Comparative Study of 2 Different Innervation Techniques in Facial Reanimation

Cross-face Nerve Graft–Innervated Versus Double-Innervated Free Gracilis Muscle Transfer

Min Ji Kim, MD, PhD, Hyung Bae Kim, MD,* Woo Shik Jeong, MD,* Jong Woo Choi, MD, PhD,* Young Kug Kim, MD, PhD,† and Tae Suk Oh, MD, PhD**

Abstract: Recently, 1-stage double innervation with the masseter nerve and the cross-face nerve graft (CFNG) has gained popularity owing to its outcomes of powerful and synchronous muscle contraction. In this study, we compared CFNG- and double-innervated free gracilis muscle transfer (FGMT) for facial palsy reconstruction.

A total of 49 patients with facial palsy who underwent facial reanimation surgery from August 2013 to January 2017 were enrolled. The CFNG group (18 patients) underwent 2-stage CFNG innervation, whereas the double-innervated FGMT group (31 patients) underwent dual coaptation with end-to-end masseter nerve and end-to-side CFNG. The FACEgram software was used for evaluating smile excursion, symmetry index, spontaneous smile occurrence, Terzis' score including palsy pathogenesis, and clinical progress.

In the CFNG group, the smile excursion at rest increased ($P = 0.000$); however, there was increased smile excursion both at rest and during smiling in the double-innervated FMGT group (rest $P = 0.002$, smile $P = 0.028$). Improvement of the symmetry index was observed only in the FMGT group (rest $P = 0.001$, smile $P = 0.000$). There was no significant difference in Terzis' scores. The average time to the first visible muscle contracture was statistically significantly shorter in the double-innervated FGMT group ($P = 0.035$). With respect to spontaneous smile achievement, the double-innervated FGMT group (25.8%) showed a satisfactory outcome.

Cross-face nerve graft-innervated FGMT improved only smile excursion at rest, whereas double-innervated FGMT provided improvement in both the resting and smiling postures. Furthermore, the double-innervated FGMT group showed a higher symmetry index. However, the 2 operations did not show a significant difference in functional aspects.

Key Words: facial palsy, functional gracilis muscle transfer, facial reanimation, double innervation

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For decades, free functional muscle transfer (FFMT) has been considered the criterion standard treatment for long-standing facial paralysis. In FFMT, there are many options for a neurotizer.[1–3] One is using the cross-face nerve graft (CFNG) to the contralateral side, and another is direct coaptation to the contralateral side. However, nowadays, direct neurotization to the masseter nerve has gained popularity owing to its outcomes of powerful muscle contraction and rapid initial movement.

The benefit of using CFNG as a neurotizer in FFMT is that it can provide synchronous and spontaneous activity of the innervated muscle.[4–6] Conversely, using a nerve graft to increase the length of the donor nerve has several drawbacks, including lack of predictability and consistency in the degree of muscle contraction and, therefore, smile excursion.[7] To overcome this limitation, 1-stage FFMT for smile reanimation has gained popularity by innervating with a muscle with a long nerve or performing additional maneuvers to increase the length of the nerve.[8–10] Among several other donor nerves used as neurotizers for FFMT, the masseter nerve is a useful neurotizer for established facial palsy reconstruction. However, there are some limitations concerning spontaneous smile generation. Double innervation with the masseter nerve and the CFNG has been used for reanimation to overcome this drawback.

Double-innervated FFMT was first described by Biglioli et al,[3] who reported achieving a significant decrease of postoperative facial asymmetry. Double innervation with end-to-end coaptation of the

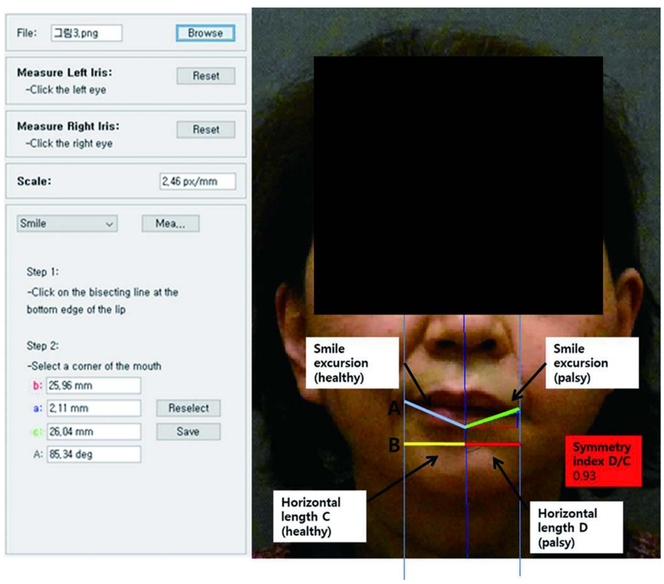

FIGURE 1. Objective outcome assessment of patients by using FACEgram. A line is the distance from the midline of the lower lip to the oral commissure. B line is the perpendicular distance from the midline of the lower lip to the oral commissure. Note that the oral commissure excursion is the A line. The symmetry index is defined as affected-side B line divided by healthy-side B line. All measurements were evaluated both in the resting and smiling postures.

