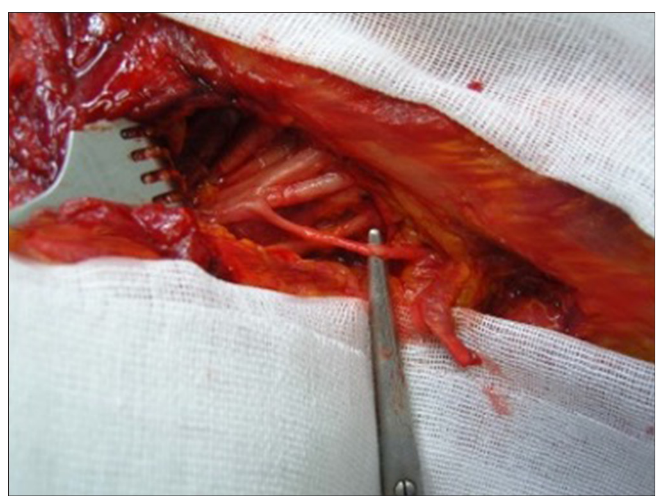

Figure 9: Exposure of the suprascapular nerve up to the notch after sectioning of the ligament.

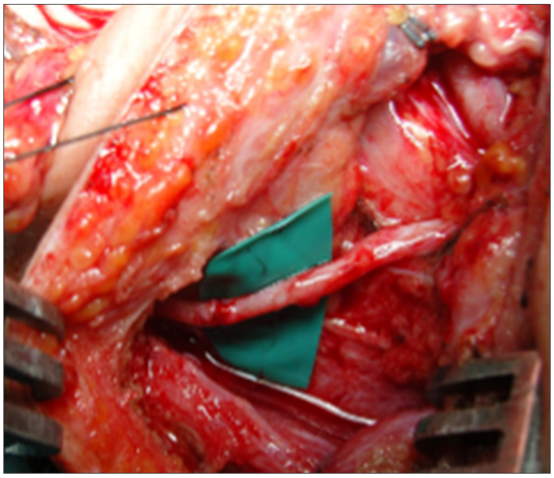

Figure 10: End-to-end anastomosis between the XI cranial nerve and the suprascapular nerve – right side.

Figure 11: Linear skin incision for the exposure of the platysma motor branch.

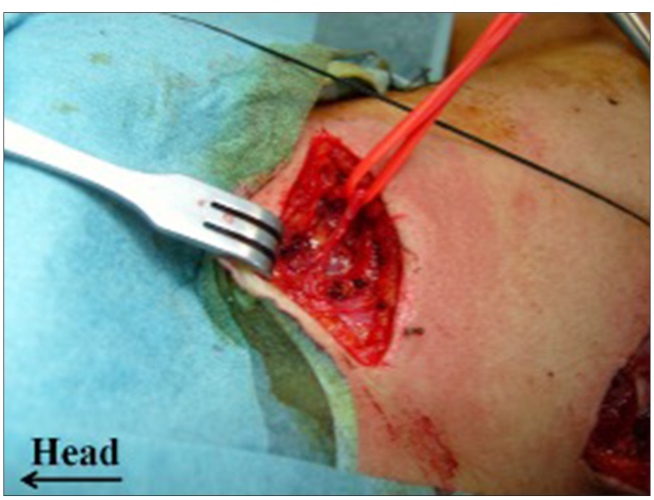

Figure 12: Exposure of the platysma motor branch – right side.

Elbow flexion

Restoration of elbow flexion, in cases where the function of the inferior brachial plexus is preserved, is performed using the classic Oberlin neurotization described in 1994, with the partial transfer of the ulnar nerve to the biceps motor branch of the musculocutaneous nerve (MCN) (7,15,21) [Figures 14 and 15].

In cases where triceps function is preserved, we always perform a double Oberlin technique with the transfer of double fascicles from the ulnar and median nerves to the MCN branches to the brachialis and biceps. All 9-0 non-resorbable sutures should not be under tension during both arm flexion and extension.

An 8 cm long incision was made on the medial aspect of the arm over the brachial vessels, beginning 4 cm distal to the lateral border of the pectoralis major. The fascia over the biceps was dissected from the coracobrachialis muscle,

Figure 13: Platysma motor branch exposure.

