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ORIGINAL ARTICLE

Double innervated free functional muscle transfer for facial reanimation

Alexander Cardenas-Mejia[1], Jorge Vladimir Covarrubias-Ramirez[1], Andres Bello-Margolis[1] & Shai Rozen[2]

[1]*Division of Plastic and Reconstructive Surgery, Hospital General Dr. Manuel Gea Gonzalez, Mexico City, Mexico and* [2]*Department of Plastic and Reconstructive Surgery, University of Texas Southwestern Medical Center, Dallas, TX, USA*

Abstract

Background: The treatment of long-standing facial palsy represents a challenge for the reconstructive surgeon. Treatment is based on dynamic procedures such as functional muscle flaps. The benefit of added axonal load has recently been reported. This study describes a two stage technique involving dual innervation of a gracilis muscle flap with initial cross-facial nerve graft (CFNG) followed by free muscle transfer co-apted to both the CFNG and a masseter nerve for facial reanimation. *Methods*: A total of nine patients from August 2008–July 2011 were operated on with the double innervated gracilis muscle flap. Pre- and postoperative electromyography was documented, and video analysis with the five-stage classification of reanimation outcomes was performed. *Results*: All patients recovered voluntary and spontaneous smile abilities, with an average of 70% motor unit recruitment. Based on the Terzis reanimation outcome classification, four patients had an excellent result, four good, and one moderate. *Conclusions*: The double innervated gracilis muscle flap is a viable technique for the treatment of long-standing facial palsy. It enables a fast recovery with fast muscle activity, and allows an emotional smile and aesthetic symmetry.

Key Words: Facial palsy, gracilis muscle flap, facial reanimation, babysitter

Introduction

The aims in reconstruction of the midface in long-lasting facial paralysis include restoration of facial symmetry at rest, along with restoration of a symmetrical and spontaneous smile [1-3].

Free Functional Muscle Transfer (FFMT) is considered the gold standard treatment for long-standing facial paralysis for decades [4], since first described by Harii et al. [5]. Traditionally, FFMT was performed as a two-stage procedure by elongation of the contralateral facial nerve using a cross-face nerve graft in the first stage followed by microneurovascular muscle transfer in a second stage.

The benefits of using the contralateral facial nerve as a neurotiser of the FFMT is that it potentially can provide synchronous and spontaneous activity of the facial muscles [6,7]. Conversely, using a nerve graft to prolong the donor nerve source of axons presents several drawbacks including the lack of predictability and consistency in the degree of muscle contraction and, therefore, smile excursion [8,9]. This may be related to the variability of the number of axons that reach the target muscle since they must grow through two coaptations, thus potentially decreasing the axonal load and the recruitment of potential motor units. To overcome this, a one-stage FFMT for smile reanimation has gained popularity innervated by different donor nerves including the contralateral facial by using a muscle with a long nerve or performing additional manoeuvres to increase the length of the nerve [10-14]. Between other donor nerves (mostly branches of the V, XI, or XII cranial nerves [15-17]) used as neurotisers for the FFMT, the motor branch of the masseter nerve has gained popularity worldwide because of its predictable results, rapid muscle innervation, low donor site morbidity, and potential for cortical plasticity [7].

A combination of both approaches has also been described and defined by dual innervation of the FFMT or neural supercharging. Yamamoto et al. [18] introduced the concept of neural supercharge in patients with recent facial paralysis and demonstrated the effectiveness of using a hypoglossal nerve input in combination with facial nerve stimulus to guarantee an adequate quantity of contraction and the correct degree of facial nerve stimulus. Watanabe et al. [19] first reported the use of a one-stage free flap surgery with double innervation for the reanimation of long-standing facial paralysis. Their study demonstrated improvement in latissimus dorsi muscle contraction by positioning the hilum of the flap in contact with a part of the denuded masseter on the paralyzed side. Biglioli et al. [20] described a one-stage gracilis functional flap using double innervation; an end-to-end masseteric to obturator nerve coaptation and an end-to-side coaptation of the contralateral facial nerve–sural nerve graft to the obturator nerve. By using dual innervation, optimal and rapid reinnervation is guaranteed by the masseter nerve and spontaneous smile can be triggered by the contralateral facial nerve.