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From the *Department of Plastic and Reconstructive Surgery, and †Department of Anesthesia and Pain Medicine, Asan Medical Center, University of Ulsan College of Medicine, Seoul, Korea.
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Reprints: Tae Suk Oh, MD, PhD, Department of Plastic and Reconstructive Surgery, University of Ulsan College of Medicine, Asan Medical Center, 88 Olympic-ro 43-gil, Songpa-gu, Seoul 05505, Korea. E-mail: tasuko@amc.seoul.kr.
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TABLE 1. Terzis' Functional and Aesthetic Grading System

Grade	Description	Result
1	Deformity, no contraction	Poor
2	No symmetry, minimal contraction	Fair
3	Moderate symmetry and contraction	Moderate
4	Symmetry, nearly full contraction	Good
5	Symmetrical smile with full contraction	Excellent

masseter nerve and end-to-side coaptation of the CFNG is hypothesized to provide enough force for smile movements and spontaneous movements elicited by emotional triggers.

To our knowledge, this is the first study to compare CFNG-innervated and double-innervated free gracilis muscle transfer (FGMT) in facial palsy reconstruction. In this study, we quantitatively evaluated the functional improvements after CFNG-innervated and double-innervated FGMT in facial palsy reconstruction and compared the results of the 2 surgeries.

PATIENTS AND METHODS

A retrospective analysis was performed on patients who presented to our hospital from August 2013 to January 2017. A total of 49 patients with unilateral facial paralysis who underwent reanimation surgery at our institution were included the study. All operations were performed by the senior author (T.S.O.). All patients were evaluated for demographic characteristics, causes of facial paralysis, time interval between surgical stages and initial movement, and evolution period. For all patients, preoperative and postoperative standard photographs, videos, and data on the existence of spontaneous smile at postoperative 1 year were collected. The photographs were analyzed using the Facial Assessment by Computer Evaluation (FACEgram) software, which provides objective quantitative analysis. We evaluated smile excursion and symmetry index preoperatively and postoperatively.[11,12]

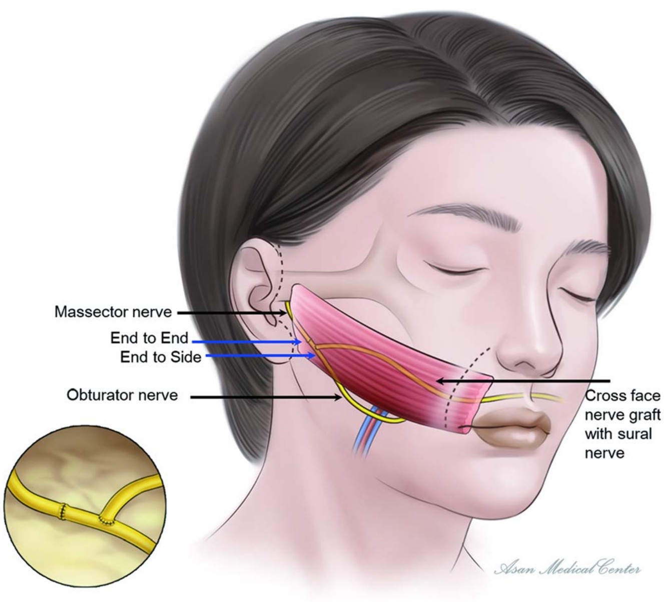

FIGURE 2. Scheme of surgery. One-stage surgery with double-innervated free functional muscle transfer innervated by the masseter nerve (end-to-end anastomosis) and the CFNG (end-to-side anastomosis).

We defined smile excursion as the distance from the midline of the lower lip to the oral commissure. The symmetry index was defined as the affected side divided by the healthy side in terms of the perpendicular distance from the midline of the lower lip to the oral commissure. Cases in which the symmetry index was close to 1 were considered to have more symmetry (Fig. 1). All measurements were evaluated both at rest and during smiling. The preoperative and postoperative videos of each patient were reviewed by an investigator, and evaluated using Terzis' functional and aesthetic grading scale with scores from 0 to 4 (Table 1). On the basis of all these measurements, we evaluated whether spontaneous smile was achieved in each patient. We defined spontaneous smile as an oral commissure excursion of greater than 3 mm in the smiling posture, a smile excursion difference between the resting and smiling postures of greater than 2 mm, and a postoperative Terzis' score of more than 3. This study was approved by the institutional review board of our institution.

Surgical Techniques

Two-Stage Surgery With Facial Reanimation With a CFNG and an FFMT

At the first stage, sural nerve was harvested in the lower leg. The grafted sural nerve was anastomosed to the buccal branch on the healthy

