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Novel Method of Dual-innervated Free Gracilis Muscle Transfer for Facial Reanimation: A Case Series

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Background: Dynamic facial reanimation is the gold standard treatment for a paralyzed face. The use of the cross-face nerve graft (CFNG) in combination with the masseteric nerve to innervate the free gracilis muscle has been reported to provide both spontaneity and strong neural input. We report a case series of dual innervation, using a novel method where the branch to masseter is coapted to the side of the CFNG.

Methods: Eight patients received free gracilis muscle transfer using the new dual innervation method between September 2014 and December 2017. The CFNG, which was performed nine months prior, was sutured in an end-to-end fashion to the obturator nerve. A nerve graft was coapted to the ipsilateral masseteric nerve and then sutured in an end-to-side fashion to the CFNG proximal to its coaptation to the obturator nerve.

Results: All patients recovered smile function with and without teeth clenching around the same time period. Smiles without teeth clenching appeared later in two of eight patients and earlier in one of eight patients, being noted at an average of 8.25 months of follow-up versus 7.6 months. The estimate of true attainment is limited by the spacing of follow-up dates. Average follow-up time was 36.07 months (range: 10–71.5). FACE-Gram software smile analysis with and without biting demonstrated similar excursion on average (7.64 mm versus 8.6 mm respectively, $P = 0.93$), both of which are significantly improved from preoperation.

Conclusion: This novel method of a dual-innervated free gracilis muscle transfer offers a viable technique that achieves a symmetric, strong, and emotional smile. *(Plast Reconstr Surg Glob Open 2023; 11:e5388; doi: 10.1097/GOX.0000000000005388; Published online 7 December 2023.)*

INTRODUCTION

The function of the face is crucial for daily interactions and function, as subtle facial expressions convey a myriad of nonverbal cues from dramatic to nuanced.[1] As a result, facial paralysis has a significant impact on quality of life for patients, and regaining a symmetric smile remains one of the most impactful reconstructive priorities.[2] Dynamic facial reanimation is the gold standard treatment for a severely paretic or paralyzed face. A variety of muscle and nerve coaptation configurations have been used in an effort to achieve the optimal outcome with the least donor site morbidity.

Harri et al pioneered the use of free functional muscle transfer in facial paralysis, using the gracilis powered by the deep temporal nerve.[3] Today, the gracilis is the muscle of choice due to the low donor site morbidity, consistent anatomy, and the excellent size match of donor and recipient vessels.[4–7] The masseteric nerve has been used to innervate the gracilis because it provides rapid, strong, and predictable reinnervation, and it has traditionally been used in cases of bilateral facial nerve palsy such as in Moebius syndrome.[8] However, this intervention does not often permit spontaneous, emotional activation; instead, it requires patients to clench their teeth to generate a smile.[9,10]

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When the contralateral facial nerve is intact, a cross-face nerve graft (CFNG) may be used to innervate the gracilis muscle. Scaramella in 1970 described the first CFNG for unilateral facial palsy.[11] Although this technique often achieves the desired muscle spontaneity, the long distance required for axonal regeneration may result in fewer nerve signals reaching the target.[12]

More recently, there have been several reports in the literature using CFNGs combined with the masseteric nerve in the setting of free functional gracilis transfer.[13–19] The powerful impulse by the masseteric nerve in conjunction with the spontaneous control from the contralateral side results in faster recovery, a stronger contraction, and a more symmetric and spontaneous smile. The concept of dual innervation is supported in the basic science animal literature.[20–22] In many of the dual innervation techniques, the arrangement of nerves allows the branch to masseter to dominate the nerve input to the gracilis muscle.[13,15–17,19,23,24]