In the current article, we report our clinical series using a new two-stage reanimation technique using a FFMT with double innervation: a cross-facial nerve graft (CFNG) from the contralateral facial nerve as the first stage and FFMT (using the gracilis muscle) as second stage, coapting the obturator nerve end-to-end to the CFNG, and adding a second input of axons from the masseteric nerve as a babysitter coapted end-to-side to

Correspondence: Alexander Cardenas-Mejia, MD, Puente de Piedra 150, C-723 TII, Toriello Guerra, Tlalpan, ZC 14050, Mexico City. Tel: +525521271052. E-mail: alexcardenas@hotmail.com

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Table I. Terzis′ Aesthetic- Functional Grading System used for grading the smile and the overall aesthetic outcome.

Group	Grading	Result	Description
I	1	Poor	Deformity, no contraction
II	2	Fair	No symmetry, bulk, minimal contraction
III	3	Moderate	Moderate symmetry, moderate contraction, mass movement
IV	4	Good	Symmetry, nearly full contraction
V	5	Excellent	Symmetrical smile with teeth showing, full contraction

the obturator nerve 1 cm distance from the muscle to ensure rapid muscle reinnervation.

Materials and methods

From 2008–2011, nine patients with facial paralysis underwent a double neurotised gracilis free flap. All patients were evaluated for demographics, causes of facial paralysis, time interval between surgical stages and functional recovery by using electrophysiological studies and Terzis grading system [21]. The Standardised evaluation of pre- and postoperative videos was performed by four separate judges using Dr Julia Terzis' aesthetic-functional scale (Table I). Post-operative follow-up was carried out for a total of 12 months after a second stage, with a mean follow-up of 26.7 months (from 12–42 months)

Statistical analysis

An analysis of correlation between the considered variables, and a regression analysis between pair of variables was performed with a SAS system version 9.0 for statistical analysis. Only those variables with statistical significance in the regression analysis were considered. A comparison test was realised with the mean of variables pre- and postoperative scale by a '*t*' Student test.

Surgical technique: Two stage dual reinnervation of a free gracilis flap

A two-stage procedure is performed, the first stage consisting of a cross-facial nerve graft using the contralateral buccal branch of the facial nerve crossing the nerve through the upper lip, banking the distal end of the nerve near the paralyzed nasolabial fold.

The second stage of the operation is carried out 3–4 months later once the viability of the nerve graft has been confirmed by neurophysiological studies. During this stage, the gracilis muscle is harvested from the leg ipsilateral to the paralyzed side and the obturator nerve dissected to the point of the obturator foramen separating it from the branch to the adductor longus muscle. The muscle is trimmed in resting length as described by Zuker et al. [22]. Simultaneously, a pre-auricular incision is made and dissection carried out towards the temporal region and the border of the mandible to create a pocket to inset the FFMT in the face. Parallel to the anterior border of the masseter the facial vein is identified and, directly anterior to it, the facial artery. We then dissect both vessels to the oral commissure where they are ligated, divided, and pulled out toward the incision. We then identify the orbicularis oris muscle and modiolus, making three or four reference suture points to recreate the contralateral fold and smile.

Then, via an intraoral incision, we find the previous nerve graft and make a tunnel between the intraoral and extraoral incisions. The masseter nerve is then dissected by opening the masseter fascia using the notch between the coronoid and the condylar process as a reference point, which is palpable below the zygomatic arch. Once the face is prepared, the gracilis muscle is transplanted to the face and attached to the orbicularis oris muscle and modiolus. The vascular anastomoses are performed and finally the nerves are coapted as follows. First, an end-to-end coaptation is performed between the CFNG to the obturator nerve and then an end-to-side coaptation from the masseter nerve to the obturator nerve ~1 cm from the gracilis muscle hilum (Figure 1).

