Pro Index Journal of Science in Medicine and Life
Volume: 2 Issue: 7 Year: 2024
http://journals.proindex.uz

Double Fascicular Nerve Transfer for Elbow Flexion

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Abstract: **Background:** Restoration of elbow flexion is one of the major aims in the therapy of upper trunks brachial plexus damage. Primary repair, nerve graft and tendon transfer were among the various procedures for rebuilding.

- **Purpose:** To analyze efficacy nerve transfer to reinnervate the muscles that comprise brachialis and the biceps to restore the function of elbow flexion after having brachial plexus damage.
- **Methods:** In this study, six patients with seven cases of upper trunk brachial plexus injury—involving the C5 and C6 spinal nerves—are examined. One expendable motor fascicle from each of the median and ulnar nerves is directly transferred to the brachialis muscular branch of the musculocutaneous nerve, and the other from the median nerve.
- The examination includes a range and function assessment of the elbow, an evaluation of the median and ulnar nerves, and a strength and sensation assessment of the post-operative muscles. The following criteria were used to assess these people's degree of flexion: the Waikakul et al. scale and the Medical Research Council (MRC) score.
- **Results:** Clinical values of reinnervation is recorded at a mean of 6 months (5–7 mo) after surgery. Elbow flexion strength was grade M4 in 4 instances according to Medical Research Council(MRC), grade M3 in 2 cases and grade M4+ in 1 case. The range of flexion was 140 degree in all individuals. According to Waikakul et al scale, elbow function were: exceptional in one patient,good in 4 patients and it was inapplicable in one patient.
- No motor or sensory impairments connected to the ulnar or median nerves was seen for extended time follow up and excellent hand function maintained for long duration. No individuals needed extra surgical procedures to increase elbow flexion power.
- **Conclusions:** The proportion of excellent elbow power strength that was recovered rose without any difficulties. This approach maybe will diminish the necessity for revision treatments to increase elbow flexion.

Introduction

For many hand surgeons, complicated nerve lacerations in the upper limbs offer a significant situation. Transfers of tendons and nerves give solutions for sustaining function.

Elbow flexion rehabilitation is the key focus in the therapy of upper roots injury (C5-C6). In root avulsion and immediately irreparable proximal lesions of the upper brachial plexus in which nerve grafting is forbidden, tendon and nerve transfers is the remaining choices.(3) The flexor pronator (Steindler flexorplasty), pectoralis major, triceps, and latissimus dorsi are the common tendon transfer options.(1) tendon transfer produces lower overall outcomes than nerve transfer; moreover, muscle function that was previously transferred is lost during tendon transfer, and the surgeon misses the best window of opportunity for nerve transfer.

In 1993, Brandt and Mackinnon presented the outcomes of transferring the medial pectoral nerves branches to the musculocutaneous nerve and they identified the important benefit of reinnervation the motor fascicles of the biceps and brachialis muscles by musculocutaneous nerve. (5) In 1994 Oberlin et al demonstrated the transfer of an flexor carpi ulnaris (FCU) fascicle from the ulnar nerve straight to the musculocutaneous nerve (6).

flexor carpi ulnaris (FCU) transfer before has been documented by Sungpet et al in 2003.(7)

The design of a double fascicular transfer were developed by Tung et al in 2004(8).

Although there are many options to reinnervate brachialis muscle as described by Tung et al in 2003(9) the preferred technique is to use a redundant motor branch of the median or ulnar nerves.

Recent investigations have showed that fibers of a separate fascicular group are found adjacent to one other, even in the proximal limb. (10)

The categorization of nerve lacerations, at start given by Seddon in 1947 and Sunderland in 1951, was expanded by Mackinnon to add a sixth division stand for a mixed damage pattern. The degree and severity of injury are crucial in selecting treatment. 1st, 2nd, 3rd degree lacerations have the possibility for recuperation and do not require surgical intervention. A 1st degree laceration retrieve function swiftly (within 3 months). A 2nd degree laceration retrieve slowly (1 mm each day) but entirely, but recovery after 3rd degree injuries is delayed and insufficient. 4th and 5th degree injuries will never retrieve without surgical intervention. A 6th degree laceration demonstrates an uneven healing. (10) 1st degree laceration (neurapraxia),2nd degree laceration (axonotmesis), 3rd degree laceration (Wallerian degeneration) is joint with some fibrosis of endoneurium, 4th degree laceration, 5th degree laceration (neurotmesis)and 6th degree laceration which represents a mix of any of the former five stages. (10)(11) The major benefits of a nerve transfer over that of a tendon transfer are: (1) a nerve transfer exhibit the power for restoring sensation in addition to motor function.