We report a novel modification to the existing nerve coaptation configurations. In our technique, the sural nerve is used as the CFNG from the contralateral facial nerve to the obturator nerve of the transferred gracilis. Innervation from the ipsilateral masseteric nerve is added via a second nerve graft sutured end-to-end to the masseteric and end-to-side to the CFNG (Fig. 1). It is generally thought that each coaptation site reduces axonal load by approximately 50%.[25,26] The additional nerve graft between the masseteric branch and the CFNG, along with the proximal location on the CFNG serves to place the masseteric nerve at a disadvantage. The nerve input from the masseteric branch traverses three coaptation sites before reaching the gracilis, giving it a major disadvantage. Additionally, at the typical regeneration rate of 1 mm per day, the extra length of the nerve graft placing it proximal to the CFNG to obturator coaptation prolongs the time it takes for the masseteric nerve axons to reach the gracilis muscle target, thereby allowing more time for the CFNG to establish reinnervation.[25] We hypothesize that this disadvantage to the masseteric nerve would allow the CFNG to contribute more input for reinnervation to the gracilis. We present our outcomes in an eight patient case series.

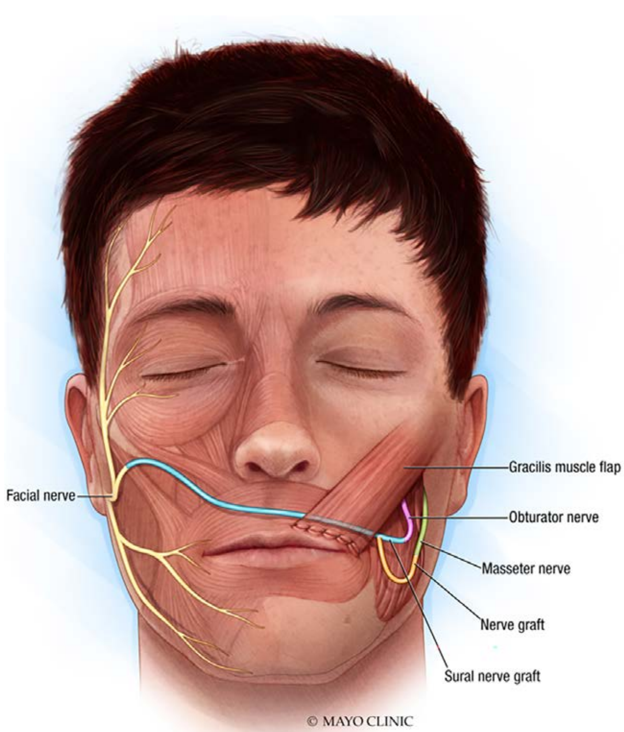

Fig. 1. Dual innervation using CFNG as an end-to-end coaptation to the obturator and the masseteric nerve as an end-to-end to a nerve graft coapted end-to-side to the CFNG. © Mayo Clinic. Used with permission.

Takeaways

Question: Is novel innervation of the gracilis with cross face nerve graft, in combination with the masseteric nerve, reliable in providing a smile without clenching?

Findings: The CFNGs were coapted in an end-to end fashion to the obturator nerve. A nerve graft was coapted to the ipsilateral masseteric nerve and then sutured to the CFNG in an end-to-side fashion. All eight patients recovered smile function with and without teeth around 8.25 months postoperatively.

Meaning: This novel method offers a viable technique that achieves a symmetric, strong, and nonclenching smile.

METHODS

After approval by the institutional review board, retrospective analysis was used to identify patients who underwent facial reanimation using our new method of dual-innervated free gracilis muscle transfer between 2014 and 2017. Patients were excluded if they had less than 6 months of follow-up. Medical records were reviewed for age, sex, race, etiology of facial paralysis, duration of facial palsy, date of each surgical procedure, complications, type of nerve coaptation, and follow-up time.

Pre- and postoperative video interview analysis was performed by observers at all clinic visits to assess for smile characteristics. The FACE-Gram smile excursion software was utilized to analyze the maximal smile excursion in images pre- and postoperatively.[27] Time-to-smile with teeth clenching and time-to-smile without clenching from the intrinsic input from the contralateral side were estimated from their presence at follow-up visits.

Statistical Analysis

Student t test was used for smile excursion analysis. A P value of less than 0.05 was considered statistically significant. All statistical analysis was performed using JMP (SAS Institute Inc.).