Results

Of the nine patients included, six were men and three women, with a mean age of 37.6 years old (range = 13–60 years-old). All patients presented with long-standing facial paralysis with a minimum 2 years since onset. Aetiologies of paralysis included direct injury to the facial nerve by trauma, surgical complication, infection, or idiopathic. The mean time from stage one to stage two was 8.78 weeks (range = 7–12 weeks). The gracilis free muscle flap procedure took an average of 6.22 hours (range = 3.2–7.3 hours), and no major complications requiring revisional surgery for the muscle transfer were needed in the immediate post-operative period. Time until reinnervation was an average of 8.78 weeks (range = 8–12 weeks), visible

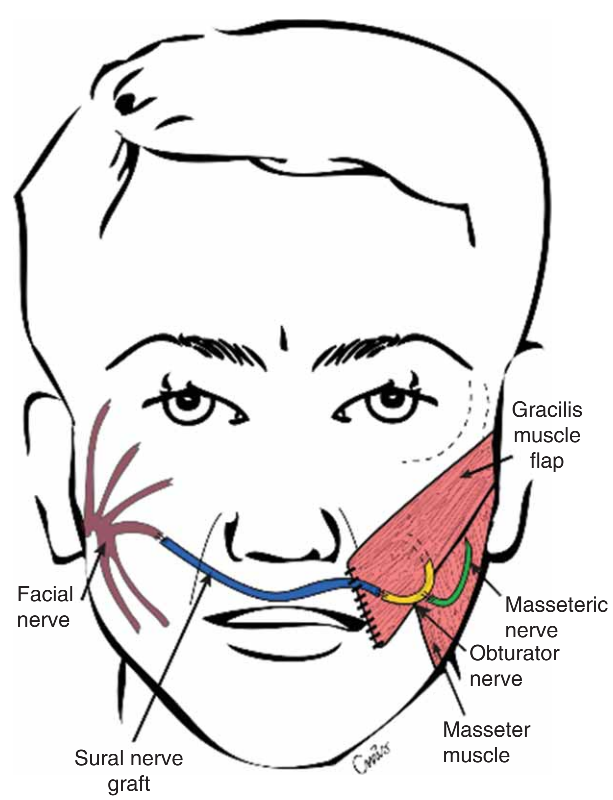

Figure 1. Scheme of surgery. The transposed gracilis muscle flap is innervated by the cross facial nerve graft (end to end anastomosis) and double innervated by masseteric nerve (end to side anastomosis).

Table II. Demographic and complete patient information and results.

Patient	Age	Sex	Affected side	Aetiology	Evolution time (years)	Time to muscle reinnervation (weeks)	Time to perceptible movement (weeks)	Preoperative Function and Est	Postoperative Function and Est	Latency EMG (mseg)	Motor unit recruitment
1	26	M	L	Tumor resection	2.5	8	13	1	4	4	80
2	28	F	R	Herpetic Infection	12	8	12	1	5	4	50
3	29	M	R	Tumor resection	3.5	9	12	1	5	4	80
4	34	M	R	Trauma	14	8	13	2	5	4.2	75
5	43	F	L	IDIOPATH	15	7	12	1	4	4.2	75
6	49	M	L	Tumor resection	1.5	9	13	1	4	4	70
7	13	M	L	Trauma	2	8	13	2	4	4.2	70
8	60	M	R	Tumor resection	5	12	15	1	3	4.5	45
9	56	F	R	Tumor resection	3	10	13	1	5	4.2	70
Average	37.6				6.5	8.8	12.9	1.2	4.3	4.1	68.3

Abbreviation: Est = Aesthetic score according with Terzis' scale; mseg = milliseconds

movement took an average of 12.89 weeks (range = 12–15 weeks), and total oedema recovery took on average 7.78 months (Table II).

Reinnervation time had a mean 8.78 weeks and median 8.0 weeks. In contrast, the clinical perception of movement had a normal distribution. Males required more time until reinnervation and perceptible movement than females, but this may be related to the sample size (Figure 2).

The preoperative video analysis using Terzis' aesthetic functional scale demonstrated grade 1 for seven patients and grade 2 for two patients. Postoperative videos demonstrated grade 3 for one patient, grade 4 for four patients, and grade 5 for four patients. The mean and median preoperative score was 1.22 and 1.0, respectively, while the mean and median postoperative score was 4.33 and 4, respectively (Figure 3). Mean comparison between the preoperative and postoperative groups by the '*t*' Student test shows that the difference between both means was statistically significant, with a p-value less than 0.0001. These results demonstrate significant post-operative improvements using this dual innervation technique (Figures 4 and 5).