Figure 14: Oberlin nerve transfer. Partial transfer of the ulnar nerve to the biceps motor branch of the musculocutaneous nerve (MCN).

and the motor branch of the biceps was identified. The motor branch was traced as far proximally as possible into the MCN and was then divided. A second fascial incision was performed posterior to the intermuscular septum, and the ulnar nerve was exposed for 3 cm. A longitudinal epineurotomy was made on the anterolateral region of the ulnar nerve, which was coapted to the biceps motor branch.[7]

Elbow extension

In patients with elbow extension impairment, we use the surgical exposure for the Oberlin neurotization to select two fascicles of the median nerve to the flexor carpi radialis (FCR) that are coapted to the motor branch of the triceps long head (recipient nerve).[10] The exposure of this nerve is obtained by extending the incision to the axilla. The radial nerve is exposed, and its branches to the long head and upper medial triceps are dissected [Figures 16 and 17].

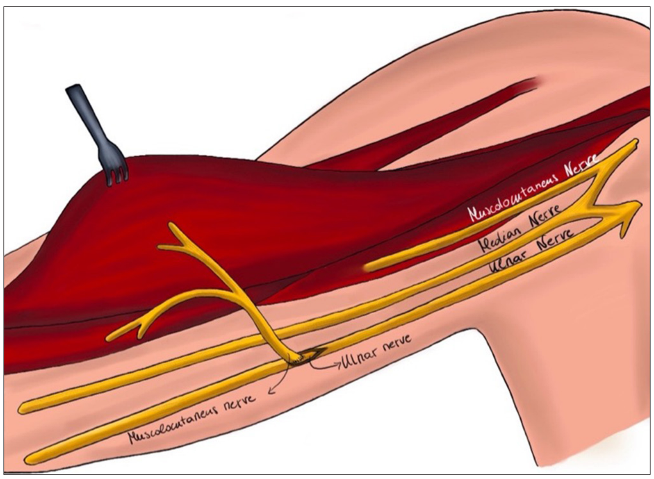

Figure 15: Oberlin nerve transfer. Transfer of the musculocutaneous nerve (recipient) to nerve fascicles of the ulnar nerve (donor).

Figure 16: Dissection of the branches to the flexor carpi radialis (FCR) of the median nerve versus the musculocutaneous nerve.

The triceps long head motor branch is traced up to its arborization inside the muscle and then cut at its origin from the radial nerve and transferred to the median nerve fascicles, performing a 9-0 nylon suture [Figure 18]. This technique, described by Bertelli and Ghizoni, allows the exposure of all the previous nerve targets through one incision on the medial aspect of the arm, extended to the axilla.

Contralateral C7

In cases of young patients with complete avulsion of the brachial plexus and the impossibility of using the intercostal nerves, we connect the contralateral half C7 root to the MCN using the vascularized homolateral ulnar nerve [Figure 19].[7,24] This is in addition to neurotization performed to restore the shoulder functions. The contralateral C7 root is exposed through a small linear incision behind the

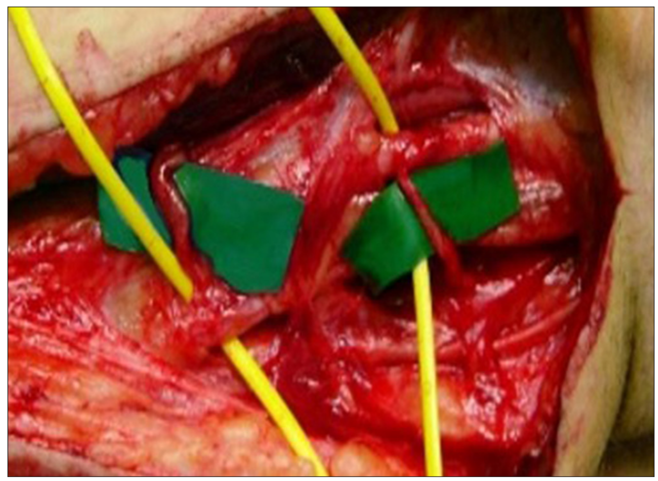

Figure 17: Oberlin + branch to flexor carpi radialis (FCR) versus triceps long head motor.