Surgical Technique

The first stage consisted of CFNG using the contralateral zygomatic branch(es) of the facial nerve identified via a preauricular facelift incision and sub-SMAS dissection. The sural graft was harvested via standard techniques and coapted to the selected zygomatic nerve branches. The sural nerve was then tunneled contralaterally through a subcutaneous tunnel in the upper lip.

Stage two was performed 9–12 months after the placement of the CFNG. During the second stage, the gracilis muscle was harvested from the contralateral leg in seven patients and ipsilateral in one patient (contralateral gracilis had been used for a previous surgery). The contralateral leg is used to allow for the proximal facia of the gracilis to be used at the upper lip and nasolabial fold. The muscle was marked at 1-cm intervals to later establish the appropriate tension upon inset. Inset in the face was as described by Terzis via a preauricular facelift incision. The muscle was anchored to the modiolus distally and the deep temporal fascia proximally.[2,28] The facial artery and vein were used as recipient vascular pedicles.

The CFNG was identified in the preauricular region via the facelift incision and coapted in an end-to-end fashion to the obturator nerve of the transferred gracilis. The ipsilateral masseteric nerve was coapted to a nerve graft obtained from the extra length of the obturator nerve from the gracilis muscle harvest. This masseter-coapted nerve graft was then sutured in an end-to-side fashion to the CFNG proximal (about 1–1.5 cm proximal) to the CFNG coaptation with the obturator nerve (Fig. 1). All nerve coaptations were then covered with an NeuraGen Nerve Protector (Integra LifeSciences Inc., Princeton, N.J.) or Axoguard (AxoGen, Inc., Alachua, Fla.).

Postoperative Care

All flaps were monitored inpatient with a Cook-Swartz implantable Doppler assessing the venous signal for 5 days before patients were discharged. Patients were actively followed up in our facial paralysis and reanimation clinic by a multidisciplinary team consisting of plastic surgery, neurology, oculoplastics, optometry, and physical therapy. Patients were taught to perform biofeedback in front of a mirror, on a daily basis. Patients were also instructed to practice smiling without biting in their daily living.

Follow-up Evaluation

Routine follow-ups consisted of multidisciplinary clinic evaluation at approximately 1 month, 6–9 months, and 10–12 months (Table 2). At all follow-up visits, video recordings of the following were performed: (1) smiling with teeth clenched to confirm innervation by the masseteric nerve, and (2) attempt at a natural smile with teeth showing (lips apart) but without clenching to evaluate for muscle innervation from the CFNG. Outcomes were graded objectively via the FACE-Gram smile excursion automated measurement software and subjectively by members of the surgical team.[27]

RESULTS

Eight patients (seven women, one man) were included in the study. The patients are shown in repose position in Figure 2 and in Supplemental Digital Contents 1 and 2. (**See figure 1, Supplemental Digital Content 1,** which shows the outcomes of our eight patients who underwent two-stage cross-face nerve graft combined with end-to-side nerve to the masseter transfer for free gracilis facial reanimation reconstruction. Standardized photographs of the patients in neutral repose preoperatively and smiling without and with biting preoperatively and postoperatively are shown. **http://links.lww.com/PRSGO/C849**.) [**See figure 2, Supplemental Digital Content 2,** which shows the outcomes of the eight patients shown in standardized neutral repose both preoperatively (top) and postoperatively (bottom). **http://links.lww.com/PRSGO/C850**.]

Mean age at the time of free gracilis transfer was 40.4 years (range: 25–58 years; Table 1). All patients had longstanding facial paralysis of greater than 2 years. Four patients had left-sided, and four had right-sided paralysis. Etiologies of facial paralysis varied: Bell palsy (n = 3), acoustic neuroma resection (n = 2), parotid mass resection (n = 1), congenital (n = 1), and unknown (n = 1). Mean time from CFNG to the gracilis transfer was 9.6 months (range: 7.5–15 months). Average follow-up time was 36.07 months (range: 10–71.5). One complication of a hematoma requiring operative drainage occurred; no flap losses occurred. Three of the eight patients (patients 3, 5, and 6) had synkinesis before their operations. All three patients underwent neurectomy during either stage 1 or 2 of their dual innervation procedures. Patient 5 required platysma myectomy 2 years postoperatively, and patient 6 required repeat neurectomy 4 years postoperatively (see table footnote for details regarding synkinesis). [**See Video (online),** which demonstrates the postoperative video taken in clinic of patient 1, showing his sequence of voluntary smile, as well as his spontaneous and naturally emotive smile.]