Electromyography analysis showed a mean lapse time of 4.14 milliseconds and a median of 4.3. Motor unit recruitment showed a mean of 68.33% and median of 70%. In terms of muscle function, this is a very good outcome, indicating less activation time and making this technique a very good instrument for patients with facial palsy requiring functional muscle transfer (Figure 6).

Palsy time relating to denervation had a positive asymmetric distribution with a mean of 6.5 years, while the median was 3.5 years. No tendency was found with regards to the sex of the patient.

In the regression analysis, a direct and linear significant relation was observed between the age and the time of reinervation, with an adjusted model of $Y = 6.348 + 0.065x$; this means that, for each unit of increase in the age it obtains an increase of 0.065 in the time of reinervation.

Patients with an age over 50 years had a longer reinervation time (two patients) Reinervation time for patients under the age of 50 averaged 8.4 compared to 11 weeks in patients older than 50 years.

Another result in the regression analysis was a significant inverse relation between the time of perceptible movement and the postoperative grading, with an adjusted model of $Y = 16.861 - 0.917x$; meaning patients with shorter time of reinnervation demonstrated a better smile postoperatively, as measured by the grading system.

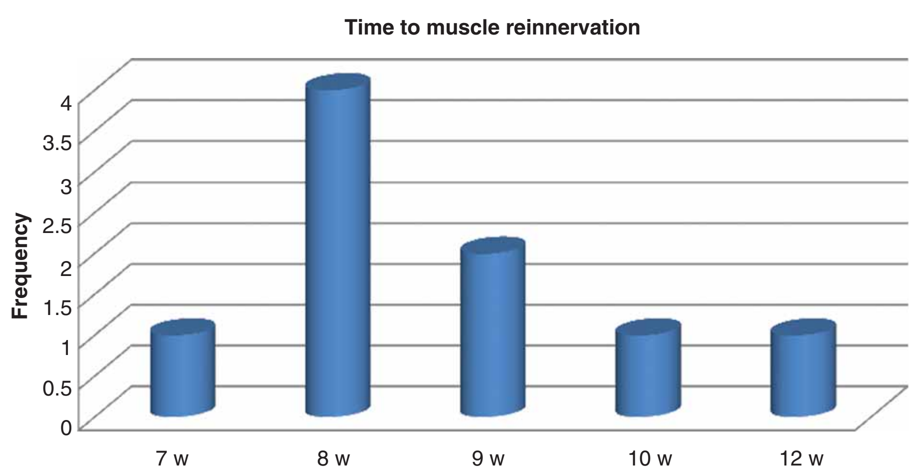

Figure 2. Time to muscle reinnervation expressed in weeks.

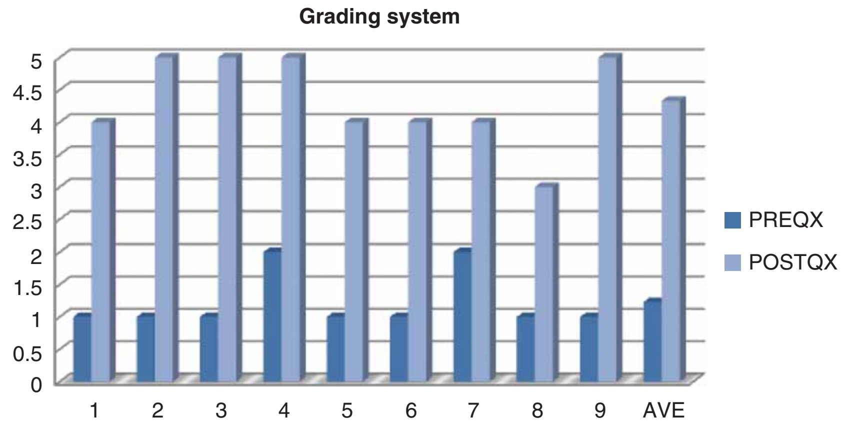

Figure 3. Aesthetic and functional preoperative and postoperative scores.