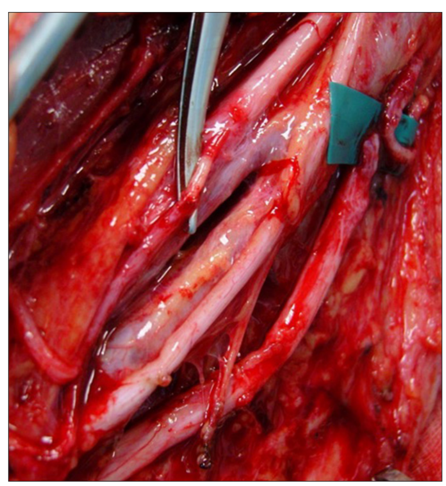

Figure 18: Oberlin + branch to flexor carpi radialis (FCR) and triceps long head motor branch.

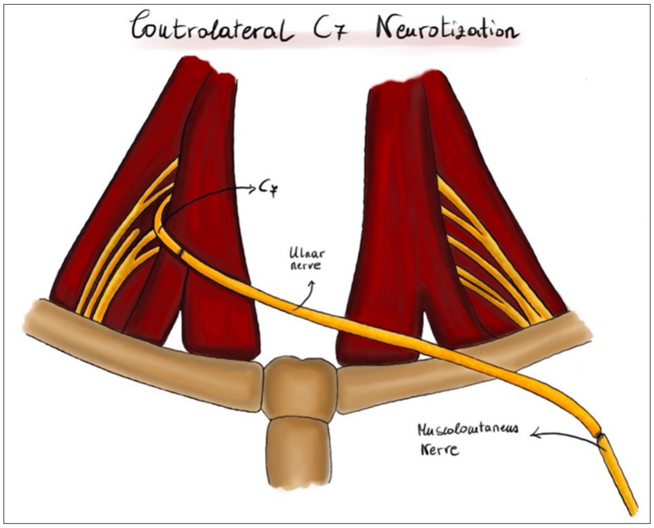

Figure 19: Connection of contralateral C7 root to the musculocutaneous nerve using the vascularized homolateral ulnar nerve.

Figure 20: Contralateral C7 exposure.

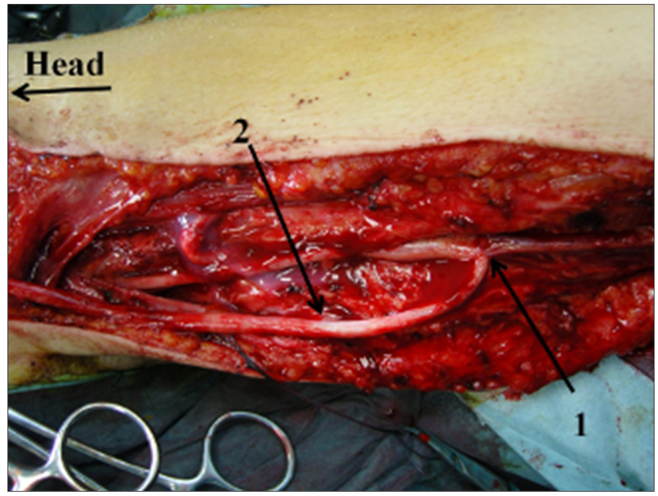

Figure 21: Entry point of the superior ulnar collateral artery (1) into the ulnar nerve (2) - left side. The ulnar nerve was sectioned at the wrist and retracted for the contralateral C7 neurotization.

Figure 22: Final view of the three linear approaches that allowed us to perform the following connections: XI cranial nerve versus suprascapular nerve direct neurotization, platysma motor branch versus anterior division neurotization through the interposition of the sural nerve, sural grafting between C5 and the posterior division, and another graft between C6 and the anterior division – right side.

contralateral sternocleidomastoid muscle [Figure 20]. Using intraoperative stimulation, we recognize the C7 component not involved in the wrist and finger extension of the donor side.

This C7 component can be transversally sectioned under the intraoperative microscope in its apical posterior segment (in our patients, no more than 50% of the root was sectioned). The ulnar nerve at the traumatic site is entirely exposed until the wrist and segmented at this level. The temperature of the operating room should not be too low to avoid vasoconstriction of the vasa nervorum. The superior ulnar collateral artery is preserved [Figure 21], and papaverine is applied to the distal stump of the ulnar nerve. Subsequently, the distal stump of the ulnar nerve is connected to a cable of the sural nerve that is coapted to the contralateral C7 previously sectioned. A proximal section of the ulnar nerve is also performed, and the stump at this level is sutured to the MCN with 9-0 nylon sutures.

