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Free Functional Gracilis for Restoration of Elbow Flexion in Late Brachial Plexus Palsy

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Abstract

Background: Functional restoration of elbow flexion represents a major reconstructive challenge for post-traumatic adult brachial plexus injuries. Free functional muscle transfer (FFMT) is the only hope in patients with a lack of local donor tissues or delayed presentation.

Objective: To study the outcome of free functional gracilis for restoration of elbow flexion in late brachial plexus palsy.

Methods: A retrospective review of 15 patients who underwent free functioning muscle transfer for elbow flexion as part of their brachial plexus injury reconstruction with an average of 22-month follow-up period. Report of the clinical outcomes of flap viability and the degree of elbow flexion restoration by range of motion and British Medical Research Council (MRC) grade.

Results: The average age was 37 years, and 60% were caused by Road Traffic Accidents. The flap survival rate reached 86.6% (n=13). The mean follow-up period was 22 months (range, 12-30 months). By the end of the follow-up period, 69% of the transfers had recovered MRC grade >M3 elbow flexion strength. They could lift an average of 2.7kg (range, 0.5-5kg).

Conclusion: The use of FFMT using the gracilis muscle is a reliable procedure in the restoration of elbow flexion in patients with brachial plexus injuries beyond 12 months from the time of injury and in patients with complete root avulsion injuries. In the hands of an experienced team, good results can be achieved.

Key Words: *Elbow flexion – Brachial Plexus – Free Functional Muscle Transfer.*

Ethical Committee: The institutional review board's authorization approval (ZU-IRB #11059- 3/9-2023).

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Introduction

Traumatic brachial plexus injuries (TBPIs) can severely impair upper limb motor and sensory function. Elbow flexion is considered a keystone function that is lost in these injuries (either upper plexus C5-C6±C7 or total plexus C5-T1) and usually has a priority during the reconstruction of TBPIs [1]. This can be achieved either primarily through direct neurotization [2-4] or secondarily through tendon or muscle transfers [5,6].

However, late presentation (beyond one year from injury) or unsuccessful previous surgical interventions through nerve reconstruction can make the original elbow flexors no longer available for neurotization [7,8]. Non-microsurgical muscle transfer cannot always achieve satisfactory elbow flexion in such complex cases [8]. In these cases, free functional muscle transfer (FFMT) is typically required for elbow flexion restoration [9].

The gracilis muscle is the preferred donor option for FFMT due to its several advantages over other options, including latissimus dorsi, rectus femoris, and medial gastrocnemius. These advantages include a relatively long vascular pedicle, only one motor nerve supply, good excursion, an accessible surgical approach, and a relatively accepted morbidity of the donor site [10]. Neurotization of the transferred gracilis can be done by utilizing local motor donors, e.g., intercostal nerves, spinal accessory nerves, fascicles from median and ulnar if available, or by previously banked nerve grafts [11].

Success of FFMT is multifactorial and could be attributed to surgical factors, in addition to patient factors. Adequate flap harvest, sound microsurgical practice, and accurate tensioning of the muscle are clearly important [12,13].

The gracilis muscle is innervated by a branch of the anterior division of the obturator nerve. It passes between the adductor longus and brevis, innervating both muscles before giving the motor branch to the gracilis muscle in an oblique fashion. Gracilis

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vascular pedicle reaches 6-8cm in length from the profunda femoris arteries, and the gracilis artery and vein have diameters of 1.6-1.8 and 1.5-2.5mm, respectively. These correspond to the thoracoacromial vessels' diameters **[14]**.

Patients and Methods

Study design and settings:

After the institutional review board's authorization approval (ZU-IRB #11059- 3/9-2023), the medical records of 15 patients who had a gracilis FFMT for TBPIs between June 2021 and June 2023 were retrospectively reviewed. We included those patients that have at least of 12 months follow-up. Exclusion criteria included patients who underwent FFMT operations in conjunction with local muscle transfer or neurotization surgery to restore elbow flexion. Patients with spinal cord injuries or those with bilateral brachial plexus injuries were also excluded.

Surgical technique:

All cases were operated upon at the Plastic and Reconstructive Surgery department (Zagazig University Hospitals) by the senior author.

Under general anesthesia with no muscle relaxant, a two-team approach, one team started harvesting the flap and the other team was preparing the recipient site simultaneously.