Discussion

Segmental gracilis muscle transplantation has long been used for facial reanimation patients with long-standing facial paralysis [23-25]. One of the critical factors of this procedure is the selection of the appropriate motor nerve to innervate the transplanted muscle, and this has been compared in different studies [15,26,27]. The choice between cross-facial nerve grafts or using the masseteric nerve to power the muscle transplant or reinnervate viable facial musculature depends on the aims of the surgery and patient factors [27].

The choice between two-stage or one-stage reanimation procedures is another often discussed issue in facial reanimation surgery. In contralateral facial nerve innervation, the aim is to restore the ability to smile naturally, but the efficacy of these techniques is partially impaired by reduced contraction or complete failure in a significant proportion of patients. On

Figure 4. Patient1. A 49-year-old man presented with complete left-sided facial paralysis following extirpation of an acoustic neuroma. Medial and lateral tarsorrhaphy was performed elsewhere. The denervation time was 18 months. He had the first stage of facial reanimation with one cross-facial nerve graft and six months later, he had a double innervated free functional muscle transfer. (Above Left) Preoperative appearance with the patient attempting to smile. Note the right complete facial paralysis. (Above Right) Postoperative appearance and smile at 2 years after completion of operations. The mean grading for smile was poor (1.0) before surgery and excellent (4.3) after the operation. (Below left) Preoperative appearence at rest. (below right) Posoperative appearence at rest.

Figure 5. Patient 2. A 26- year-old man presentd with complete left-sided facial paralysis following extripation of an acoustic neuroma. Denervation time was 30 months. He had a first stage of facial reanimation with a cross facial nerve graft from contralateral side and 4 months after we performed a double innervated free functional muscle transfer. (left) Preoperative appearance trying to smile (right) Posoperative appearance while smiling.

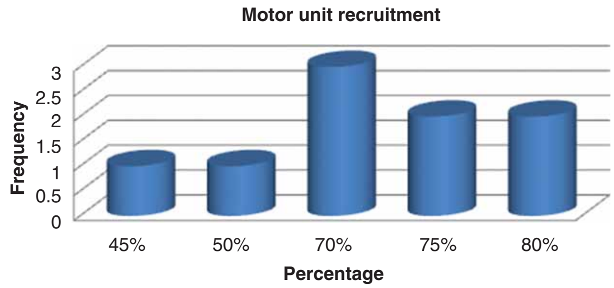

Figure 6. Graphic showing the motor unit recruitment from all the patients. Motor unit recruitment showed a mean of 68.33% and median of 70%.

the other hand, neurotisation by nerves other than the facial nerve or transfer of muscles beyond the territory of the facial nerve requires long-term biofeedback training [5].

Traditionally, and most commonly, reconstruction is performed in two stages, consisting initially of a cross-facial nerve graft followed by a second-stage free muscle transfer 6–12 months later. Despite good and fairly reproducible results obtained with the two-stage procedure, the search to obtain similar or better results in a shorter time frame with only a one-stage procedure continues. Thus, a free nerve–muscle transfer concomitantly coapted to a recipient contralateral facial nerve in a single procedure has been described [14,18-20].

Watanabe et al. [19] first reported the use of a one-stage free-flap surgery with double innervation for the reanimation of long-standing facial paralysis. This improved latissimus dorsi contraction by placing the hilum of the flap in contact with part of the denuded masseter on the paralysed side.

Yamamoto et al. [18] introduced the concept of neural supercharging in cases of recent paralysis and demonstrated the effectiveness of using a hypoglossal input in combination with facial nerve stimulus to guarantee an adequate quantity of contraction and the correct facial nerve stimulus. Their concept was based on the observation of reanimation procedures for long-standing paralysis in which a reduced number of axons reached the muscle as compared to healthy subjects.

Biglioli et al. [20] described a one-stage gracilis functional flap using double innervation; an end-to-end masseteric to gracilis nerve coaptation and end-to-side nerve coaptation of the contralateral facial nerve graft to the gracilis nerve.