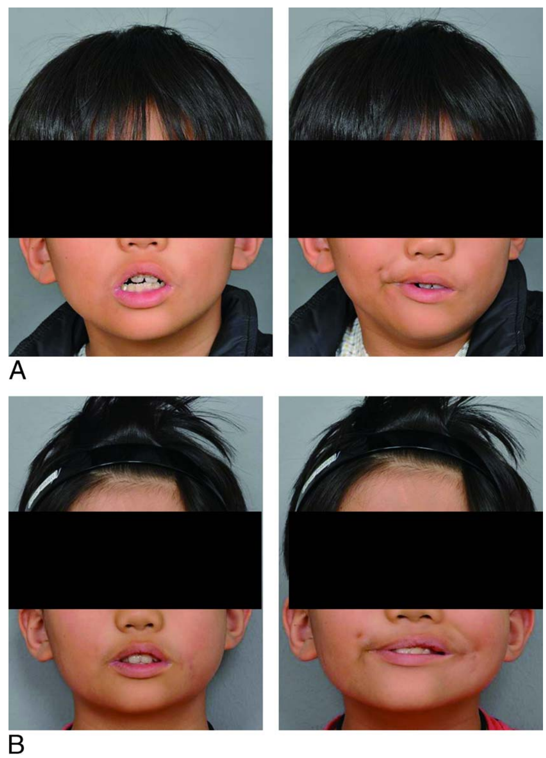

FIGURE 3. A 10-year-old boy who presented with bilateral facial palsy with Moebius syndrome. His facial asymmetry was more severe in the right side than in the left side. Eye closure is not complete on both sides. Because he has incomplete palate at birth, he underwent palatoplasty at our institution at age 1 year. He underwent CFNG transfer as a first stage at age 9 years. Then, 10 months later, he underwent free functional gracilis muscle transfer as a second stage. After 4.8 months from the last operation, he presented with a first facial expression (muscle movement around the lip). A, Preoperative (left) rest posture and (right) smile posture. B, Postoperative 2 years (left) rest posture and (right) smile posture.

side, which was located through a cheek incision. A subcutaneous tunnel was made through the upper lip and healthy side of the cheek. The sural nerve was placed under the tunnel. The mean period between CFNG innervation and FFMT was 10.3 months.

At the second stage of free tissue transfer, a facelift-type incision was made on the paralyzed face. Dissection was performed with a dual plane–like facelift. The harvested gracilis muscle flap including the artery, vein, and obturator nerve was inserted in the subsuperficial musculoaponeurotic system space. The distal part of the flap was anchored to the modiolus. The pedicle was anastomosed to the facial vessels.

Another incision was made at the upper gingiva of the paralyzed side. Neurorrhaphy of the sural nerve and the internal obturator nerve was done (Fig. 2).

All patients were educated about the use of an external electrical muscle stimulator for rehabilitation of the transferred muscle 2 weeks after the surgery (Fig. 3 and Video, Supplemental Digital Contents 1, http://links.lww.com/SAP/A389 and 2, http://links.lww.com/SAP/A390).

One-Stage Surgery With Double-Innervated FFMT

A facelift-type incision was made on the paralyzed face. Dissection was performed with a dual plane–like facelift. The masseter nerve was found in the masseter muscle below the zygomatic arch.

A gracilis muscle flap with an average size of 10 × 5 cm was harvested at the medial thigh, using standard methods. The gracilis muscle was dissected, and flap vessels and the obturator nerve were dissected with sufficient pedicle length. The gracilis muscle was cut using a reloadable linear cutter with a safety lockout device (Ethicon Endo-surgery, LLC, a Johnson & Johnson company, Germany), which is a tool usually used to cut the intestine. Vascular anastomosis was performed in the usual manner. All donor vessels were facial vessels. End-to-end neurorrhaphy of the masseter nerve and obturator nerve was done under a microscope.

On the healthy side of the face, incision at Zuker's point was performed and the buccal branch of the facial nerve was located with a nerve stimulator. By using the nerve stimulator, we checked the movement of the zygomatic major muscle. At the same time, a second team harvested the sural nerve. The mean length of the sural nerve graft was 18 cm. The sural nerve graft was coapted with the buccal branch of the facial nerve in an end-to-end manner and also coapted with the masseter nerve in an end-to-side manner (Fig. 2).

Finally, the gracilis muscle was fixed at the periosteum of the lateral zygomatic bone and the medial side of the modiolus.

All patients were educated about the use of the external electrical muscle stimulator for rehabilitation of the transferred muscle 2 weeks after the surgery (Fig. 4 and Video, Supplemental Digital Contents 3, http://links.lww.com/SAP/A391 and 4, http://links.lww.com/SAP/A392).

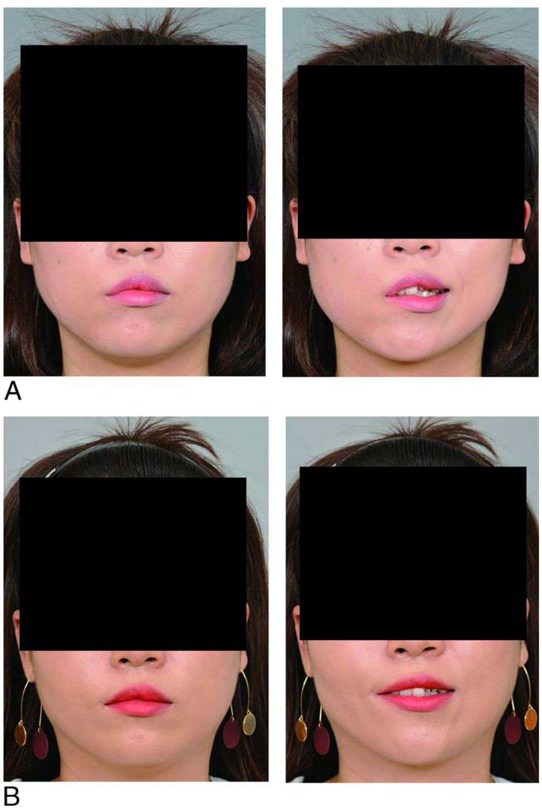

FIGURE 4. A 25-year-old woman who presented with complete right-sided facial paralysis of unknown origin. The denervation time was 22 years. She underwent double-innervated free functional muscle transfer. A, Preoperative (left) rest posture and (right) smile posture. B, Postoperative 2 years (left) rest posture and (right) smile posture.