All patients were discharged from inpatient care at 5 days with follow-up at 1 month (Table 2). Continual

Table 1. Patient Demographics

Patient No.	Age	Sex	Affected Side	Etiology	Duration of Paralysis before Gracilis Transfer (y)
1	43	M	R	Unknown	6
2	38	F	L	Acoustic neuroma	10
3	39	F	L	Bell palsy	2
4	34	F	L	Parotid mass resection	34
5	55	F	R	Bell palsy	2
6	39	F	R	Bell palsy	11
7	23	F	L	Congenital	25
8	52	F	R	Acoustic neuroma removal	16
Average (range)	40.4	F(7), M(1)	L(4), R(4)		13.2 (2–34)

Table 2. Patient Outcomes Excursion (mm) on Paralyzed Side Using FACE-Gram Synkinesis

Patient No.	Paralyzed Side	Earliest Follow-up Dates (mo)	Longest Follow-up Date (mo)	Follow-up Date Noting Movement of Transplanted Muscle with the Masseter Nerve (mo)	Follow-up Date Noting Spontaneous Movement of Transplanted Muscle with the Masseter Nerve (mo)	Preoperative Smile (No Biting)	Post-operative Smile (No Biting)	Post-operative Smile (Biting)	Ancillary Procedures	Present	Intervention
1	R	1, 4, 7	26	7	7	–5.2	9.9	10.0	Fat grafting, canthopexy, botox	No	—
2	L	3, 7, 14	38	7	7 (4.5 self noted)	–3.2	6.8	7.4	Canthopexy, botox	Yes, recurrent	Neurolysis x2, orbicularis botox injection
3	L	1, 7	10	7	7	–1.9	4.03	2.4	Canthopexy, botox	No	—
4	L	1, 7, 11	26	7	7	2.1	10.5	8.4	Browlift, blepharoplasty, botox	Yes, recurrent	Neurolysis x1, botox injection
5	R	1, 3, 6, 9, 12	73	3	6	0.8	2.25	9.6	Browlift, canthopexy, fat grafting, facelift, botox	No	—
6	R	0.5, 1, 10	60	10	10	–0.2	7.38	8.4	Botox, fat grafting	No	—
7	L	1, 10, 12	26	12	10	8.1	6.4	4.9	Facelift, canthopexy, fat grafting, botox	Yes	Neurolysis x1
8	R	1, 8, 12	57	8	12	0.2	13.85	18.0	Canthopexy	No	—
Average (range)		36.1 (10–73)	7.6 (3–12)	8.25 (6–12)	0.1	7.64	8.6				