In contrast to Biglioli et al., our technique includes a two-stage reanimation procedure. The first stage involves a short cross-facial nerve graft (coapting the proximal stump to the buccal branch of healthy facial nerve and leaving the distal stump by the contralateral nasolabial fold). The second stage involves a free functional gracilis muscle transfer and a double nerve coaptation; an end-to-end coaptation from the distal stump of the sural cross facial nerve graft to the proximal stump of the gracilis nerve and a second nerve end-to-side coaptation using the masseteric nerve to the gracilis nerve (1 cm from the muscle).

Different studies [28,29] demonstrate that the masseter nerve provides a more powerful smile than cross facial nerve graft due to the great axonal load of the masseter nerve and the fact that nerve sprouts have to cross through just one nerve coaptation in a shorter distance, so in our opinion doing an end-to-end coaptation of the masseter with the obturator can achieve a shorter reinnervation time and stronger muscle contraction, but may lack spontaneity because, by the time the sprouts from CFNG arrive to the gracilis, nerve sprouts from masseter could complicate the recluitment of motor units already occupied by the masseter nerve fibres. So we believe that doing CFNG-obturator in a end-to-end fashion could give the biggest chance to the contralateral facial nerve to recluit major motor units in the gracilis muscle.

Recently Farber and Mackinnon [30] demonstrated the positive effect of a supercharged nerve transfer in an experimental study based on peroneal nerve transfers in rats, which demonstrated improvements resulting from the double axonal charge. This technique was then later used in the treatment of patients with brachial plexus injuries with similar improvements in outcome.

A double axonal input results in a greater proportion of reinnervated fibres, which more closely resembles that of healthy subjects, and most authors agree that the contralateral side of the face provides the correct stimulus for unilateral facial palsy reanimation [1,31].

Our results show an average reinnervation time of 8.8 weeks and a significant increase in the degree of motor unit recruitment at 1 year post-surgery (68.3%).

The relative improvement in contraction during spontaneous smiling may occur because axons passing through the cross-face nerve graft also trigger the activation of masseteric nerve fibres.

Decision-making in the preoperative period regarding choosing a donor nerve in facial palsy is commonly very difficult. The masseter nerve produces powerful muscle contraction and near symmetric smile, but rarely achieves true spontaneity. In contrast, cross facial nerve grafts have the potential to restore emotionally mediated facial motion; however, the muscle excursion produced is often weak and a symmetric smile is seldom achieved. This study examines the potential benefit of combining these two techniques in an effort to produce a functional synergy or at least the masseteric nerve input is guaranteed even if the axonal input from the cross-facial nerve graft fails to reach any clinical significance.

Moreover, our technique helps minimise muscle atrophy, which may improve functional results (Figures 2 and 3). Masseteric innervation helps reduce muscle flap atrophy during the denervation period because reanimation starts sooner than when cross-facial nerve grafts are used.

We believe end-to-end CFNG to obturator nerve coaptation carries the main impulse, thus allowing a more symmetrical and spontaneous smile while the end-to-end masseteric to obturator nerve coaptation derives more power from the masseteric nerve and, therefore, a more powerful, but less spontaneous smile.

These different techniques have different outcomes in the overall aesthetic evaluation, with practically all of our patients showing a significant improvement.

We devised our technique in an effort to treat patients who were not responding to the classic two-stage procedure. For our patients who failed to show any contraction in the transplanted muscle several months after the conventional two-stage procedure, we brought them back to the operating room to perform a masseteric nerve transfer in order to avoid complete denervation. Soon we decided to treat all of our patients with a double innervation and we observed that our results were consistent and, in addition to this, patients could activate the gracilis when biting and smiling.

Conclusions

Double neurotised functional muscle transfer has proven in our series to provide a predictable and consistent smile restoration in facial paralysis. By close coaptation of the masseter nerve to the muscle a shortened reinnervation time is ensured, and an increasing number of functional motor units is observed, providing more power on muscle activation in less time concurrently with a spontaneous and independent function. Time to muscle reinnervation (weeks).

***Declaration of interest*:** The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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