Free *Gracilis* muscle transfer to restore elbow flexion in brachial plexus injuries

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**KEYWORDS**

*Gracilis* transfer; Paralysis; Brachial plexus; Elbow flexion recovery

**Summary**

**Introduction:** Restoration of elbow flexion is an important step in managing brachial plexus injuries. After more than one year of functional denervation, the muscle atrophy is significant enough that transferring a free muscle to act as a new effector becomes a treatment option. The goal of this study was to evaluate the effectiveness of transferring a *gracilis* free muscle, innervated by three intercostal nerves, to restore elbow flexion.

**Material and methods:** This was a retrospective study of a series of *gracilis* transfer procedures in 12 men having an average age of 25.6 years (23–37) and average follow-up of 112 months (28–260). The patients were operated on average at 42 months (14–153) following their motor vehicle accident; five had a partial paralysis (C5C6C7) and seven had a complete paralysis (C5–T1). The surgical technique and rehabilitation protocol were the same for all the patients.

**Results:** There were two cases of acute arterial thrombosis (17%) that led to functional failure. When these two cases were excluded from the analysis, all the remaining patients had a useful result (British Medical Research Council score ≥ M4) and 2.5 kg of elbow flexion strength measured on a dynamometer. The strength was 3.8 kg (2.7 to 5.5) for partial plexus injuries and 1.6 kg (0.3 to 1.5) for complete plexus injuries. For partial injuries, active elbow flexion was 128\(^\circ\) and extension −38\(^\circ\), versus 103\(^\circ\) and −23\(^\circ\) for complete injuries. The average DASH score was 42 for partial injuries and 32 for complete injuries.

**Discussion:** Free *Gracilis* muscle transfer is a challenging technique that leads to reproducible and encouraging results, but has vascular failure rate that cannot be ignored. When compared to published results, our series provides similar results to primary suturing performed within 6 months for cases of complete paralysis and within 12 months for cases of C5C6C7 partial paralysis; our series was better for cases beyond 12 months.

**Level of evidence:** Level IV.

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Introduction

Trauma to the brachial plexus in adults often results in paralysis of elbow flexion and sometimes the hand. The main goal of any surgical treatment is to restore elbow flexion.

Direct neurotization of the elbow flexors by nerve transfer is a common surgical approach [1—5]. Other than patient age, the main prognostic factor is the time before treatment is started. The amount of time allowed before a surgical procedure is not well defined. It depends on the type of transfer, proximity of the effector and motoneuron population abundance. Jivan et al. [6] showed that beyond 2 months post-injury, nerves grafted from C5 to reinnervate elbow flexion had inferior results. Transferring intercostal nerves (IC) or the part of the ulnar nerve that is closest to the effector muscle is more robust, with a maximum delay of 6 and 12 months, respectively [2,5,7]. Beyond the 12th month, the muscle atrophy appears irreversible and it is unrealistic to perform a reinnervation procedure with the goal of achieving a useful result. Palliative tendon transfer of the forearm flexor-pronator (Steindler), triceps brachii, pectoralis minor or pectoralis major muscles cannot be performed with cases of complete or partial (C5C6C7) paralysis because these muscle often are deficient themselves.

When patient management is delayed or the initial nerve transfer surgery fails, the only alternative is to bring in an effector muscle and reinnervate it with a nerve transfer. The first cases of vascularized muscle transfer to restore elbow flexion were described by Ikuta et al. [8]. In the published literature, three types of free muscle transfers were used for traumatic brachial plexus injuries in adults: gracilis, latissimus dorsi and rectus femoris [5,9—13]. The first two are most commonly used, but it is difficult to compare them because of different surgical techniques and the British Medical Research Council (BMRC) score (the only scoring system available) does not allow for an objective evaluation of patients who have a flexion strength of M4. For Chuang et al., gracilis muscle transfer was the most effective [5,14]. Terzis et al. [13] described a homogenous series of 73 free muscle transfers and found a latissimus dorsi transfer to be better than a gracilis transfer. They showed that patient age is a prognostic factor but did not provide evidence for one type of muscle transfer being better than another.