(2) single nerve transfer may restore many muscle groups function, (3) the insertion and attachments of the muscle(s) in issue are not disturbed, so that the original muscle function is Preserved. The donor nerves were selected based on the closeness to the motor end-plate, and the repair was done without stress. (12)

Materials and Methods:

This research deals with 7 consecutive instances of upper brachial plexus damage with excellent hand function who came to Al-Wasity teaching hospital, unit of micro-surgery within 10 months of injury throughout the period of August 2005 and September 2010. The average age of patients was 32.04 years (3months–43 years). There were 5 men and one female. The mechanism of damage included road traffic collision in 2 male patients, blast injury in 3 male patients and bilateral obstetric brachial plexus injury in one female patient. Three of adult patients were damaged at right side and 2 of them at left side.

These individuals were diagnosed as having damage to C5 and C6 spinal nerves. All included patients had received a double fascicular nerve transfer operation. A complete preoperative examination for elbow flexion range of motion was done in all the patients and reported as the base line. Clinical and electro-physiologic testing(EMG and NCS) evaluation were done for all patients with no indication of recovery after 4-6 months following the injury. Biceps, and brachialis muscles were paralyzed and rated M0 (13) (table1). The criteria utilized to determine the degree of flexion in these individuals, are: Medical Research Council (MRC) score and the scale developed by Waikakul et al(14)(table 2). The range of flexion examined by goniometry (Figure1).

Table 1 [13]

Observation	Muscle quality
No contraction	0
Flickering or mild contraction	1
Weightless contraction	2
Active defiance of gravity	3
Active motion defying resistance and gravity	4
Ordinary strength	5

Table 2 [14]

Grade	Functional status
Excellent	Capable of lifting 2 kilograms with the elbow flexed between 0 and 90 degrees for over 30 times.
Good	Can lift 2 kilograms with the elbow flexing from 0 to 90 degrees, but only for a limited number of repetitions, typically 30.
Fair	The engine has a more powerful power than the M3, but it is not sufficient to lift a two-kilogravload.
Poor	less motor power than the M3.

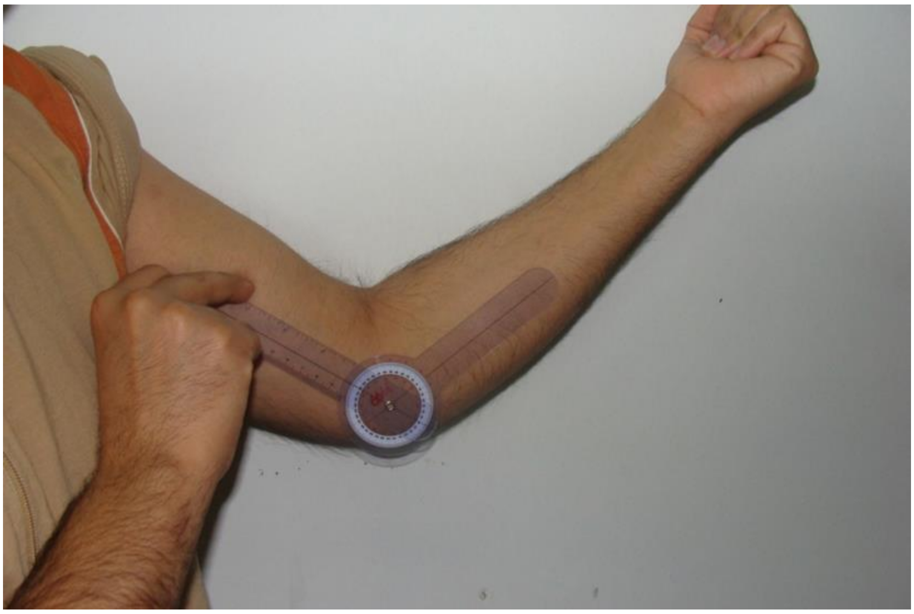

Figure (1):evaluation of flexion range by goniometry

Surgical Procedure:

The patient was anesthetized using general methods without the utilization of muscle relaxants, they placed the shoulder in a 90 degree position. The surgical area was covered with a 1:200,000 solution of epinephrine. A Lazy-S incision was created across the middle bicipital channel of the upper arm's skeleton; the incision began at the axilla and extended approximately 4 centimeters into the middle of the epicondyle.