TABLE 2. Patient and Operative Characteristics

	CFNG Innervated	Double Innervated FGMT
Age, average, y	32.77	46.55
n (men/women)	18 (11/7)	31 (16/17)
Duration of paralysis (range), y	8.91 (1–30)	9.07 (1–62)
Follow-up time (range), mo	34.73 (11–58)	20.88 (8.9–61)

Statistical Analysis

Statistical analysis was performed with SPSS software (version 21; IBM Corporation, Armonk, NY). A paired 2-tailed *t* test was used to compare the preoperative and postoperative smile excursion distances and angles in the affected and unaffected sides. Symmetry scores were obtained by calculating the ratio between the affected and unaffected sides, and the preoperative and postoperative scores at rest and during smiling were compared using the paired 2-tailed *t* test. Preoperative and postoperative Terzis' scores were also evaluated with the paired 2-tailed *t* test. Differences between excursion at rest and excursion during smiling were evaluated and used to compare CFNG-innervated and double-innervated FGMT by using the Mann-Whitney test. Differences in Terzis' scores were also evaluated with the Mann-Whitney test.

TABLE 3. Pathogenesis of Facial Palsy

	CFNG Innervated (n = 18)	Double-Innervated FGMT (n = 31)
Complete palsy	13 (72.22)	27 (87.09)
Incomplete palsy	5 (22.22)	4 (12.90)
Causes of facial palsy		
Tumor resection	8 (44.44)	14 (45.16)
Bell's palsy	5 (27.77)	5 (16.13)
Congenital	3 (16.66)	3 (9.68)
Trauma	1 (5.55)	4 (12.90)
Otitis media	1 (5.55)	5 (15.12)

Data are number of patients (%).

RESULTS

During the study period, a total of 49 patients underwent facial palsy reconstruction. Among them, 18 patients underwent 2-stage surgery with facial reanimation with a CFNG and an FGMT, and 31 patients underwent 1-stage surgery with double-innervated FGMT. The average time between facial palsy onset and reconstruction was 8.91 years in the CFNG group and 9.07 years in the double-innervated FGMT group. The mean follow-up period was 34.73 months (range, 11–58 months) and 20.88 months (range, 8.9–61 months), respectively (Table 2). All patients had unilateral facial palsy, with 72.22% of the CFNG group and 87.09% of the double-innervated FGMT group showing complete palsy. With respect to the cause of facial palsy, tumor resection and Bell's palsy were the most common (Table 3).

Through a quantitative analysis with FACEgram, we compared the smile excursion and symmetry index at rest and during smiling in both groups. In the CFNG group, there was a statistically significant increase in oral commissure excursion at rest (preoperative, 22.63 ± 5.70; postoperative, 27.62 ± 5.86; $P = 0.000$) (Fig. 5). In the double-innervated FGMT group, there were statistically significant increases in oral commissure excursion in both the resting and smiling postures (rest preoperative, 23.56 ± 5.25; rest postoperative, 27.88 ± 6.70; $P = 0.002$; smile preoperative, 25.44 ± 6.38; smile postoperative, 29.54 ± 6.52; $P = 0.028$) (Fig. 6). With respect to the symmetry index, in the CFNG group, there was no statistically significant difference between the preoperative and postoperative values at rest and during smiling (Fig. 5). However, in the double-innervated FGMT group, there were statistically significant improvements in the symmetry index in both resting and smiling postures (rest preoperative, 0.85 ± 0.36; rest postoperative, 0.96 ± 0.34; $P = 0.001$; smile preoperative, 0.75 ± 0.34; smile postoperative, 0.89 ± 0.29; $P = 0.000$) (Fig. 6).

In the postoperative outcome assessment with respect to the nerve used, we compared each measurement of the affected and healthy sides. A smaller gap between the affected and healthy sides was considered to indicate effective restoration of facial animation. When we compared the absolute differences in smile excursion, there was a statistically significant difference in the resting posture between the 2 groups. The double-innervated FGMT group showed a smaller gap with the healthy side in smile excursion during resting (CFNG, 11.96 ± 10.20; double-innervated FGMT, 5.95 ± 5.18; $P = 0.031$). With respect to the smiling posture, the