RESULTS

This study analyzed 19 patients who underwent surgical treatment for brachial plexus injuries based on the degree and topographic level of brachial plexus damage, with outcomes assessed according to key functional objectives: shoulder control, elbow flexion, and elbow extension. The detailed morphometric measurements and surgical techniques applied were critical for optimizing nerve exposure, mobilization, and coaptation, ensuring tension-free and anatomically precise repairs [Tables 1-5].

Table 1: Spinal accessory nerve.

	Average (mm)	Range (mm)	Standard deviation (mm)
Length of exposure of the anterior margin of the trapezius muscle	40.5	33–70	2.8
Length of the trapezius muscle band incision	30	20–40	1.3
Shortest distance between the spinal accessory nerve (after fascia dissection) and the anterior margin of the trapezius muscle	11	5–13	2.0
Shortest distance between the spinal accessory nerve (after fascia dissection) and the suprascapular nerve	35	22–45	1.6
Shortest distance between the spinal accessory nerve (after fascia dissection) and the upper margin of the clavicle	45	28–55	1.3
Distance between the projection point of the spinal accessory nerve (at its crossing of the anterior margin of the trapezius muscle) on the clavicle and the sternoclavicular junction	120	100–150	2.3
Diameter of the spinal accessory nerve after dissecting the trapezius muscle for 30 mm from its anterior margin	2.8	0.5–4	0.3
Length of the spinal accessory nerve after dissecting the trapezius muscle for 30 mm from its anterior margin	22	7–35	1.8
	Average (degrees)	**Range (degrees)**	**Standard Deviation (degrees)**
The angle between the spinal accessory nerve and the clavicle	45°	20–75°	1

Table 2: Suprascapular nerve.

	Average (mm)	Range (mm)	Standard deviation (mm)
Shortest distance between the upper margin of the clavicle and the coracoid process	35	28–47	2.8
Shortest distance between the upper margin of the clavicle and the suprascapular ligament	30	24–40	2.7
Shortest distance between the suprascapular ligament and the accessory nerve	54	39–40	3.8
Shortest distance between the suprascapular notch and the coracoid process	28.7	14–45	1.2
Distance between Erb's Point and the origin of the SSC from the TPS	9.7	4–25	4.7
Shortest distance between the origin of the SSC from the TPS and the upper margin of the clavicle	26	8–48	2.9
Shortest distance between the SSC and the accessory nerve (when crossing the anterior margin of the trapezius muscle) before suprascapular ligament dissection	36	25–44	2.5
Shortest distance between the SSC and the accessory nerve after suprascapular ligament dissection	110	90–130	1.5
Length of the SSC before dissection of the trapezius muscle from the nerve origin	37	26–57	1.5
Length of the SSC after detaching the trapezius muscle from the clavicle	76	65–91	1.8
Length of the SSC after suprascapular ligament dissection from the nerve origin	110	97–130	2.3
Length of the suprascapular ligament	15	9–20	2.8
Diameter of the suprascapular nerve at the notch	4	2–5	1.2
Distance between the SSC projection point (isolated at the notch) on the clavicle and the sternoclavicular junction	120	100–150	1.2
Diameter of the suprascapular ligament	4	3–6	1.4

(Contd...)

Table 2: *(Continued).*

	Average (mm)	Range (mm)	Standard deviation (mm)
Depth of the SSC to the homohyoid muscle	5	3–8	0.1
	Average (Degrees)	**Range (Degrees)**	**Standard deviation (Degrees)**
Angle of dissection through deep structures to the notch	90°	80–110°	0.2°
The angle between the suprascapular ligament and the clavicle	90°	80–110°	0.1°
The angle between the SSC and the line perpendicular to the clavicle	45°	30–50°	0.2°

SSC: Suprascapular nerve, TPS: Primary superior trunk

Table 3: Platisma motor branch.