The musculocutaneous nerve was located in the deep valley of the brachial region between the biceps and brachialis, the branches of these muscles were easily identified.

The branches of the biceps and brachial artery were neurolized near their attachment points, they were then divided and moved towards the median and ulnar nerves, respectively. Topographically, the motor portion of the median nerve is located medially, while the sensory portion is located on the lateral side. The available motion portion of the ulnar nerve is located on lateral or in the middle of the ulnar nerve.

Locate collections of uniform length and similar diameter that can be directly transferred. Internal neurolysis of these nerve fibers is facilitated by the bicipital and brachial artery anastomoses. Use a portable stimulator for the nerve to verify the functionality of these nerve fibers and locate the necessary bundles of nerve. Ensure that the remaining function of the median and ulnar nerves is sufficient by stimulating the remaining nerve prior to its transmission.

Transect the donor bundle of nerve fibers as necessary and the recipient bundle as necessary to facilitate direct repairs without transferring needed.

Extra-neural healing is facilitated by 10/0 nylon ties and conventional micro-neurosurgical methods, the transferred bundle is tied to the muscle branches in a single-end position. After performing a faded drainage, the incision is sealed using conventional surgical methods. (Figure 2)

After the operation, treatment and rehabilitation.:

The patient's arm was kept in a shoulder strap with elbow flexion, internal rotation, and shoulder adduction for ten to fourteen days following surgery. On the first day, parenteral prophylactic antibiotics were administered; oral medication was then administered for seven days.

On the second day, the flooded drain was removed. Stitches were extracted from the 10th to the 14th day. They were removed the day after surgery. Two weeks later, the patient was told to increase the number of upper body range of motion exercises to regain all lost mobility.

Six weeks later, the patient had an appointment with a physical therapist to improve grip strength. As soon as the patient noticed the first decrease in biceps size, he was instructed to start active activities in the supine position, retrain the movement, and strengthen the patient's strength. The patient was initially allowed to exercise the muscles that were originally innervated by the donor nerve, such as the FCU and FDS, FCR, or palmaris longus. This was achieved by placing the patient on a program to improve grip strength. The goal was to promote muscle training and participate in sports preparation. Over time, resistance training was incorporated into the practice to increase elbow flexion strength and isolate it from the activity of other muscles.