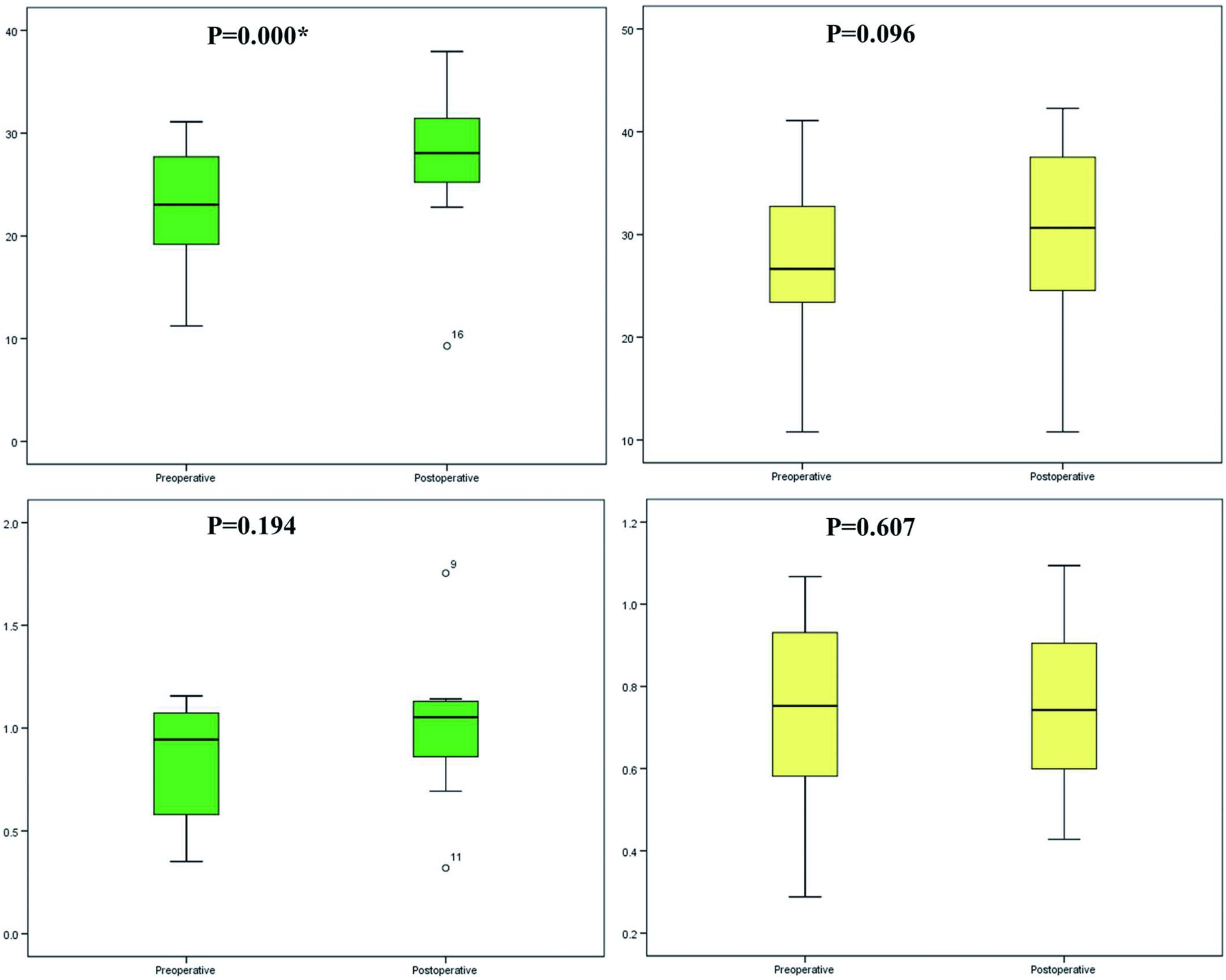

FIGURE 5. Objective facial assessment of the CFNG. A, Smile excursion of the affected side (rest). B, Smile excursion of the affected side (smile). C, Symmetry index at rest (affected/healthy). D, Symmetry index during smiling (affected/healthy).

double-innervated group also showed a smaller gap; however, the difference was not significant (CFNG, 13.75 ± 10.89; double-innervated FGMT, 10.98 ± 9.99; P = 0.089). Concerning the symmetry index, a statistically significant difference was observed in the smiling posture. The double-innervated group showed a smaller gap with the healthy side (CFNG, 0.09 ± 0.07; double-innervated FGMT, 0.27 ± 0.28; P = 0.011) (Fig. 7).

In the evaluation of Terzis' functional and aesthetic grading scores, there were no significant differences between the 2 groups. However, there was an average 1.09 score improvement in the CFNG group and 2.22 score improvement in the double-innervated FGMT group, with the latter group showing a higher improvement (Table 4). The average time to the first visible muscle contracture was statistically significantly shorter in the double-innervated FGMT group (CFNG, 9.38 ± 5.08 months; double-innervated FGMT, 2.88 ± 5.55 months; P = 0.035) (Table 5). With respect to spontaneous smile achievement, 4 patients (22.22%) in the CFNG group and 8 patients (25.8%) in the double-innervated FGMT group showed a satisfactory outcome (Fig. 8 and Video, Supplemental Digital Contents 5–8, http://links.lww.com/SAP/A393, http://links.lww.com/SAP/A394, http://links.lww.com/SAP/A395, http://links.lww.com/SAP/A396).

DISCUSSION

Traditionally, and most commonly, reconstruction of unilateral facial palsy is performed in 2 stages, consisting initially of a CFNG transfer followed by free muscle transfer as the second stage 6 to 12 months later. Despite the good and fair results obtained with 2-stage surgery, several negative outcomes were noted. One is the major length of the flap nerve, which is known to be an obstacle to nerve regeneration. Another is axonal loss resulting from the 2 anastomoses created in 2-stage procedures, which reduce the in-growth of regenerated axons. This may result in a long denervation time that leads to muscle atrophy.