	Diameter of the branch for the platysma muscle	Length of the branch for the platysma muscle from its origin
Average (mm)	2.6	23
Range (mm)	1.3–3.8	14–27
Standard deviation (mm)	1.8	0.7

Table 4: Angle between the branch for the platysma muscle and the inferior margin of the mandible.

	Angle between the branch for the platysma muscle and the inferior margin of the mandible
Average (degrees)	45°
Range (degrees)	30–90°
Standard deviation (degrees)	3.8°

The XI cranial nerve and the suprascapular nerve were exposed through an oblique supraclavicular incision, starting at the junction between the medial and middle thirds of the clavicle [Figures 3-5]. The angle between the spinal accessory nerve and the clavicle was 45° (range 20–75°). The length of exposure of the anterior margin of the trapezius muscle was 40.5 mm (range 33–70 mm), and the length of the trapezius muscle band incision was 30 mm (range 20–40 mm). The shortest distance between the spinal accessory nerve (after fascia dissection) and the anterior margin of the trapezius muscle was 11 mm (range 5–13 mm). The shortest distance between the spinal accessory nerve (after fascia dissection) and the suprascapular nerve was 35 mm (range 22–45 mm). The XI cranial nerve is harvested at the anterior border of the trapezius muscle, approximately 4 cm from the clavicle (range 28–55 mm). It is identified in the fat between the trapezius muscle and its fascia, retracted like a book page in an avascular plane [Figure 4]. The diameter of the spinal accessory nerve, after dissecting the trapezius muscle for 30 mm from its anterior margin, was 2.8 mm (range 0.5–4 mm), and its length was 22 mm (range 7–35 mm) [Table 1].

The same surgical incision allows for the identification of the suprascapular nerve [Figures 3 and 5]. The omohyoid muscle, retracted or dissected, serves as the anatomical landmark to reach the suprascapular nerve. The suprascapular nerve lies 5 mm (range 3–8 mm) deep from the omohyoid muscle. A lateral extension of the incision toward the acromion in a zigzag pattern was used to expose the nerve more distally at the notch [Figures 6-9]. The deep fascia over the trapezius muscle was dissected, and the muscle was detached from the clavicle and acromion. The coracoid process, located under the clavicle within the fat tissue, was then identified by finger palpation. The shortest distance between the upper margin of the clavicle and the coracoid process was 35 mm (range 28–47 mm), and the shortest distance between the upper margin of the clavicle and the suprascapular ligament was 30 mm (range 24–40 mm). The shortest distance between the suprascapular ligament and the accessory nerve was 54 mm (range 39–40 mm), and the shortest distance between the suprascapular notch and the coracoid process was 28.7 mm (range 14–45 mm). The length of the suprascapular nerve before dissection of the trapezius muscle from the nerve origin was 37 mm (range 26–57 mm). The length of the suprascapular nerve after detaching the trapezius muscle from the clavicle was 76 mm (range 65–91 mm).

The final step was the exposure and sectioning of the ligament. The length of the suprascapular ligament was 15 mm (range 9–20 mm). The diameter of the suprascapular nerve at the notch was 4 mm (range 2-5 mm). The depth of the suprascapular nerve from the omohyoid muscle was 5 mm (range 3–8 mm). After the ligament was transected, it was possible to mobilize the suprascapular nerve until the notch, obtaining nerve exposure of approximately 11 cm (range 97–130 mm) in length from its origin. The angle of dissection through deep structures to the notch was 90° (range 80–110°), and the angle between the suprascapular ligament and the clavicle was 90° (range 80–110°) [Table 2].

Table 5: Oberlin.

	Average (mm)	Range (mm)	Standard Deviation (mm)
Diameter of the biceps branch of the MCN before its branching at the level of the muscle belly	2.7	1.9–3.4	0.8
Length of the biceps branch of the MCN from its origin to its arborization at the muscular level	47.7	38.6–59	3.7
Diameter of the brachial branch of the MCN before its branching at the level of the muscle belly	2	1.4–2.7	0.9
Length of the brachial branch of the MCN from its origin to its arborization at the muscular level	52.2	41.4–68.4	2.4
Diameter of the triceps branch of the radial nerve before its branching at the muscular level	3.1	1.5–4	1.3
Length of the triceps branch of the radial nerve from its origin to its arborization at the muscular level	60	51–71	2.4
Shortest distance between the ulnar nerve and the biceps branch of the MCN at the origin of the biceps branch	31	25–37	1.4
Shortest distance between the median nerve and the triceps branch of the radial nerve at the level of the origin of the triceps branch from the radial nerve	42	30–51	2.4