The technique described by Addosooki et al., **[14]** was used for harvesting the flap. The contralateral gracilis was constantly utilized. Supine positioning of the patient with hip abduction, slight flexion, and external rotation. Palpation of the tendon of the adductor longus was done. A line is marked just inferior to this tendon towards the medial condyle of the femur as the gracilis lies medial to the adductor longus. An elliptical skin paddle, measuring about 9 cm by 5cm, is marked over the upper one-third of this line. marking of one perforator or more supplying the skin paddle enhances its reliability (Fig. 1).

Fig. (1): Skin paddle marking.

Dissection of the muscle enclosed in its fascia to enhance gliding in its bed and suturing the skin paddle to the deep fascia to prevent its shearing. To ensure proper tension during later in setting of the flap, suture markings were taken at 5cm intervals along the length of the gracilis muscle belly (Figs. 2,3).

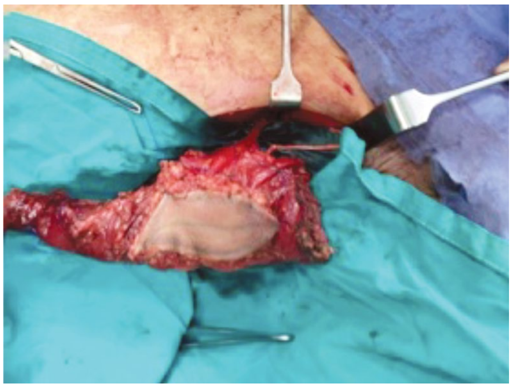

Fig. (2): Intraoperative Photo shows the gracilis muscle after isolating it on the vascular pedicle and the motor branch of the obturator nerve.

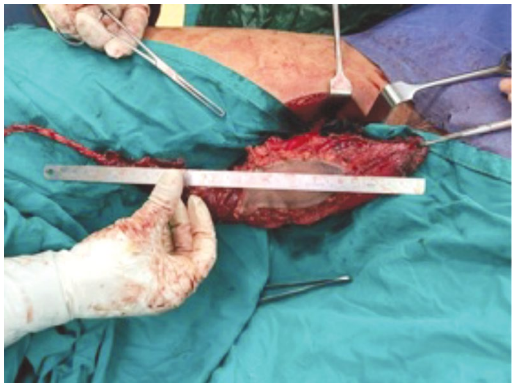

Fig. (3): Intraoperative photo shows the length of the gracilis muscle after harvesting with the suture markers every 5cm.

In the recipient upper limb, a slightly curved incision is made along the anteromedial surface of the arm extending from the clavicle to the antecubital fossa with w-plastic across the axilla to avoid axillary contracture postoperatively (Fig. 4). Insetting of the flap was done by anchoring the gracilis' origin to the clavicle or the coracoid of the scapula, distally the gracilis flap tendon is weaved through the distal biceps tendon using #2 nonabsorbable suture. Additional fixation to the lacertus fibrosus can be accomplished with 2-0 or 3-0 nonabsorbable suture. The muscle's physiological resting length is verified by checking that the suture markers are spaced correctly when the elbow is extended to a 120° angle. Guiding marking over the arm skin and the suture spacing may help to achieve adequate tension (Fig. 5).

Arterial anastomosis was done between the flap artery and the brachial artery (end to side), one of its branches, or the thoracoacromial artery (end to end). The thoracoacromial vein, or the deep venae comitans of the brachial artery, are the recipient of the end-to-end venous anastomosis. An extra venous anastomosis to the cephalic vein may be done to improve the venous drainage of the flap. Special attention was considered to keep the ischemia time less than 60 minutes.

Fig. (4): Intraoperative photos illustrate the marking for the recipient site in the upper limb as well as the incision line for Intercostal nerve harvesting.