Another good option for the neurotizer in free muscle transfer is the masseter nerve, which can lead to an almost total functional recovery of flap contraction.[4,5] Masseter-to-facial nerve transfer is already

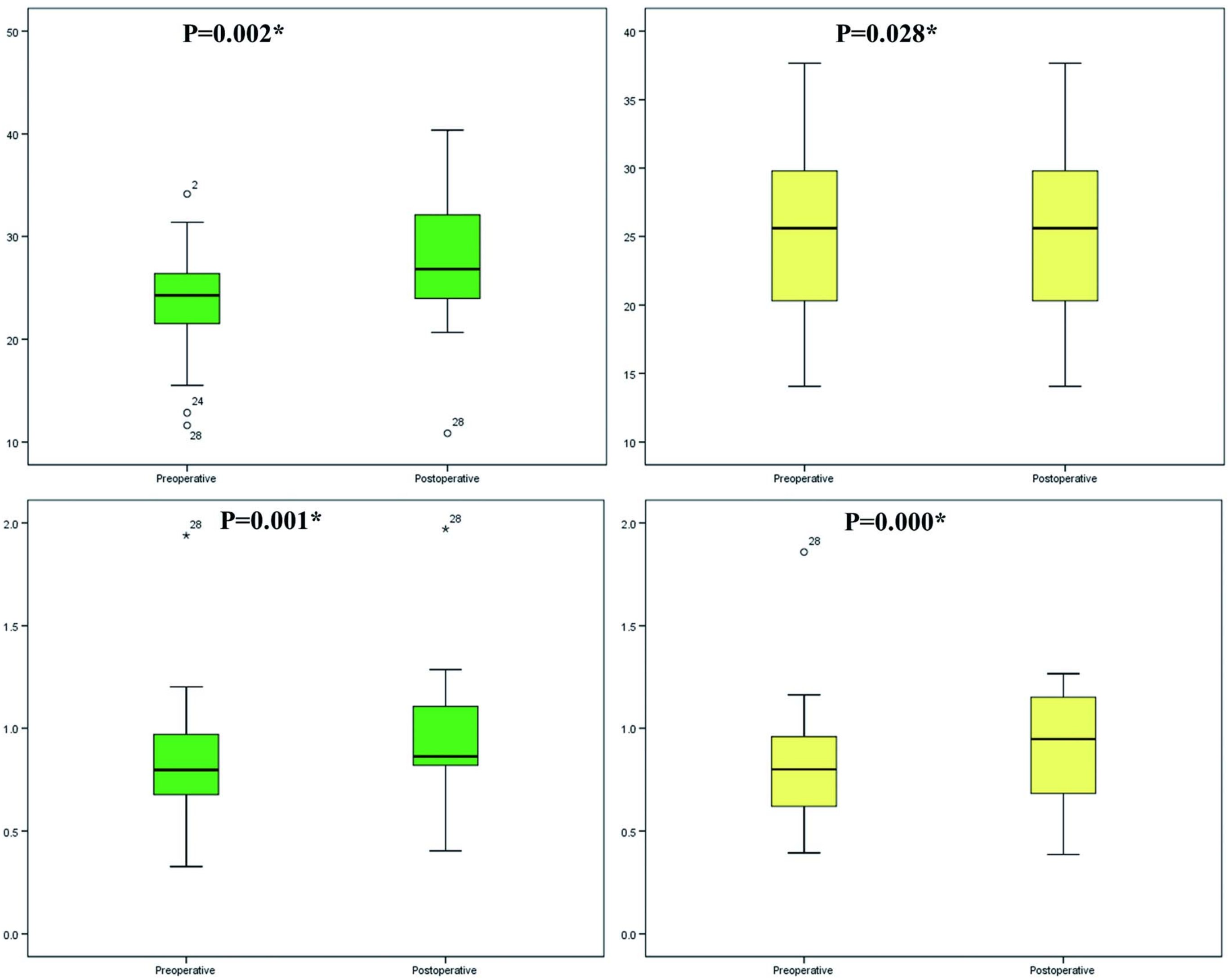

FIGURE 6. Objective facial assessment of double-innervated free functional muscle transfer. A, Smile excursion of the affected side (rest). B, Smile excursion of the affected side (smile). C, Symmetry index at rest (affected/healthy). D, Symmetry index during smiling (affected/healthy).