The goal of our study was two-fold: evaluate the results and function of a Gracilis Free Muscle Transfer (GFMT) in adults for traumatic brachial plexus paralysis where management is delayed, and compare these to published primary reinnervation results to defined appropriate indications.

Material and methods

Series

From 1991 to 2008, 14 GFMTs were performed to restore elbow flexion in cases of traumatic brachial plexus injuries. Twelve of these cases were available for clinical follow-up (Table 1). The population was exclusively male, had an average age of 28 years at surgery (range 23—37) and had been involved in a motor vehicle accident an average of 42 months (range 14—153) beforehand. The dominant side was affected three times.

There were five partial (C5-C6-C7) and seven complete (C5-T1) injuries. Initially, three patients required an emergency axillary artery bypass. A GFMT was indicated in six cases after direct nerve transfer surgery failed and in six other cases because of delayed care.

The 12 GFMT cases that were retrospectively reviewed are part of a prospective database that includes all patients with a brachial plexus injury treated by our team within the scope of a regular specialized consultation.

Patients with less than 24 months follow-up and those who received an additional palliative procedure to reinforce elbow flexion were excluded from the analysis.

Surgical technique

In most cases, the procedure was performed by two teams according to the technique described by Chammas and Allieu [15]. The first team prepared the recipient site and dissected the ICs; the second team harvested the gracilis muscle from the ipsilateral thigh (Figs. 1 and 2). The gracilis was reinnervated with the third, fourth and fifth ICs without graft interposition and revascularized with end-to-side
Table 1  Demographic data and results from the patient series grouped by partial or complete injury.

<table>
<thead>
<tr>
<th>Case</th>
<th>Nerve lesion</th>
<th>Injured side (dominant)</th>
<th>Age</th>
<th>Delay before surgery</th>
<th>Follow-up (months)</th>
<th>Previous direct nerve surgery</th>
<th>Complications with transfer</th>
<th>Associated surgery</th>
<th>Elbow flexion</th>
<th>Elbow ROM</th>
</tr>
</thead>
<tbody>
<tr>
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<td>Hand</td>
<td>Shoulder</td>
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<td>BMRC score</td>
<td>Strength</td>
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<td>Active Flexion</td>
<td>Extension</td>
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<td></td>
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<td></td>
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<td>degree</td>
<td>degree</td>
</tr>
</tbody>
</table>

**Partial injury**

1. C5-C6-C7  
   - L (R)  
   - 25  
   - 48  
   - 260  
   - Tendon transfer finger ext.  
   - Humeral derotational osteotomy  
   - Shoulder fusion  
   - 4  
   - 5.5  
   - 140  
   - 20

2. C5-C6-C7  
   - L (R)  
   - 31  
   - 36  
   - 204  
   - +  
   - Wrist fusion  
   - Shoulder fusion  
   - 4  
   - 4  
   - 120  
   - 60

3. C5-C6-C7  
   - L (R)  
   - 27  
   - 74  
   - 194  
   - +  
   - Skin paddle trouble  
   - Tendon transfer wrist & finger ext.  
   - 4  
   - 2.7  
   - 120  
   - 40

4. C5-C6-C7  
   - R (R)  
   - 23  
   - 20  
   - 29  
   - +  
   - Tendon transfer finger ext.  
   - 4  
   - 3  
   - 130  
   - 30

5. C5-C6-C7  
   - R (R)  
   - 30  
   - 23  
   - 84  
   - +  
   - 4  
   - 3.8  
   - 120  
   - 40

**Mean SD**

<table>
<thead>
<tr>
<th>Case</th>
<th>Nerve lesion</th>
<th>Injured side (dominant)</th>
<th>Age</th>
<th>Delay before surgery</th>
<th>Follow-up (months)</th>
<th>Previous direct nerve surgery</th>
<th>Complications with transfer</th>
<th>Associated surgery</th>
<th>Elbow flexion</th>
<th>Elbow ROM</th>
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<td>BMRC score</td>
<td>Strength</td>
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<td>degree</td>
<td>degree</td>
</tr>
</tbody>
</table>