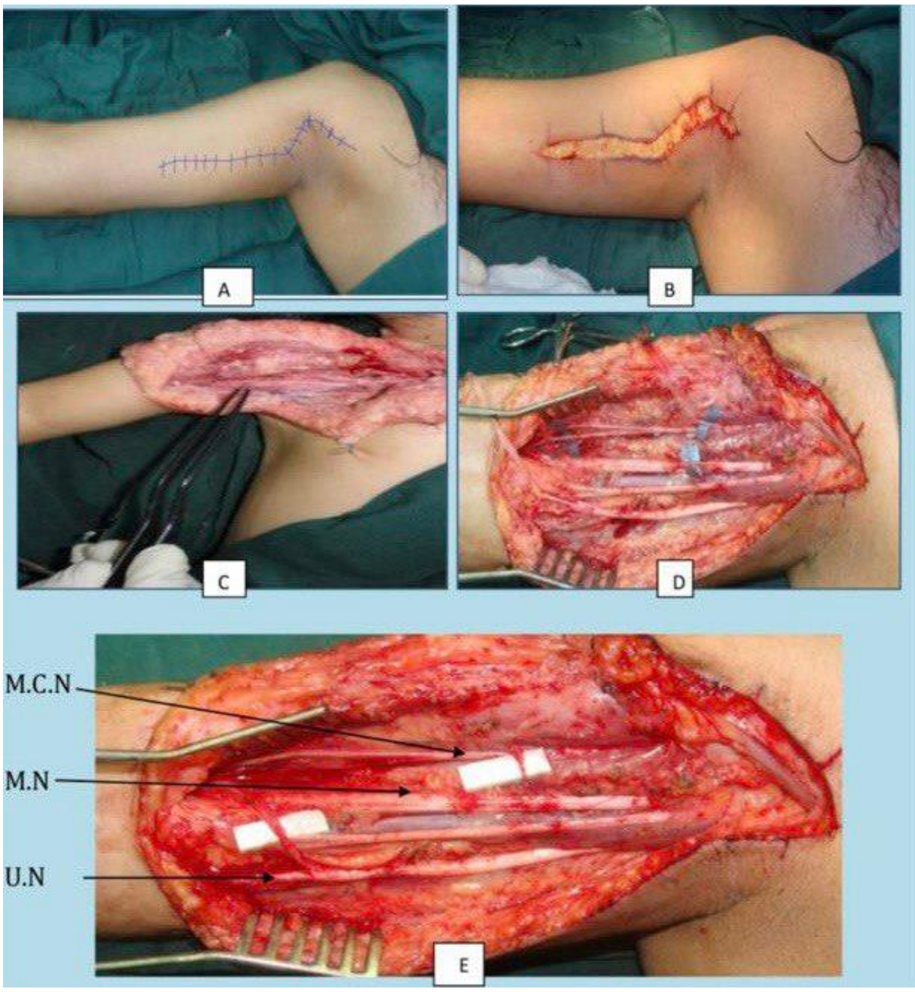

Figure (2): The process of surgical examination. A: Preoperative planning. B: Surgical incision after injection of diluted epinephrine. C: Examination of the musculocutaneous, median, and ulnar branches of the nerve by intraoperative stimulation of the nerve to locate the removable nerve bundle. D: Identification of the bicipital and brachial branches of the nerve by separation of the removable bundle. E: Coaptation of the extraneural end-to-end sutures of the median and ulnar branches to the brachial branch.

Results:

Clinical evidence of neural innervation was documented at a mean of 6 months postoperatively (5-7 months), the average follow-up period was 14 months (6-20 months).

The elbow's flexion strength at the most recent or previous follow-up was MRC M4 in 4 patients (57.15%), M4+ in 1 patient (14.3%), and M3 in 2 patients (28.6%).

The span of motion was 140 degrees in all instances. No patient had a hand deficiency that was long-lasting. One patient had paresthesia in the small finger that would vanish after a few weeks, however, the other patients had no sensory loss either immediately following surgery or over the long term. According to the scale of Waikakul et al., the elbow's function was adequate in one patient (20%), it was adequate in four patients (80%), and it was not applicable in patient 6.

The attributes of the patients and the final assessment of the elbows are documented in (Table 3). One patient had a puncture wound that was infected with bacteria, he received local treatment for the infection. Another patient had a scar that was overgrown. Postoperative complications are listed in Table 4.

Table (3)

s. no.	Age\Sex	Accidents	Time since injury	Foll-ow up \mo.	Elbow flexion grade (Waikakul)	Range of flexion\ degree	Motor grading
1	30y\♂	Shell injury\C5,C6	4 mo.	20mo.	good	140 degree	M4
2	36 y\♂	RTA\C5,C6	4 mo.	18mo.	excellent	140 degree	M4+
3	43y\♂	Shell injury\C5,C6	8 mo.	16mo.	good	140 degree	M4
4	20y\♂	Shell injury\C5,C6	6 mo.	20 mo.	good	140 degree	M4
5	38y\♂	RTA\C5,C6	10 mo.	11 mo.	good	140 degree	M3
6	3 mo.\♀	Obst.B.P.InjuryC5,C6 Rt. side	3mo.	8 mo.	inapplicable	140 degree	M4
7	6mo.\♀	C5,C6(Same pt.)Lt.side	6 mo.	6 mo.	inapplicable	140 degree	M3

RTA: road traffic accident.

Obst. B.P: obstetrical brachial plexus.