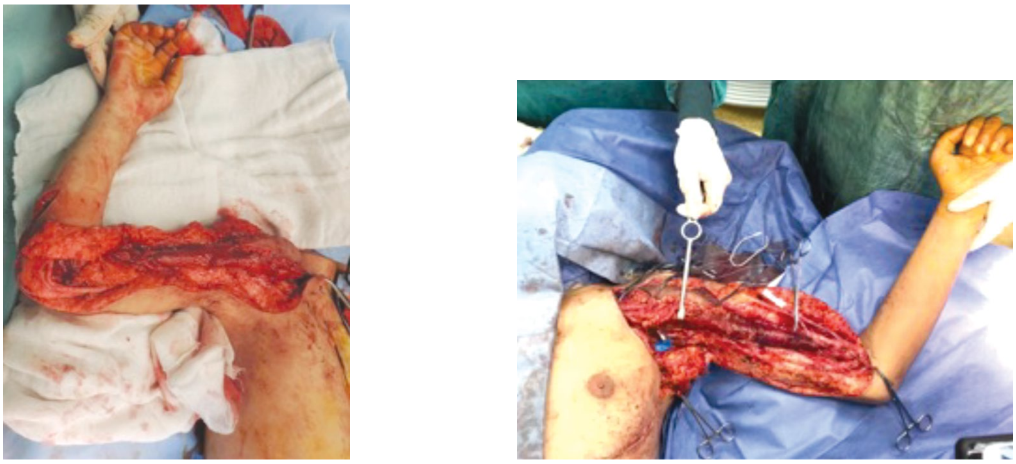

Fig. (5): Intraoperative photos show the gracilis muscle after insetting and neurovascular anastomosis.

Under microscopic magnification, the chosen donor nerve was repaired to the obturator nerve branch supplying the gracilis muscle by epineurial repair (Fig. 6).

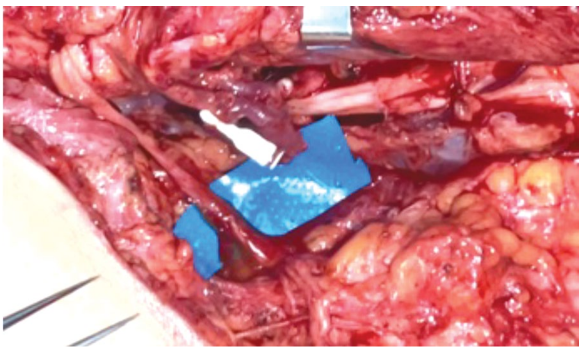

Fig. (6): Zoom photo shows the epineurial repair between the intercostal nerve and the nerve to gracilis.

After skin closure of the recipient limb adequate, a well-padded dressing was placed and a long arm splint was applied with the elbow flexed at 120°, shoulder immobilization in a slight flexion. Postoperatively, the flap was checked hourly for the first 48 hours by clinical evaluation of the skin paddle color, capillary refill time, turgor and temperature. I.V fluids (ringer lactate) were administered for a balanced perfusion state guided by Urine Output (1-2ml /kg/hour) for 5 days then gradual weaning. No anticoagulant was given except if vascular thrombosis occurred intraoperatively. Typically, drains were removed a week after surgery.

Follow-up:

The postoperative protocol included 6 weeks of immobilization in a splint, at 120° of elbow flexion. After that, two more weeks of immobilization in an elbow splint with a 90° flexion. Starting from the sixth week, active elbow flexion and extension exercises were initiated, with the extension gradually increasing by 10° each subsequent week. Electrostimulation was applied to the transferred gracilis till the appearance of active muscle contraction.

Outcome:

Flap viability was considered the first studied outcome. Active range of motion and the muscle grade of elbow flexion were the main outcomes and were studied for every patient using the MRC grading system (illustrated in Table 1).

Table (1): MRC grading system used in evaluating the elbow restoration of function.

Degree of Muscle Strength	
M0	- No muscle contraction
M1	- Muscle contraction not resulting in joint movement
M2	- Muscle contraction with movement excluding gravity
M3	- Muscle contraction effective against gravity but doesn't overcome resistance
M4	- Muscle contraction that does overcome resistance
M5	- Normal muscle strength

Data analysis:

Data entry and encoding of the studied variables into Microsoft Excel (version 356) was done. Descriptive data were retrieved in terms of frequencies, continuous variables, on the other hand, were shown as means plus standard deviations (SD). For the statistical studies, SPSS for MacBook (version 29) was used.

Results

Demographics:

We had a total of 15 patients with post-traumatic TBPI who underwent FFMT for the restoration of elbow flexion. Table (2) summarizes the demographic characteristics and intraoperative technical data of the studied cases.

The rate of flap survival was 86.6% (n=13). Major complications represented as flap loss occurred in 13.3% (n=2). Minor complications such as hematoma and wound dehiscence occurred in 13.3 (2 cases) and 20% (3 cases) respectively (Table 3).

Table (2): The demographics and the operative findings of the studied cases.