**Complete injury**

6. C5 to T1  
   - L (R)  
   - 24  
   - 35  
   - 126  
   - +  
   - Tendon transfer finger ext.  
   - 4  
   - 2.5  
   - 90  
   - 30

7. C5 to T1  
   - L (R)  
   - 27  
   - 55  
   - 100  
   - +  
   - Arterial thrombosis then revision  
   - 1  
   -  —  
   -  —  
   - 30

8. C5 to T1  
   - R (R)  
   - 22  
   - 23  
   - 168  
   - +  
   - Arterial thrombosis then revision  
   - 4  
   - 1.5  
   - 90  
   - 10

9. C5 to T1  
   - L (R)  
   - 30  
   - 23  
   - 92  
   - 3  
   - 1  
   - 90  
   - 20

10. C5 to T1  
    - L (R)  
    - 37  
    - 30  
    - 96  
    - Arterial thrombosis then revision  
    - 1  
    -  —  
    -  —  
    - 10

11. C5 to T1  
    - L (R)  
    - 32  
    - 153  
    - 28  
    - 4  
    - 2.5  
    - 115  
    - 25

12. C5 to T1  
    - L (R)  
    - 29  
    - 14  
    - 180  
    - 3  
    - 0.25  
    - 135  
    - 30

**Mean SD**
anastomosis onto the humeral artery and two satellite veins. A skin paddle indicator was preserved in all cases (Fig. 3). The gracilis was attached proximally to the coracoid process and distally to the biceps tendon. The forearm was supinated and the elbow placed at 40° of flexion to allow the muscle body to return to its initial length after suturing. Post-operative care consisted of a posterior splint to immobilise the elbow at 110° of active flexion for 5 weeks; rehabilitation was initiated while keeping a 30° flexion deformity.

In certain cases, once sufficient active elbow flexion was achieved, additional surgical procedures to stabilize the shoulder and restore hand function were performed in six patients: two glenohumeral fusions, one humeral derotational osteotomy, three tendon transfers to provide wrist extension, one wrist fusion (Table 1). In one case, the shoulder fusion was performed after elbow flexion was restored and tendons were transferred in the hand. Procedures to augment elbow flexion were not needed.

Evaluation

All the patients were monitored monthly within the scope of specialized visits until the first clinical or electromyographical signs of reinnervation, then every 3 months until elbow flexion strength had stabilized. All the patients were seen again at the last follow-up by an independent examiner (other than the surgeon) an average of 78 months later (range 28–260).

Along with the BMRC score, elbow flexion strength was measured with a dynamometer (Kinetc®) with one end attached to the ground and the other to the elbow, with the elbow flexed at 90° against the body. The functional deficit was evaluated with the validated, French version of the DASH [16], quality of life was assessed with the MOF SF-36, and satisfaction, attractiveness and surgical recommendation were evaluated with a visual analogic scale (VAS).

Statistics

Data were collected into a Filemaker Pro v8® database while respecting patient confidentiality. The statistical analysis was performed with SAS® software by the medical information department at our institution. Mann Whitney non-parametric tests were used for non-paired data.

Results

The results are shown in Table 1.

Post-operatively, two patients (17%) required surgical revision because of arterial thrombosis that was seen via problems in the skin paddle. In these two patients, partial resection of necrotic tissue in the gracilis was subsequently performed. Both were cases of complete plexus injury and had poor function result (BMRC score of M1).

The first clinical and electromyographical signs of reinnervation were observed at the seventh month, on average. No further change in the BMRC score were found after the 24th month.

For the entire series, 10 patients (83%) had a useful result of M3 or better, which corresponds to all the patients if the cases of initial vascular failure are excluded. Eight patients had a score of M4 (66%), with 2.3 kg average flexion strength (range 0.3–5.5) (Fig. 4). Partial plexus injury (C5C6C7) patients had 3.8 kg average flexion strength (range 5.5–2.7). Complete plexus injury (C5-T1) patients had a useful result in five cases (71%) with 1.1 kg of average flexion strength (range 0–2.5). If the two vascular failure cases are excluded, useful results were obtained in 100% of cases and strength was 1.55 kg (range 0.25–2.5). Differences found between the two types of paralysis in the BMRC score (Mann Whitney) and flexion strength (Student’s t-test) were statistically significant (P = 0.02), even after the failures were excluded (P = 0.01).