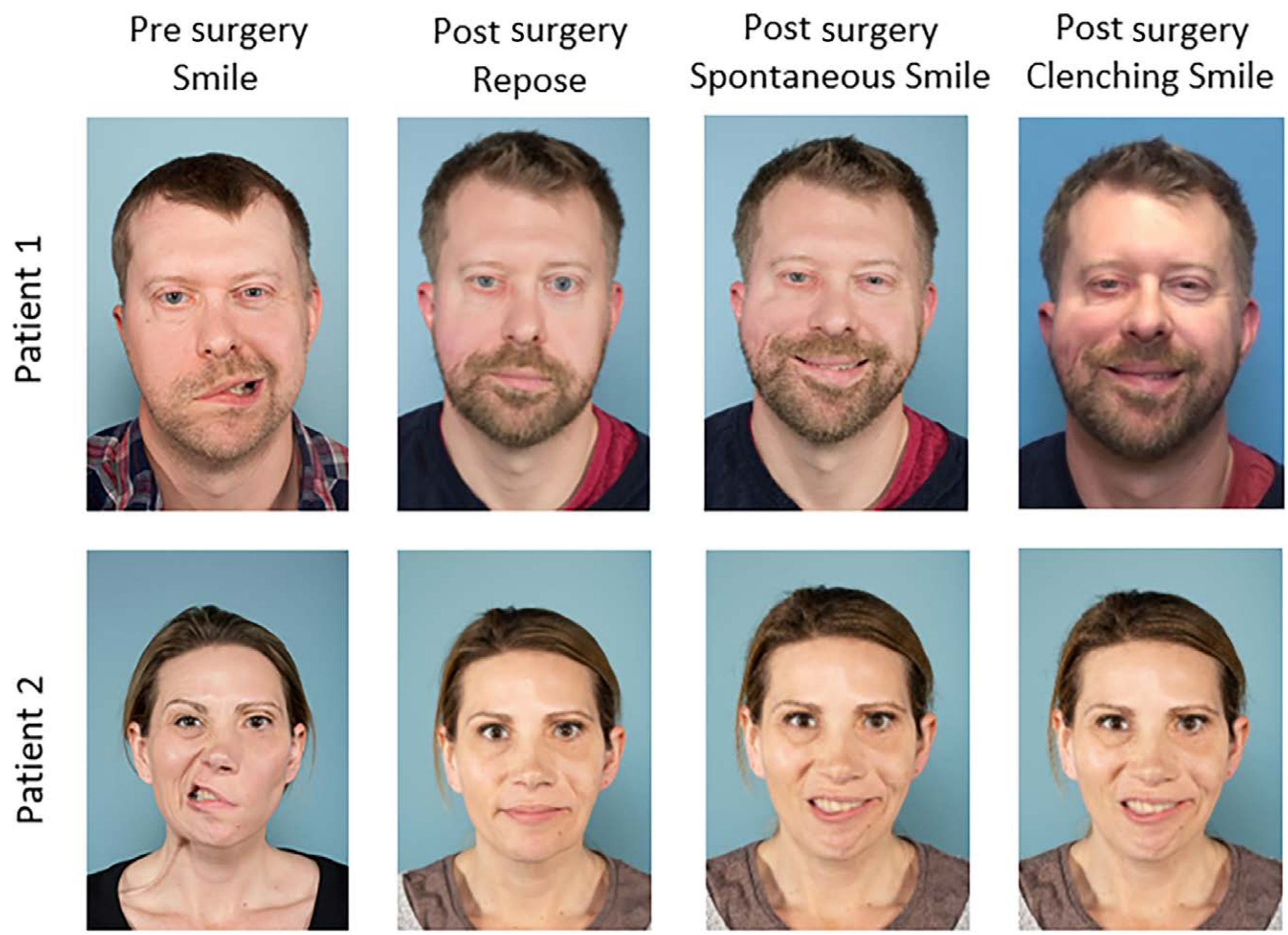

Fig. 2. Photographs of patients 1 and 2, who underwent two-stage CFNG combined with end-to-side nerve to the masseter transfer for free gracilis facial reanimation reconstruction. Standardized photographs of the patients in neutral repose preoperatively and smiling without and with biting preoperatively and postoperatively are shown.

follow-up visits showed the attainment of a smile without teeth clenching and a smile with teeth clenching in all patients (eight of eight). Smile with clenching was noted as early as a 3-month follow-up visit and as late as a 12-month visit (average 7.6 months follow-up; Table 2). Two patients had not recovered smile function at their 4- and 8-month follow-up appointments but eventually were able to smile with teeth clenching at their 10- and 12-month follow-ups, respectively.

Smiles without clenching were observed in eight of eight patients, being noted as early as a 6-month follow-up visit and as late as 12 months of follow-up (average 8.25 months follow-up; Table 2). One patient self-reported this smile before their 7 months follow-up visit at 4.5 months.