Complication	No. of patients
Parasthesia of little finger	1
Stitch abscess	1
Hypertrophic scar	1

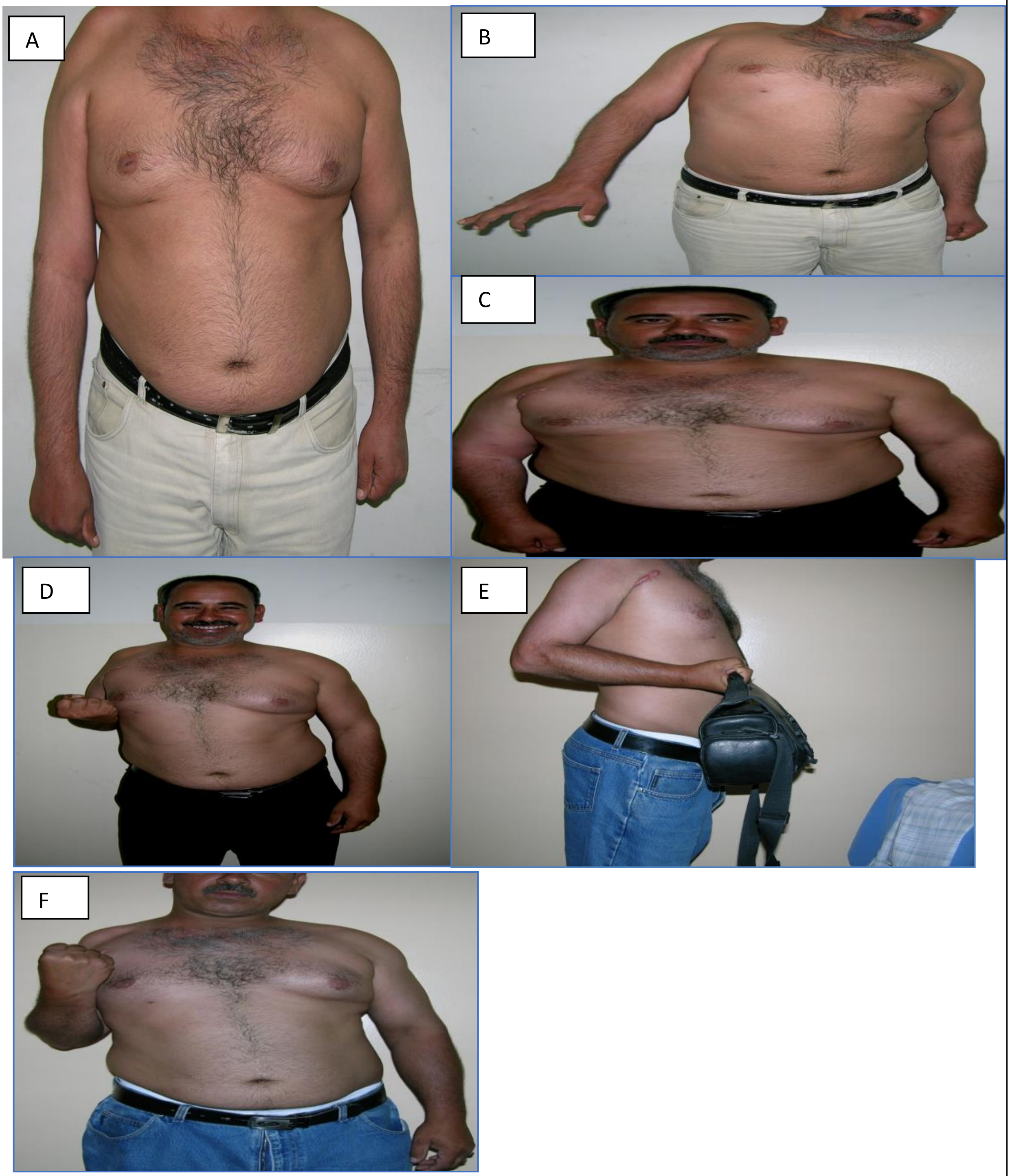

Figure (3):36 y. old patient, presented with injury to right upper trunk with loss of right elbow flexion, due to RTA. Double fascicular nerve transfer was used for reconstruction after 4 months from injury. A,B: pre-operative pictures. C,D: patient regained full range of elbow flexion 9 months after operation.E,F: elbow flexion with M4+ grade,13 mo. post-operatively.