MCN: Musculocutaneous nerve, SSC: Suprascapular nerve, TPS: Primary superior trunk

The platysma motor branch was exposed with a 3 cm incision located one finger below the mandible [Figure 11]. The diameter of this branch was 2.6 mm (range 1.3–3.8 mm), and its length was 23 mm (range 14–27 mm). The angle between the platysma motor branch and the inferior margin of the mandible averaged 45° (range 30–90°). The nerve, which emerges just beneath the platysma muscle, was connected to the medial pectoral nerve or the anterior division, using a sural nerve cable [Figures 12 and 13; Tables 3 and 4].

The Oberlin procedure, aimed at restoring elbow flexion, involves transferring a fascicle from the ulnar nerve to the musculocutaneous branch to the biceps. An 8 cm long incision was made on the medial aspect of the arm over the brachial vessels, beginning 4 cm distal to the lateral border of the pectoralis major [Figures 14 and 15]. The diameter of the biceps branch of the MCN before its branching at the level of the muscle belly was 2.7 mm (range 1.9–3.4 mm), and the diameter of the brachial branch of the MCN before its branching at the level of the muscle belly was 2 mm (range 1.4–2.7 mm). The shortest distance between the ulnar nerve and the biceps branch of the MCN was 31 mm (range 25–37 mm) [Table 5].

To restore elbow extension, the same surgical exposure for the Oberlin neurotization was used to select two fascicles of the median nerve to the FCR, which were coapted to the triceps head motor branch. The shortest distance between the median nerve and the triceps branch of the radial nerve was 42 mm (range 30–51 mm). The diameter of the triceps branch of the radial nerve before its branching at the muscular level was 3.1 mm (range 1.5–4 mm). The length of the triceps branch of the radial nerve from its origin to its arborization at the muscular level was 60 mm (range 51–71 mm) [Figures 16-18 and Table 5].

DISCUSSION

Different techniques and experiences of brachial plexus surgical reconstruction are described in the medical literature.[16,22,23] According to Bertelli and Ghizoni's techniques, upper brachial plexus avulsions are treated by restoring the suprascapular nerve function using the XI cranial nerve harvested at the anterior border of the trapezius muscle.[4,8] Direct coaptation between the accessory nerve and the suprascapular nerve, without the interposition of sural nerve grafts, was always possible in our patients. In fact, the best results in neurotization are obtained by performing nerve-to-nerve sutures as distally as possible, close to the receiving muscle.

Opening the trapezius fascia like a book page [Figure 4] in an avascular plane is a safe procedure, as the target nerves are relatively superficial structures. Different target nerves, such as the XI cranial nerve, the suprascapular nerve, and the anterior and posterior divisions, are exposed through a single, carefully planned linear incision [Figures 3 and 5]. In patients with extensive neuromas and post-traumatic scars, the incision was extended to the acromion in a zigzag fashion, and the suprascapular nerve was exposed at its notch [Figures 6-9]. This technique offers the advantage of exposing the notch using a single incision, without turning the patient into a prone position. According to our clinical results, we believe that exploration of the suprascapular nerve at the notch could be useful in patients with scapular fractures, clavicular dislocations, or extensive neuromas, due to the high risk of double crush syndrome.[8] Direct exploration of the coaptation site during shoulder mobilization is easily feasible because the patient remains in the supine position, and all nerves are exposed through a single incision. We did not report postoperative clinical complications related to XI cranial nerve distal sectioning.

The integrity of the C5 and C6 roots is evaluated using our specific magnetic resonance imaging protocol before their grafting and connection with the anterior and posterior divisions.[11,16] The surgical preparation of the healthy root stumps is a crucial "biological" step before grafting.

As a collateral reinforcing neurotization, we typically add a connection between the platysma motor branch and the medial pectoral nerve or the anterior division, interposing a 10 cm sural nerve graft [Figure 22]. After sectioning the platysma motor branch (mean diameter = 2 mm), muscle contraction was preserved in all our patients [Figures 12 and 13].