The recognition of a smile without clenching occurred at roughly the same time as the reinnervation by the masseteric nerve in the majority of patients. In patients 5 and 8, apparent reinnervation by the masseteric nerve through smiling with teeth clenching preceded recognition of an effortless smile at their prior follow-up 3 and 4 months earlier, respectively. Patient 7 achieved a smile without clenching at a follow-up visit 2 months before reinnervation of the masseteric nerve was noticed.

On evaluation using the FACE-Gram software, smile excursion preoperatively was 8.7mm on the nonparalyzed side and 0.1 mm on the paralyzed side. This improved postoperatively to 7.6 mm for smile without biting on the paralyzed side ($P = 0.0015$), and to 8.64 mm for smile with biting ($P = 0.0013$). There was no statistical difference between excursion from smile with biting and without biting ($P = 0.93$). There was little change in the nonparalyzed side (8.7 mm preoperatively versus 7.7 mm postoperatively with no biting, and 5.2 mm with biting).

DISCUSSION

In the facial reanimation literature, there has been growing interest in providing dual innervation to a free gracilis muscle transfer, using both a CFNG and the ipsilateral masseteric nerve.[14–19,30,31] The powerful impulse by the masseteric nerve results in faster recovery, a stronger contraction, and a more symmetric smile, whereas the CFNG contributes spontaneity.[6,9,10,32]

The reported approaches can be categorized into three methods, as summarized in Figure 3. The most common approach uses the CFNG as an end-to-side coaptation

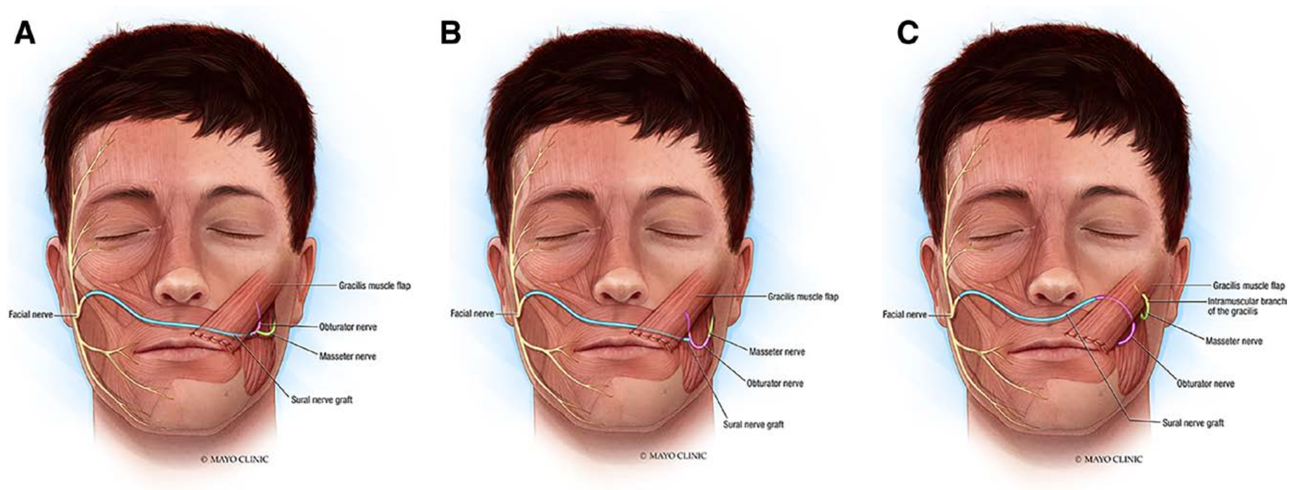

Fig. 3. A, Dual innervation using CFNG as an end-to-end coaptation to the obturator and the masseteric nerve as an end-to-side to the obturator nerve. B, Dual innervation using CFNG as an end-to-side coaptation to the obturator and the masseteric nerve as an end-to-end to the obturator nerve. C, Dual innervation using two end-to-end coaptations: CFNG with the obturator nerve, and the masseteric nerve with an intramuscular motor branch. © Mayo Clinic. Used with permission.