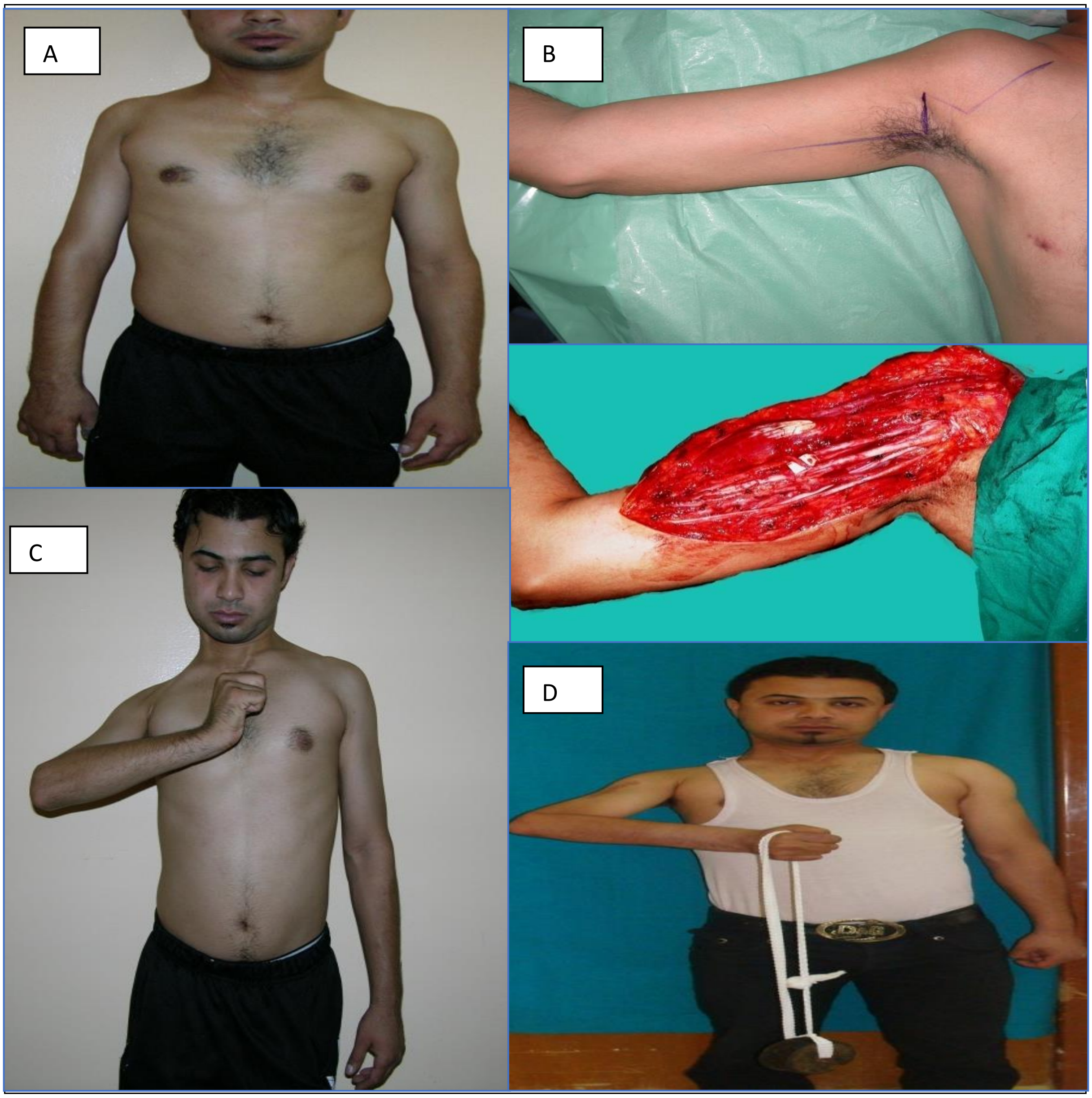

Figure (4): A 20 year old patient was admitted with a blast that resulted in a right upper body injury, the loss of the right elbow's flexion, and the shoulder's abduction. After six months, a dual nerve fiber transplant was employed to remap the elbow's flexion. A: Preoperative picture. B: Preplanning and images during surgery. C: The 10-month postoperative photograph demonstrates the patient's full range of motion and the muscle grade M4. D: 12-month postoperative picture, the patient is able to lift 2 kilograms and flex the elbow between 0 and 90 degrees, but the number of repeated attempts is less than 30.

Figure (5): A 3-month-old patient had both sides of the brachial plexus lacerated, this led to the loss of elbow flexion and the inability to abduct the shoulder. Reconstruction was intended to occur at the age of 3 months with a right-sided nerve transplant to achieve elbow flexion and shoulder abduction.