In cases of selected superior brachial plexus injury, we restore elbow flexion using Oberlin neurotization as described in the medical literature [Figures 14 and 15].[15,18,21]

In our experience, the intercostal-to-MCN transfer should be used as a second choice to restore elbow flexion, due to the time-consuming and challenging nature of the surgery. Intercostal nerves are very thin, and the risk of damage to the anastomosis should be considered [Figure 23].[19]

In young patients affected by total avulsion or damage to the entire brachial plexus with no intercostal nerves available (e.g., chest trauma, pulmonary pathologies),[13] we usually perform the contralateral C7 neurotization, using the MCN as the recipient to restore elbow flexion [Figure 19]. Deficits in triceps function are relatively infrequent because the triceps is innervated by C6 to T1, with its long head innervated by C8 and T1.[7] Only one patient reported some transient paresthesia on the posterior aspect of the arm.

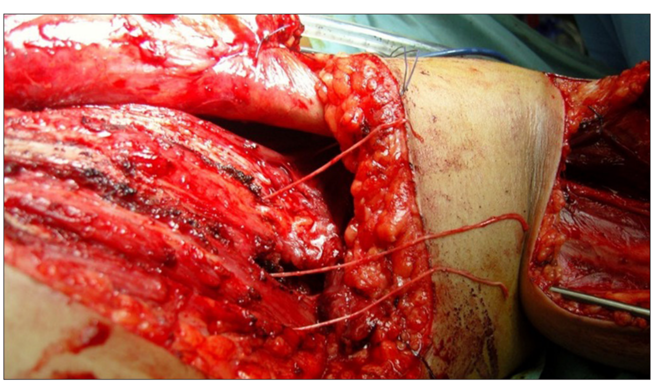

Figure 23: Intercostal nerves exposure.

Intraoperative stimulation is mandatory during this kind of surgery.[17] When a nerve is so severely damaged that it does not elicit a muscular response after direct stimulation, it should be replaced using a graft or bypassed with a neurotization. Thanks to intraoperative stimulation, we did not report significant clinical complications after neurotization techniques.

The reasons for non-recovery are related to biological aspects, such as a lower chance of improvement in older patients due to reduced regenerative capacity and a decreased ability to follow rehabilitation. Furthermore, patients with complete paralysis of the arm and advanced muscular atrophy showed a reduced likelihood of achieving functional results. On the other hand, some patients failed to recover due to surgical factors, such as the possible disruption of nerve-to-nerve coaptation.[4] In conclusion, patients with brachial plexus injuries should undergo a thorough diagnostic workup to ensure an accurate diagnosis and optimal surgical timing. Based on our experience, the surgical approaches and nerve exposure techniques described herein align well with the fundamental principles of brachial plexus surgery. This approach enables patients to be discharged within a few days, minimizing the risks associated with prolonged hospital stays. Our outcomes and patient satisfaction are consistent with findings reported in the medical literature.[7,14,22]

CONCLUSION

This study demonstrates the effectiveness of advanced surgical techniques for traumatic brachial plexus injuries, emphasizing precise nerve coaptation and strategic donor nerve selection. Key procedures such as XI cranial nerve-to-suprascapular nerve neurotization and Oberlin transfer yielded promising results in restoring shoulder and elbow function. The incorporation of intraoperative morphometric analysis, including nerve length and diameter measurements, enabled accurate, tension-free coaptation, significantly enhancing functional outcomes. Our findings confirm that timely intervention, combined with careful surgical planning guided by morphometric data and the use of topographically localized linear incisions and direct neurotizations, can achieve substantial functional recovery and improve patients' quality of life.