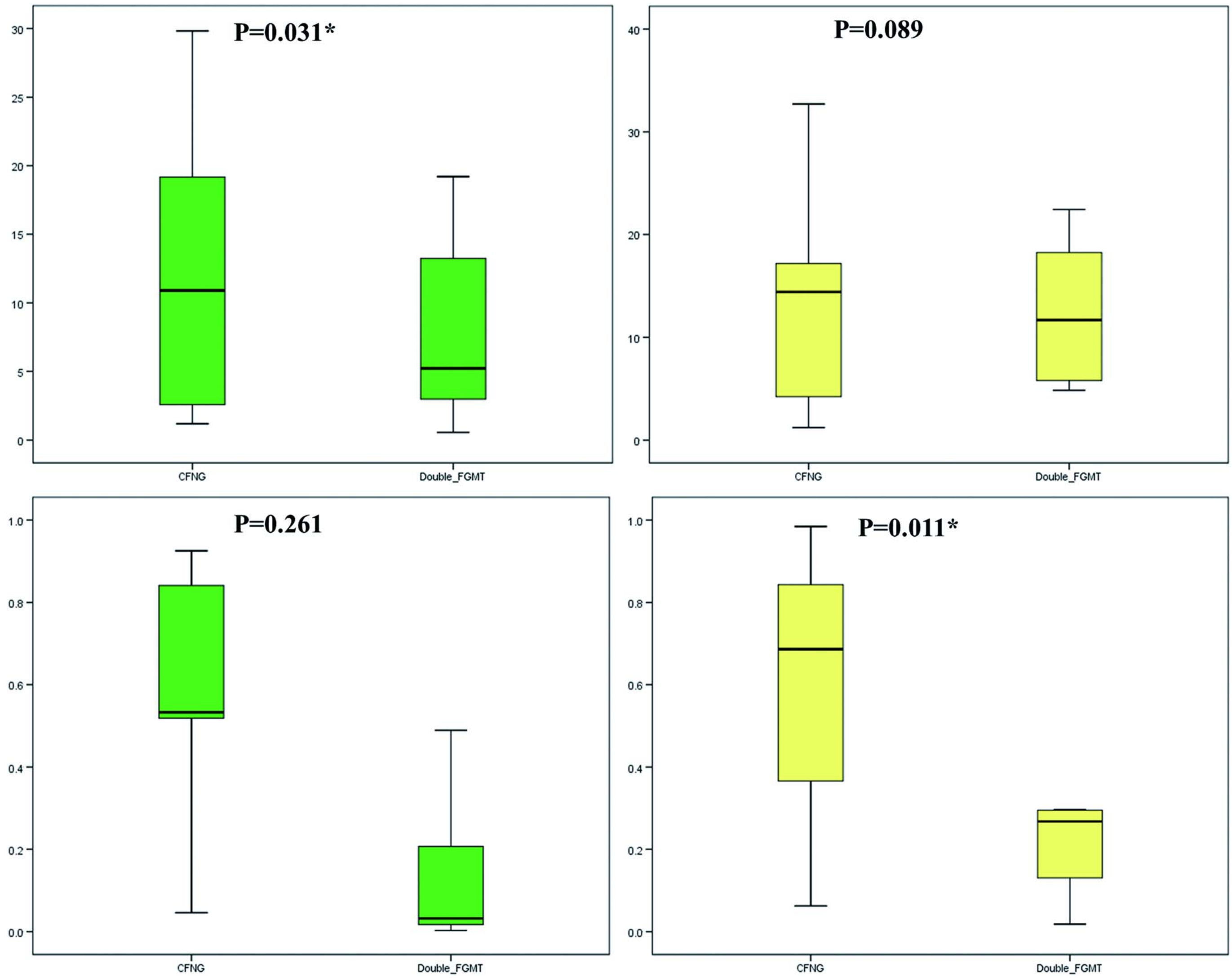

FIGURE 7. Postoperative outcome assessment with respect to the nerve used; Δ difference is the absolute difference between affected and healthy sides. A, Smile excursion difference at rest. B, Smile excursion difference during smiling. C, Symmetry index difference at rest. D, Symmetry index difference during smiling. Double_FGMT, double-innervated free functional muscle transfer.

used in the reanimation of the midface and perioral region in a select group of patients with facial paralysis, and this has been proven to be an effective method.[13] Despite its advantages of strong motor impulse and low morbidity, the masseter nerve has significant disadvantages including difficulty in spontaneous smile generation or the need to use jaw movements. However, some reports have assessed the recovery of spontaneous smiling ability. Manktelow et al[5] reported that spontaneous smiling, the ability to smile without premeditation, occurred routinely in 59% and occasionally in 29% of patients with free muscle transfer innervated by the masseter motor nerve. They explained this result based on the cerebral adaptation theory.

Watanabe et al[14] first reported the use of 1-stage free muscle transfer with dual innervation for the reanimation of facial paralysis. This technique improved the latissimus dorsi muscle contraction with achievement of spontaneous smile and voluntary smile on both sides. Yamamoto et al[15] introduced the concept of neural supercharging in cases of paralysis. With the construction of a facial-hypoglossal network system by using the end-to-side neurorrhaphy technique, both facial and hypoglossal motor signals were provided to the compromised facial mimetic muscles.

We used 1-stage gracilis functional flap transfer with double innervation: an end-to-end masseter-to-gracilis nerve coaptation and end-to-side nerve coaptation of the contralateral facial nerve graft to the gracilis nerve, as described by Biglioli et al.[3] A potential advantage of this neurotization technique is that end-to-side neurorrhaphy without disruption of the inner fibers avoids wasting of any regenerated axons from the masseter nerve. Moreover, the masseter nerve input remains guaranteed, even in cases of failure of the CFNG nerve input. Spontaneous smiling can occur because axons passing through the CFNG also trigger the activation of the masseter nerve fibers.[10]

TABLE 4. Comparison of Terzis' Grading System Scores Between Groups

	CFNG	Double Innervation	*P*
Preoperative	2.12 ± 1.09	1.41 ± 0.51	0.066
Postoperative	3.21 ± 0.97	3.63 ± 0.50	0.166

TABLE 5. Comparison of Time to the First Visible Muscle Contracture Between Groups

	CFNG	Double Innervation	*P*
Postoperative period, d	281.40 ± 152.02	86.14 ± 167.10	0.018*
Postoperative period, mo	9.38 ± 5.08	2.88 ± 5.55	0.035*

*Statistically significant.

Single-stage reanimations with the contralateral facial nerve achieve initial functional recovery within 7 to 12 months.[8,16,17] During the recovery time, muscle fibers can be irreversibly atrophied. This double-innervation technique can provide more rapid innervation and thus may reduce muscle atrophy. Moreover, minimization of muscle atrophy can enhance the functional results.