Preoperative imaging. B: Preoperative planning. C: The superior, posterior, and infraclavicular parts of the brachial plexus were evaluated during surgery using nerve stimulation. D: Additionally, a dual-bundle nerve transfer was employed to mend the elbow's flexion (arrows). E: After ten days, the wound was healed following the removal of the sutures and the hand function was normal. Q: After surgery was complete, the patient had full mobility of the elbow's shaft.

Discussion:

The frequency and number of traumatic brachial plexus injuries has increased dramatically worldwide as a result of the increasing number of motor vehicle accidents, blast victims, and obstetric brachial plexus injuries. (15) (16) The treatment should concentrate on restoring and preserving the function of the upper limb as much as possible. Early procedures include the repair of damaged nerve fibers or the reconstruction of scar tissue using neurolysis, direct repair, decompression, nerve grafting, and transfer of nerve tissue; later procedures include the pedicled grafting of functional muscles that restores the shoulder's function and stability, as well as the elbow's flexion. Muscle grafts are used to reconstruct the elbow's flexibility, these include pectoralis major, latissimus dorsi, Triceps grafts, and Steindler's flexorplasty, which is performed using a flexor pronator approach. (1) It's crucial to consider the length of the recovery process, as it involves permanent alterations to the motor endplates and internal fibrosis, this results in a decrease in the muscle's resistance to neuronal stimulation, which can occur as early as 12-18 months after the injury. (18) (19)

For injuries to the brachial plexus, nerve regeneration is consistently more successful than temporary or permanent substitutes for muscle or tendon. Since Seddon's article in 1963, renervation has become commonly embraced by utilizing intact adjacent nerves to re-innervate the majority of functional nerve tissue. (20) The treatment of brachial plexus injuries involves restoring the full range of motion and tensile strength of the elbow, maintaining the stability of the shoulder, and restoring the active rotation of the elbow and part of the external rotation. This can be accomplished by innervation of the musculocutaneous and suprascapular nerves as well as the axillary nerve. (1) The primary objective of renervation is to re-innervate the musculocutaneous nerve to re-innervate the biceps, this also helps to maintain the stability of the shoulder. (21) The restoration of elbow function via renervation utilizing available axons from the motor cortex provides a surgical alternative to the typical procedure of repairing the upper trunk's brachial plexus. (1) It's often necessary to utilize donor neurons that innervate muscles that have a complementary relationship to the target muscle. However, this is sometimes necessary because of an inability to utilize donor nerves that supply muscles that have an opposing or supplementary role to the target muscle. However, patients who are taught the motor reeducation protocol and receive appropriate physical therapy will have a remarkable functional outcome. To reduce the amount of time needed to reconfigure, nerves that are donated are selected based on their availability and proximity to the neuromuscular junction of the intended muscle. This facilitates the tension-free association of the nerve without the need for a graft.(22)

Oberlin et al. In 1994 (6) initiated the concept of neurolysis, which involves removing specific bundles of motor neurons from the ulnar nerve that is associated with the biceps muscle.

The innervation of the brachialis (the primary elbow flexor) increases the biomechanics of the elbow, which supports the strong elbow flexion that is achieved with this maneuver. The findings of this research were in line with previous investigations: Mackinnon et al. 2005 (22) and Liverneaux et al. 2006 (3) There were no late complications due to the ulnar or middle nerve that occur during donor harvesting, and all patients had a strong elbow flexion that is either excellent or good. This method leaves the surgeon free to place any desired number of motor branches, these branches can be used as donors for any level. Additionally, other common donors, including the medial thoracic nerve and the thoracodorsal nerve, are safeguarded for additional transplants that require shoulder function and elbow extension, and previously ineligible donors (median and ulnar) can be utilized as donors. Donor bundles are excised at the location of minimal regeneration to the intended muscle, as the ulnar or median nerve may be cross-fasciculated at any level of the proximal arm.(23)

Livno et al. demonstrated in 2006 (3) that nerve transfers from the median and ulnar nerves are associated with the regeneration of motor axons that are close to the neuromuscular junction of the biceps and brachialis, these nerve transfers are therefore likely to be successful in patients whose treatment is initiated as early as possible, which is consistent with patient 5 in our study.