Elbow range of motion for the partial plexus injuries was 128° of active flexion for a passive extension deficit of −38°; for complete injuries, range of motion was 103° of flexion with an extension deficit of −23°. There was a weak correlation between patient age and flexion strength (ρ = −0.29).

Patients who initially needed a bypass or those who smoked did not have worse results. The two vascular failure patients had a healthy humeral artery and did not smoke. The attractiveness evaluated with the VAS had an average of 1.8 (where 0 = no embarrassment, 10 = unbearable outer appearance).

There were no donor site complications, no pneumothorax during IC collection and no respiratory decompensation later on.

One patient reported feeling knee instability on the side the gracilis was harvested from, without objective medial laxity found upon examination.

The DASH score was on average 32 (range 22–40) for the complete plexus injury patients and 42 (range 15 to 55) for the partial injury patients.

Quality of life was better in the partial paralysis cases than the complete paralysis cases. Ninety-one percent of patients were satisfied with this surgery and would recommend it. One patient felt he did not receive any...
Elbow flexion restored with *gracilis* after brachial plexus injury

Figure 4  Final result for this patient (case no. 4). He came to us with a C5C6C7 paralysis 20 months after the initial accident and after primary surgery failed. Transfer of *gracilis* reinnervated with three intercostal nerves. In a second procedure, tendon transfer performed to restore hand and wrist extension.

benefit from this procedure and did not provide further information.

Discussion

This study described a homogenous series of GFMT with the same indication (post-traumatic injuries in adults), same type of nerve transfer (three IC nerves), same population (young men) and same procedure. Using a dynamometer provides an objective measure of elbow flexion strength.

In this series, the GFMT results are affected, as with any nerve-related surgery, first by the revascularization of the transferred muscle and then by the quality of the muscular reinnervation.

The risk of early vascular thrombosis primarily depends on the background, but also the experience of the surgical team. In this series, the initial failure rate was 17%; it was 20% in the 10 cases reported by Verkris et al. [17]; it was 11% in a large series of 72 transfers reported by Terzis et al. [13], and 10% in the series by Kai et al. [12] where half the 33 case were children with a more favorable vascular background. These differences can in part be attributed to the post-trauma context of our series and older subjects, although we did not find initial vascular injury (axillary bypass) or smoking to have a negative effect. We also did not find any link between patient age and the result, but our series had a very tightly grouped age range.

The goal of this surgery is to provide good, long-term functional results. Our series clearly showed that if initial vascular complications do not occur, useful results are consistently attained. Kay et al. [12] reported 53% useful results in adult patients but they used a different type of nerve transfer, the contralateral C7 root. Chuang et al. [9] presented a series of 19 GFMT for brachial plexus injuries that were reinnervated by three IC nerves; their results were comparable to ours, with 74% of cases scored as M4.

Verkris et al. reported having 80% useful results after *latissimus dorsi* muscle transfer with IC reinnervation.

BMRC scoring lacks precision above M4. For this reason, Chuang et al. [5] proposed a subjective change; a 2 kg object can be lifted starting at a score of M4. The use of a dynamometer provides an objective evaluation of GFMT, which only Hosseinian et al. have done [18].

In the published literature, functional muscle transfer is a last-resort procedure that is done in cases of delayed management. To define indications, muscle transfers should be compared to classic approaches.

The comparison of GFMT with primary biceps reinnervation is interesting. The percentage of useful results after IC transfer ranges from 60 to 80% (Table 2, [19]). It is 72% in the meta-analysis of published English studies performed by Merrell et al. [1]. This rate varies from 70 to 100% when ulnar nerve fascicles are transferred [2,20–22]. Coulet et al. [7] evaluated the results of IC nerve transfer onto the musculo-cutaneous nerve in 17 cases of C5C6 ± C7 paralysis, accounting for delay in care. When patients were operated before the sixth month, the rate of useful results was 83%, the average BMRC score was 3.7 and the flexion strength was 3.1 kg; these results were slightly worse than those obtained after GFMT with reinnervation by three IC nerves. In this same study, none of patients that were operated after the sixth month had a useful result.