We used the FACEgram software to evaluate facial function. With this method, we found a statistically significant functional benefit of FGMT in both surgical techniques. In the CFNG-only group, a statistically significant increase in excursion at rest was seen after muscle transfer. In the double-innervated group, there were statistically significant increases in excursion both at rest and during smiling, as well as improvements of the symmetry index in both postures. Because this was a retrospective study, we enrolled the patients consecutively. Each group did not consecutively select their operative options; however, selection bias from the senior operator's preference could not be excluded with respect to the latest patients enrolled. With accumulated experience in double-innervated FGMT, which provides faster recovery with satisfactory results, there was some interference of the surgeon, which was reflected in the different number of patients between groups.

Terzis' functional grading partly reflects smile spontaneity. In this study, there was a significant difference in Terzis' scores in the double-innervated group. A comprehensive integration of measurements and dynamic evaluation enabled us to evaluate whether a patient had spontaneous smile or not. We observed more patients with spontaneous smile and a shorter time to first visible muscle contracture in the double-innervated group. In addition, interestingly, we observed that the power of masseter muscle contraction weakened upon CFNG innervation. This probably proves the theory that shifting of the motor center occurs after FGMT with the masseter nerve (cortical plasticity).[5] When nerve innervation was started in the CFNG group, several patients reported feeling the innervation of the CFNG and that they could control it.

However, a limitation of the study is the short follow-up period of the double-innervation group. Therefore, we did not sufficiently observe the outcome of the innervation of the CFNG in the double-innervation group. A longer follow-up of these patients is needed to observe the ability of spontaneous smiling.

Although double-innervated FGMT did not show definitively superior results in terms of smile excursion and symmetry index over those of CFNG-innervated FGMT, it enabled 1-stage surgery and a short interval between surgery and recovery of muscle contraction, which may be clinically meaningful. Furthermore, another meaningful result was that the aesthetic outcome was comparable with that of the CFNG group. We could conclude that double-innervated FGMT provided more symmetry correction than CFNG alone. This does not mean that double-innervated FGMT is always superior to CFNG. However, this study could serve as a basis for the comparison of fundamental differences between these 2 techniques.

In FFMT with double innervation, the issues of which nerve are the main neurotizer of the transferred muscle and the timing of reinnervation of the 2 nerves are controversial. Biglioli et al[3] recorded the motor potentials during electrical stimulation of the contralateral facial nerve by using the coaxial needle inserted to the transferred muscle in patients with double-innervated FGMT and observed the excitability of the grafted facial nerve fibers. However, they reported that they failed to check the masseter muscle because of artifacts. Further studies with electromyography, nerve conduction velocity evaluation, or functional magnetic resonance imaging will be needed to identify which nerve is the main neurotizer. There was a clinically observable reduction of excursion with mastication at the timing of innervation of the CFNG being transmitted to muscle in patients with double-innervated FGMT. This might be another phenomenon that explains the cerebral adaptation theory, and it is likely that the smile center of the cerebral cortex is shifted from the facial movement center to the jaw muscle center.

CONCLUSIONS

Cross-face nerve graft-innervated FGMT improved only smile excursion at rest, whereas double-innervated FGMT provided improvements both in the resting and smiling postures. In addition, double-innervated FGMT provided a higher symmetry index. However, concerning which nerve was used, the difference from the healthy side postoperatively is related to the smile symmetry index, not the smile excursion. Therefore, we recommend double-innervated FGMT for specific situations in which asymmetry correction is the surgical goal, as this technique could produce a strong, potentially spontaneous smile in a short time after surgery.

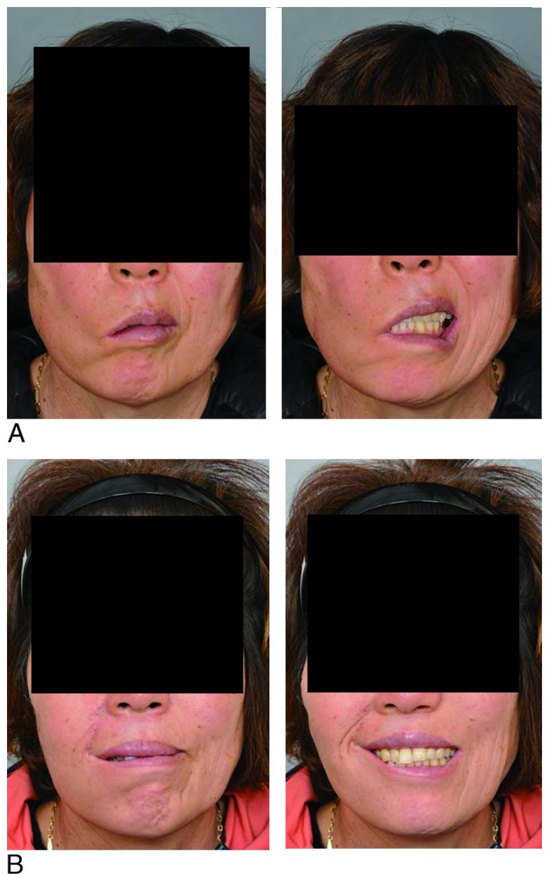

FIGURE 8. A 57-year-old woman who presented with complete right-sided facial paralysis after excision of parotid cancer. The denervation time was 23 years. She underwent double-innervated free functional muscle transfer. A, Preoperative (left) rest posture and (right) smile posture. B, Postoperative 2 years (left) rest posture and (right) smile posture.

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