and masseteric nerve as an end-to-end coaptation to the obturator nerve.[15,16,18] Another approach coapts the CFNG end-to-end and the masseteric nerve end-to-side to the obturator nerve.[17] Lastly, both the CFNG and masseteric nerve are coapted end-to-end to the obturator nerve, using the distal stump of the intramuscular branch of the obturator nerve.[19]

In these previously described dual innervation techniques, there is a question of whether the strong neural input of the masseteric nerve takes over completely, thus limiting the ability of the CFNG to provide adequate innervation. This is especially true in a single-stage, dual innervation approach where the reinnervation distance for the CFNG is much longer than that of the masseteric nerve. Snyder-Warwick et al[26] studied the myelinated fiber counts in their pediatric facial reanimation patients. The downstream count in the CFNG at the second stage was only 24% of the count at the facial nerve donor branch, whereas the count from the masseteric nerve was 78% compared with the facial nerve.[26] In addition, in a rat animal model, there is evidence that end-to-end coaptation results in faster innervation and better muscle recovery after denervation compared with end-to-side innervation.[33–38]

In our coaptation variation, the procedure occurs in two stages, allowing the CFNG signal to reach the paralyzed side before transferring the gracilis. The masseteric nerve is also connected in an end-to-side fashion. This, in addition to the nerve graft between the masseteric and obturator nerves, theoretically gives an advantage to the CFNG signal. Our findings on smile excursion using the FACE-Gram software[27] did not show significant differences between smile excursion with biting and without biting. The analysis did show a trend toward a stronger excursion with biting smile, which is consistent with previous reported work evaluating excursion strength with the CFNG only versus masseteric nerve only.[9,39,40] The stronger excursion with the additional input from the masseteric nerve is well supported by various basic science animal studies that show stronger nerve input and faster muscle recovery with dual innervation, as opposed to single innervation.[20–22,26] Time to reinnervation was shown to be important for muscle force.[41] We postulate that the masseteric nerve provides additional input to the muscle and prevents atrophy of the gracilis after transfer. The nerve signal provided by the CFNG then leads to stronger contraction of the muscle and smile commissure excursion. Our findings of 7.6 mm of excursion are comparable and slightly improved to previously reported excursion values of 6.6 mm for CFNG.[7,42] Our excursions during biting are slightly lower than the reported value of around 11 mm for masseteric only innervation[42] likely due to our additional nerve graft, or by chance given the low patient numbers. An interesting future animal model would be to perform a dual-innervated muscle transfer, then eliminate one innervation source and see if the previously dual-innervated muscle maintained stronger force than the single innervated muscle just due to muscle mass preservation. We believe our method allows the most signal from the CFNG to contribute to reinnervation of the gracilis without risking prolonged denervation and atrophy.

In previous reports of dual innervation techniques, there has been an attempt to assess how much each neural input contributes to the reinnervation of the gracilis muscle and the subsequent smile. To address this question, authors have compared the time to gracilis movement with clenching (masseteric nerve) and the time-to-smile without teeth clenching (CFNG). Three groups have also previously used electromyography to evaluate the contribution of the CFNG to reinnervation, but the reported results are inconsistent due to difficulty with electromyography analysis.[13,17,19]

Biglioli et al in 2012 were the first to report on dual innervation of the gracilis in four patients using the CFNG as an end-to-side coaptation to the obturator nerve and masseteric nerve as an end-to-end coaptation to the obturator nerve.[15] The authors noted reinnervation by clenching on average 3.8 months postoperatively, and a similar time-to-gracilis reinnervation was reported by all authors, ranging from 3.2 to 5.1 months postoperatively, with almost 100% success.[13,15,17–19] This is consistent with the previously reported reinnervation time of the gracilis by masseteric nerve alone, and much shorter than the time required for CFNG reinnervation.[6,8–10,28,29,32,43,44]