If GFMT is compared to partial transfer of the ulnar nerve, the latter is slightly better. Teboul et al. [2] reported that 82% of cases had a useful result and a flexion strength of 4.2 kg. Coulet et al. [7] found comparable results with the same technique but no useful results beyond the 12th month.
### Table 2  
**Review of published literature on methods used to restore active elbow flexion after paralysis of brachial plexus due to trauma. Comparison between classic nerve transfer and free muscle transfer.**

#### Classic nerve transfer

<table>
<thead>
<tr>
<th>Authors</th>
<th>Paralysis level</th>
<th>Sample size</th>
<th>Nerve transferred</th>
<th>Useful results (&gt; M3) (%)</th>
<th>Average BMRC score</th>
<th>Elbow flexion strength (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nagano et al. (1989) [26]</td>
<td>C5</td>
<td>149</td>
<td>2 × IC</td>
<td>73</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Chuang et al. (1992) [23]</td>
<td>C5</td>
<td>29</td>
<td>2 × IC</td>
<td>59</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Chuang et al. (1992) [23]</td>
<td>C5</td>
<td>37</td>
<td>3 × IC</td>
<td>79</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Kline and Hudson 1995 [27]</td>
<td>C5</td>
<td>37</td>
<td>3 × IC</td>
<td>57</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Maley et al. (1998) [28]</td>
<td>C5</td>
<td>17</td>
<td>3 × IC</td>
<td>59</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Leechavengvong et al. (1998) [29]</td>
<td>CSC6</td>
<td>26</td>
<td>UF</td>
<td>96</td>
<td>4</td>
<td>3.2</td>
</tr>
<tr>
<td></td>
<td>CSC6C7</td>
<td>6</td>
<td>UF</td>
<td>83</td>
<td>3.3</td>
<td>1.8</td>
</tr>
<tr>
<td>Waikakul et al. (1999) [19]</td>
<td>C5-T1; C5C6</td>
<td>75</td>
<td>3 × IC</td>
<td>64</td>
<td>—</td>
<td>—</td>
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<tr>
<td>Sung et al. (2000) [22]</td>
<td>CSC6</td>
<td>25</td>
<td>UF</td>
<td>92</td>
<td>—</td>
<td>2</td>
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<tr>
<td></td>
<td>CSC6C7</td>
<td>11</td>
<td>UF</td>
<td>64</td>
<td>—</td>
<td>1.2</td>
</tr>
<tr>
<td>Merrell et al. (2001) (meta-analysis) [1]</td>
<td>C5</td>
<td>521</td>
<td>2–4 × IC</td>
<td>72</td>
<td>—</td>
<td>—</td>
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<tr>
<td>Bertelli et al. (2004) [30]</td>
<td>CSC6</td>
<td>10</td>
<td>UF</td>
<td>100</td>
<td>3.8</td>
<td>—</td>
</tr>
<tr>
<td>Teboul et al. 2004 [2]</td>
<td>CSC6</td>
<td>18</td>
<td>UF</td>
<td>75</td>
<td>3.4</td>
<td>5</td>
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<tr>
<td></td>
<td>CSC6C7</td>
<td>8</td>
<td>UF</td>
<td>76</td>
<td>3.3</td>
<td>3.5</td>
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<td>Leechavengvong et al. (2006) [20]</td>
<td>CSC6</td>
<td>15</td>
<td>UF</td>
<td>87</td>
<td>3.7</td>
<td>3</td>
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<tr>
<td>Coulet et al. (2010) [7]</td>
<td>CSC6 ± C7</td>
<td>12</td>
<td>IC (&lt; 6 months)</td>
<td>83</td>
<td>3.7</td>
<td>3.1</td>
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<tr>
<td></td>
<td></td>
<td>5</td>
<td>IC (&gt; 6 months)</td>
<td>0</td>
<td>1.8</td>
<td>0</td>
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<tr>
<td></td>
<td></td>
<td>10</td>
<td>UF (&lt; 6 months)</td>
<td>100</td>
<td>3.9</td>
<td>4.5</td>
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<tr>
<td></td>
<td></td>
<td>13</td>
<td>UF (6 months &lt; T &lt; 12 months)</td>
<td>70</td>
<td>3.3</td>
<td>4.5</td>
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<tr>
<td>Bertelli et Ghizoni (2010) [30]</td>
<td>CSC6</td>
<td>7</td>
<td>UF</td>
<td>100</td>
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<td>5.2</td>
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#### Free muscle transfer