	Mean (range)	SD	Frequency	Percent (%)
Age	37.1 (5-48)	9.4		
Sex:				
Male			13	86.7
Female			2	13.3
BMI:				
Normal			5	33.3
Overweight			6	40
Obese			4	26.7
Mechanism of injury:				
RTA			9	60
Fall			4	26.7
Industrial			2	13.3
Months from injury to surgery	30.4 (18-56)	11.08		
Roots involved:				
C5,C6			3	20
C5,C6,C7			1	6.7
C5-T1			11	73.3
Operative time (hours)	7.7 (6.5- 9)	0.8		
Proximal fixation:				
Coracoid			7	46.7
Clavicle			8	56.3
Donor nerves:				
Intercostals			12	80
FCR, FCU fascicles			3	20
Follow-up in months	22.08 (12-30)	6.934		

Table (3): Complications and its frequency among the studied cases.

Complications	Frequency	Percent %
Flap loss	2	13.3
Hematoma	2	13.3
Wound dehiscence	3	20.0

The follow-up time had a mean of 22 months and a range of 12-30 months. In our clinical practice, the EMG is not employed as a routine method to assess gracilis muscle reinnervation. Clinical follow-up examination usually detects gracilis muscular contraction at an average of six months. Two patients (15%) had recovered MRC grade 5 elbow flexion strength (Fig. 7), 7 patients (54%) had acquired MRC grade 4 strength, 3 patients (23%) had recovered MRC grade 3 strength, and one patient (8%) had an MRC grade 2. Patients with MRC 4 and MRC 5 could lift an average of 2.7kg (range, 0.5-5kg), (this data is represented in (Fig. 8).

The average active elbow flexion was 90.8° (range, 20°-150). Patients developed 0° to 10° elbow flexion contracture after surgery.

Fig. (7): Preoperative Vs Postoperative Photo shows good outcome as regards ROM, MRC grade.

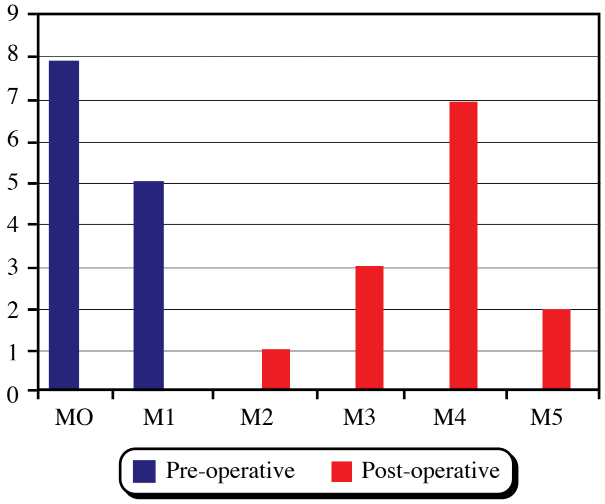

Fig. (8): Bar chart shows the difference between MRC of elbow flexion preoperatively and postoperatively.

Discussion

Road traffic accidents represent the predominant cause of traumatic brachial plexus injury in Egypt. Advances in medical care have contributed to the increased survival rate among affected individuals. Comparable to the literature [13,15], the majority of our population was male patients, the median age of the studied cases was 37 years, and the most common etiological cause was RTA (n=9, 60%). The restoration of elbow flexion is often prioritized as the primary objective in the functional reconstruction of the upper extremity [16]. In cases of traction injuries of the brachial plexus, nerve repair and grafting procedures are constrained to situations where a viable proximal stump is present and the intervention is done promptly within 9-12 months after injury. Even with panplexal injury, it can be treated within one year with nerve transfer procedures such as the contralateral C7 (CC7), phrenic, spinal accessory, intercostal nerve, and motor nerve of the cervical plexus [17].

For cases that present late and with no salvageable elbow flexors or tendons appropriate for transfer, FFMT is the sole solution for the restoration of elbow flexion [18]. In this research, the average delay till the time of surgery was thirty months. Thus, it is essential to provide patients with appropriate health education and counseling on their treatment and rehabilitation plan to promote excellent compliance and patient satisfaction with the outcome.

Gracilis muscle is the preferred option as FFMT for elbow flexion restoration. following the first description in the medical literature by Ikuta et al., 1979 [19]. Several studies have reported good functional success ranging from 68 to 90% with recovery of M3, M4, or M5 elbow flexion strength [20-23]. In our study, we achieved a muscle grading > M3 in 69% of cases, which is similar to the findings of the current medical literature.

The mean follow-up period in our study was 22 months (range, 12-30 months). This is quite similar to the follow-up period of the study done by Martins-Filho et al., [24]. However, there are some studies like Kay et al., [25] reviewed their patients for 14 years. It has been observed that improvements in functional results may continue for up to two years following surgery; this goes hand in hand with that reported by Seal and Stevanovic [26]. Hence, it's important to do good counselling and not to let the patient give up the rehabilitation protocol for 2 years and maintain an adequate strengthening routine.