Similar to cases #4, 6, and 7 in this research, the extra transfers of nerve that were described in order to supplement the double-bundle transfer included the following: the distal part of the spinal accessory nerve was transferred to the suprascapular nerve, and the anterior branch of the axillary nerve was connected to the lateral head of the triceps in order to supply the shoulder stabilizers.(14)

Supporting the previous findings of the ulnar nerve's bundle reported by Oberlin et al. in 1994 (6) and Venkatramani et al. In 2008 (12), no patients in our study had long-term complications from the donor. Intraoperative verification of individual nerve function via direct electrical stimulation will preserve the remaining muscle function of the donor nerve after the latter is freed.

Norman et al. In 2004, 7 cases of brachial plexus injuries during childbirth were repaired using the Oberlin method (24). They occurred late (average: 16 months) in the postpartum period. The biceps were M5 in two instances, M4 in two instances, M3 in one instance, and M1 in two instances. Our investigation involved two instances of upper trunk brachial plexus damage caused by birth (one patient had both injuries). Following Colbert's team. in 2006 (25), we employed this dual-bundle nerve grafting method to increase the likelihood of successful elbow flexion and its strength. The early surgical intervention in this patient during the fourth month of life is not typical of the typical time frame for brachial plexus injuries caused by birth (i.e., six months following birth). This should give time for the regeneration of nerve tissue on the other side to avoid the development of muscle loss that can occur with later reconstruction.

We followed the scale established by Waikakul et al. In 1999 (14) the authors developed a new instrument to assess the effects of elbow flexion in adults. Four of the five adult patients were successful, and one patient was exceptional (Table 2). Compared to Venkatramani's study. 2008 (15) who employed this scale, our results failed to demonstrate patients with sufficient abilities.

Venkatramani's team Investigated 15 patients with superior trunk brachial plexus injuries and loss of elbow flexion who were treated by the Oberlin nerve. This resulted in the healing of the plexus. Of the total population, 2 patients received an exceptional rating, 11 patients were considered good, and 2 patients were considered fair. All patients in our study had the full range of flexion (140 degrees). According to the MRC's assessment, 4 patients were considered M4, 1 patient was considered M4+, and 2 patients were considered M3. The investigation by Venkatramani et al. demonstrated that 13 patients possessed a flexion degree of 140 degrees, while another patient had a M3 of 90 degrees, the remaining patients possessed a M3 of 100 degrees.

In research, McKinnon et al. 2005 (22) studied 6 patients with upper trunk brachial plexus injuries that were successfully healed through double-bundle nerve transfer. According to MRC, 4 of the 6 were considered M4+, and the other 2 were considered M4. No deficiencies in hand function or sensation were encountered. Another study from 2006, Liverneaux et al. published (3) that studied 10 patients with upper trunk brachial plexus injuries that were treated with a double-bundle nerve graft to regrow the elbow's flexion. All 10 patients achieved an elbow flexion of M4. After this, there was no loss of grip power or acuity. Contrastingly, the previous two studies had 4 of their cases being classified as M4 (57.15%) and 1 being classified as M4+ (14.3%), both of which had associated changes in hand function and sensation, but no changes in sensation or hand function were made in patient 5's case. After a few weeks, the paresthesia in his little finger was healed. Our two instances (no's 5 and 7) had a M3 rating of 28.6%. We assume that the patient's tardy presentation to our department may be responsible for the lack of a significant difference in the classification of muscle power. In the scenario's no. 7, the quality of the muscle can increase with time as a result of continued physical therapy. In both instances, the strength of the muscle increased over time and was enhanced by following a physical therapy regimen that was appropriate. Patients must be told that the full effects of nerve regeneration may not be observed after 2.5 years if additional physical therapy is available and the patient is familiar with the appropriate methods of motor retraining.(11)

Conclusion and Recommendation:

This procedure is the standard of care for C5-C6 injuries, except for those that occur within the 12th month.

Increases the strength of elbow flexion through the reinnervation of the brachialis and biceps muscles.

No permanent sensory or motor damage was observed in the medial or ulnar regions during the longer period of observation.

• The double-bundle nerve transplant is a viable method of treating brachial plexus injuries that lead to loss of function at the elbow, and multiple transplants help to facilitate an early return to function.

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