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REFERENCES

1. Bertelli JA. Platysma motor branch transfer in brachial plexus repair: Report of the first case. J. Brachial Plex Periph Nerve Inj 2007;2:12.
2. Bertelli JA, Ghizoni MF. Controlateral motor rootlets and ipsilateral nerve transfers in brachial plexus reconstruction. J Neurosurg 2004;101:770-8.
3. Bertelli JA, Ghizoni MF. Concepts of nerve regeneration and repair applied to brachial plexus reconstruction. Microsurgery 2006;26:230-44.
4. Bertelli JA, Ghizoni MF. Improved technique for harvesting the accessory nerve for transfer in brachial plexus injuries. Neurosurgery 2006;58(Suppl 2):366-70.
5. Bertelli JA, Ghizoni MF. Long thoracic nerve: Anatomy and functional assessment. J Bone Joint Surg Am 2005;87:993-8.
6. Bertelli JA, Ghizoni MF. Nerve repair by end-to-side coaptation or fascicular transfer: A clinical study. J Reconstr Microsurg 2003;19:313-8.
7. Bertelli JA, Ghizoni MF. Reconstruction of C5 and C6 brachial plexus avulsion injury by multiple nerve transfers: Spinal accessory to suprascapular, ulnar fascicles to biceps branch, and triceps long or lateral head branch to axillary nerve. J Hand Surg 2004;29:131-9.
8. Bertelli JA, Ghizoni MF. Transfer of the accessory nerve to the suprascapular nerve in brachial plexus reconstruction. J Hand Surg 2007;32A(7):989-98.
9. Bertelli JA, Kechele PR, Santos MA, Duarte H, Ghizoni MF. Axillary nerve repair by triceps motor branch transfer through an axillary access: Anatomical basis and clinical results. J Neurosurg 2007;107:370-7.
10. Bertelli JA, Kechele PR, Santos MA, Duarte H, Ghizoni MF. Triceps motor nerve branches as a donor or receiver in nerve transfers. Neurosurgery 2007;61:333-8; discussion 338-9.
11. Bowen BC, Pattany PM, Lavi ES, Maravilla KR. The brachial plexus: Normal anatomy, pathology, and MR imaging. Neuroimaging Clin N Am 2004;14:59-85.
12. Brophy RH, Wolfe SW. Planning brachial plexus surgery: Treatment options and priorities. Hand Clin 2007;21:47-54.
13. Chalidapong P, Sananpanich K, Kraisarin J, Bumroongkit C. Pulmonary and Biceps function after intercostal and phrenic nerve transfer for brachial plexus injuries. J Hand Surg (Br) 2004;1:8-11.
14. Chuang DCC. Nerve transfers in adult brachial plexus injuries: My methods. Hand Clin 2005;21:71-82.
15. Ferraresi S, Garozzo D, Buffetti P. Reinnervation of the biceps in C5-7 brachial plexus avulsion injuries: Results after distal bypass surgery. Neurosurg Focus 2004;16:1-5.
16. Gerevini S, Mandelli C, Cadioli M, Scotti G. Diagnostic value and surgical implications of magnetic resonance imaging in the management of adult patients with brachial plexus pathologies. Surg Radiol Anat 2008;30:91-101.
17. Harper CM. Preoperative and intraoperative electrophysiologic assessment of brachial plexus injuries. Hand Clin 2005;21:39-46.
18. Liverneaux PA, Diaz LC, Beaulieu JY, Durand S, Oberlin C. Preliminary results of double nerve transfer to restore elbow flexion in upper type brachial plexus palsies. Plast Reconstr Surg 2006;117:915-9.
19. Malessy JA, Thomeer RT. Evaluation of intercostal to musculocutaneous nerve transfer in reconstructive brachial plexus surgery. J Neurosurg 1998;88:266-71.
20. Moran SL, Steinmann SP, Shin AY. Adult brachial plexus injuries: Mechanism, patterns of injury, and physical diagnosis. Hand Clin 2005;21:13-24.
21. Oberlin C, Beal D, Leechavengvongs S. Nerve transfer to biceps muscle using a part of ulnar nerve for C5-C6 avulsion of the brachial plexus: Anatomical study and report of four cases. J Hand Surg (Am) 1994;19:232-7.
22. Songcharoen P, Wongtrakul S, Spinner RJ. Brachial plexus injuries in the adult. Nerve transfers: The Siriraj Hospital experience. Hand Clin 2005;21:83-9.
23. Spinner RJ, Shin AY, Bishop AT. Update on brachial plexus surgery in adults. Curr Opin Orthop 2004;15:203-14.
24. Waikakul S, Orapin S, Vanadurongwan V. Clinical results of controlateral C7 root neurotization to median nerve in brachial plexus injuries with total root avulsions. J Hand Surg 1999;24B:556-60.

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