Our own results, with the mean time-to-smile with clenching of 7.6 months and range of 3-12 months, exceed the numbers reported in the literature.[44] It is possible that this increased time is attributable to the disadvantage we placed on the masseteric nerve, prolonging time to reinnervation. A meta-analysis looking at masseteric nerve only transfer noted delayed recovery of 6.24 months, from 4.06 months in those with interposition graft.[44] However, it is also possible that this may instead be a result of our facial paralysis and reanimation clinic protocol. Typically, within the first year, we schedule follow-up visits at 1 month and 6 months postoperatively with variability by patient schedule. As a result, we may be missing the early reinnervation that is reported to occur approximately between 3 and 5 months. Of note, patient 5 had a small hematoma that required operative drainage and, thus, was more frequently followed up. Therefore, this patient had a 3-month follow-up visit, at which time the gracilis demonstrated evidence of reinnervation by the masseteric nerve.

To try to address the CFNG input to the gracilis muscle, previous studies have attempted to assess whether the patient is able to smile effortlessly (without clenching their teeth to activate the masseteric nerve). Bianchi et al, Biglioli et al and Sforza et al, and Uehara and Shimizu assessed spontaneous smile by counseling the patients to smile without clenching their teeth and by using emotional stimuli (ie, watching a funny video) to trigger a spontaneous smile.[14,15,18,19] There was a high level of effortless smiles reported in these studies, with only two failures noted in the Sforza et al series of 13 patients.[18] The two articles that discussed time-to-spontaneous smile used a single stage procedure and noted an average time of 7.2 months[15] and 9.5 months.[19] In our two-stage method, all eight patients (100%) achieved an effortless smile. The localizing time of attainment can be estimated at between 5 and 7 months. As seen in Table 2, second follow-up visits commonly occurred in the time frame of 6 to 9 months. All patients but one who were seen at 7 months or later had developed a smile without clenching their teeth. Only three patients had been seen between 1 and 6 months without evidence of this smile (additional 3 to 4-months follow-up visits). All three of these patients had achieved the smile without clenching by their next visits at 6 or 7 months. The limitation of spaced follow-up restricts our estimate of time to effortless smile attainment to be a range of around 5–7 months. We are limited in the statement due to one patient not having achieved an effortless smile at 8 months. Moreover, two patients had second follow-up visits at more than 10 months; however, they both had achieved a smile without clenching at that time. Interestingly, one patient self-reported a spontaneous smile at 4.5 months, which was 2.5 months before their scheduled follow-up of 7 months, showing our range may be an overestimate for our patients. We see here that the likely window of spontaneous achievement is between 5 and 7 months, with the most frequently reported attainment being at 7 months follow-up. In conjunction, our estimated range of attainment is consistent with the reported findings of Biglioli et al and Uehara et al.[15,19]

Of note, there have been previous claims of spontaneity in the masseteric nerve transfer alone, especially in children.[7,12] In contrast, Chuang et al described a series of 22 patients with masseteric nerve innervated gracilis, and none of the patients achieved a spontaneous smile using a “tickle test” (average follow-up of more than 2 years).[9] It is therefore difficult to know whether the patients who were reported to have a spontaneous smile or smile without clenching achieved this based on the additional CFNG or cortical plasticity,[45,46] a limitation that is difficult to discern in human case studies.

Our study shared common limitations with other authors, including a low volume of cases and variable patient etiology of paralysis. Our patients also had many ancillary procedures, including botulinum toxin injections, selective neurectomy, and symmetry procedures such as rhytidectomy, browlift, and canthopexy, which might influence our outcome measurements. The timing of clinic follow-up postsurgically may have also overestimated the time-to-smile, as mentioned previously.

CONCLUSIONS

Our new novel method of a dual-innervated free gracilis muscle transfer for facial reanimation represents a viable technique that does not risk denervation of the gracilis muscle and results in a strong symmetric smile with and without teeth. We hypothesize that using an extra nerve graft between the masseteric and obturator nerves places the masseteric nerve at a disadvantage and allows the CFNG to provide input to the reinnervated gracilis muscle without being taken over by the masseteric nerve input.

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DISCLOSURE

The authors have no financial interest to declare in relation to the content of this article.

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This study conforms to the Mayo institutional review board.

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