<table>
<thead>
<tr>
<th>Authors</th>
<th>Muscle transferred</th>
<th>Sample size</th>
<th>Initial failure level (%)</th>
<th>Nerve transferred</th>
<th>% Useful results</th>
<th>Average BMRC score</th>
<th>Elbow flexion strength (kg)</th>
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</thead>
<tbody>
<tr>
<td>Chuang et al. (1997) [25]</td>
<td><em>Gracilis</em></td>
<td>31</td>
<td>—</td>
<td>3 × IC</td>
<td>78% &gt; M4</td>
<td>—</td>
<td>—</td>
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<tr>
<td>Verkis et al. (2008) [17]</td>
<td><em>Latissimus dorsi</em></td>
<td>7</td>
<td>20</td>
<td>Contralateral C7 root + graft</td>
<td>80% &gt; M3</td>
<td>—</td>
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<tr>
<td>Hosseinian et al. (2008) [18]</td>
<td><em>Gracilis</em></td>
<td>12</td>
<td>—</td>
<td>3 × IC</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Kay et al. (2009) [12]</td>
<td><em>Gracilis</em></td>
<td>13</td>
<td>10</td>
<td>or contralateral C7 root + graft</td>
<td>58% &gt; M4</td>
<td>—</td>
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<tr>
<td></td>
<td><em>Latissimus dorsi</em></td>
<td>37</td>
<td>—</td>
<td>UF or contralateral C7 root + graft</td>
<td>46% &gt; M4</td>
<td>—</td>
<td>—</td>
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<tr>
<td></td>
<td><em>Rectus femoris</em></td>
<td>7</td>
<td>—</td>
<td>IC or contralateral</td>
<td>—</td>
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</table>

IC: intercostal; UF: ulnar fascicle.
Elbow flexion restored with gracilis after brachial plexus injury

The better results with partial paralysis (C5C6C7) than with complete paralysis can be explained by Steindler type forearm flexor-pronator compensation, and also by greater use of the still-functioning hand, which in itself supports elbow function [23,24].

Unusually high DASH scores in partial paralysis cases are probably related to a sampling bias, since these values are higher than those usually found in the same conditions. They can be linked to the handicap being harder to accept or live with in cases of partial paralysis, because patients still have a functioning hand.

Good GFMT results can be attributed to the shortest possible delay in denervation and time for axon regrowth. It is directly correlated to the length of the muscular nerve pedicle and corresponds to the delay between suturing and the first contraction. In our series, this time frame averaged 7 months; published reports give 7 to 9 months as the first contraction. For a primary surgical intervention, this time frame aver-

Muscle performance must also be considered, but the published results in this area are not consistent. Chuang et al. [5,10,25] along with Kay et al. [12] believe that it is best to transfer the gracilis muscle, while Terzis et al. [13] did a comparative study and decided on using the latisimus dorsi muscle. The latter muscle is quite large and can be challenging to attach to the biceps tendons.

Even if the motoneuron population brought in by these different nerve transfers are not the same [12], Terzis et al. [13] found this not to be an important factor. However, the fixation tension set for the gracilis significantly affects its mechanical performance [10].

GFMT is a reliable procedure that is independent of the delay in the patient receiving care. Before the sixth month, the results are worse than with a primary nerve transfer and the surgical procedure is clearly more complicated and has an initial vascular risk that cannot be reduced. The most appropriate indications for GFMT are cases of complete paralysis (C5-T1) beyond the sixth month post-trauma and in partial paralysis (C5C6 ± C7) cases where partial upper nerve transfer is an option and is typically less sensitive to denervation time.

In the hands of a well-trained team, this procedure is a satisfactory and reproducible treatment option when classical procedures are no longer indicated.

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

References