As regards the donor nerve choice in our study, 80% of transferred muscles were neurotised by Intercostal nerves (typically 3,4,5) in cases of total TBPI. In cases of upper brachial plexus injury (20% of cases in this study), motor fascicles of the ulnar or median nerves were utilized. Spinal accessory nerve, or cross C7 can be used if the motor donors were previously used up [17]. In a study conducted by Kay and colleagues [25], superior motor outcomes were observed when utilizing intercostal nerves as donor nerves, in contrast to ulnar fascicles. Other investigators have reported successful reconstructions by employing the contralateral C7 or the contralateral medial pectoral nerve through nerve grafting. However, Terzis et al., found this factor not to be of paramount importance. Notably, the fixation tension applied to the gracilis significantly impacts its mechanical performance [27].

In our study, we were cautious to limit the ischemia time to less than 60 minutes and to add extra venous anastomosis. This goes hand in hand with a recent study by Martins-Filho et al., [24], it was noted that patients who had only one venous anastomosis for the free gracilis drainage and those who had a prolonged intraoperative ischemia time had a higher incidence of poor functional outcomes.

In this study, the proximal fixation of the transferred muscles to the clavicle or the coracoid and the distally the tendon was weaved through the biceps tendon. This is the same technique emphasized by multiple studies such as [12,21]. Bertelli (2019), proposed the utilization of reverse gracilis muscle in combination with Steindler flexorplasty for the reconstruction of elbow flexion following the unsuccessful primary repair of extended upper-type paralysis of the brachial plexus [7].

In our practice, the skin paddle was preserved in all cases as it enables good coverage, helps secure closure and functions as a post-operative monitoring device. This was adopted in many studies [20,21,28]. However, It was believed that the skin paddle of gracilis is not reliable and may add confusion in the monitoring of the flap especially beyond the proximal third over the muscle [29]. Implantable Doppler may be a good substitute but it also has its pitfalls [30]. On the national level, implantable Doppler isn't available, so preservation of the skin paddle would be of value especially if a handheld Doppler was used for confirmation of perforators supplying it.

Certain authors advocate the use of the double-free muscle technique for severe brachial plexus avulsion injuries [31]. However, Barrie et al., [32] found that overall elbow flexion strength was decreased when transferring for both elbow flexion and wrist extension rather than just elbow flexion. Due to these considerations, we refrain from employing this technique. A study conducted in 2016 by Estrella and Montales [33], used the gracilis and adductor longus muscles in conjunction. While the former is passed beneath the biceps tendon before being woven through the flexor digitorum profundus, the latter is woven through the tendon.

There are other muscles that can be used for free functional muscle transfer such as latissimus dorsi and rectus femoris [34]. Verkris et al., documented an 80% success rate with favorable outcomes following latissimus dorsi muscle transfer with intercostal reinnervation. However, the latissimus dorsi muscle, being large, presents challenges in its attachment to the biceps tendon [35]. Alternatively, the rectus femoris, a robust muscle employed for restoring elbow flexion, has shown promise. Eight of the eleven patients were able to obtain a muscle grading greater than M3, according to research by Akasaka et al., employing free rectus femoris innervated via intercostals [36]. Conversely, the rectus femoris is not as well suited for elbow flexion range of motion because of its pennate muscle type, which limits its range of motion.

Despite the favorable outcome of the gracilis FFMT, several complications were also reported. The major complication reported in this study was flap loss in 13.3% of patients. Vascular impairment or inadequate strength in the transfer post re-innervation are among the disadvantages of this procedure. This may be due to loss of active muscle fibers or insufficient neural input from the donor nerve. It was 20% in the 10 cases reported by Vekris et al., 2008 [35]; it was 11% in a large series of 72 transfers reported by Terzis and Kostopoulos, 2010 [27], and 10% in the series by Kay et al., 2010 [25] where half the 33 cases were children with a more favorable vascular background.

Limitations to this study are mainly attributed to the relatively small sample due to the rarity of indications, being retrospective, and the heterogeneous population.

Conclusion:

In conclusion, utilizing functioning free muscle transfer, specifically the gracilis muscle, has proven to be a dependable approach for elbow flexion restoration in late-presented TBPI. Despite the potential for complications, favorable outcomes can generally be anticipated. With a proficient surgical team, gracilis FFMT can be a reliable treatment option.

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