Using the "Sugarcane Chewing" Concept as the Directionality of Motor Neurotizer Selection for Facial Paralysis Reconstruction: Chang Gung Experiences

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Background: Facial paralysis and postparalysis facial synkinesis both cause severe functional and aesthetic deficits. Functioning free muscle transplantation is the authors' preferred method for reconstructing both deformities.

Methods: From 1985 to 2017, a total of 392 patients underwent 403 gracilis functioning free muscle transplantations for facial reanimation. Different motor neurotizers were used: cross-face nerve graft (74 percent), spinal accessory nerve (17 percent), and masseter nerve (8 percent). Smile excursion score, cortical adaptation stage, patient questionnaire, Hadlock lip excursion, and the Terzis evaluation systems were used to assess outcomes.

Results: For smile excursion score, the spinal accessory and masseter nerve groups showed higher scores than the cross-face nerve graft group in the first 2 years, but no difference by 3-year follow-up. For cortical adaptation stage, nearly all cross-face nerve graft patients achieved stage IV or V spontaneity, the spinal accessory nerve group achieved at least stage III (independent) movement, but individuals in the masseter nerve group achieved only stage III or less. The cross-face nerve graft group also achieved higher scores according to the Hadlock system and the Terzis evaluation system compared with the other two groups.

Conclusions: The concept of "sugarcane chewing" where the sweetness is the least at the tail but the most at the head can be simply applied for surgeons and patients in weighing the benefits and drawbacks during the motor neurotizer selection. Cross-face nerve graft–innervated gracilis is analogous to chewing sugarcane from tail to head; despite lower outcome measures earlier, it yields the highest scores at 3 years postoperatively. Masseter-innervated gracilis is akin to chewing sugarcane from head to tail, with greater outcome scores initially but little improvement at longer follow-up. Spinal accessory–innervated gracilis results fall in between these two groups. (*Plast. Reconstr. Surg.* 144: 252e, 2019.)

CLINICAL QUESTION/LEVEL OF EVIDENCE: Therapeutic, IV.

Two major dysfunctions of the facial nerve, true facial palsy (incomplete or complete) and postparalysis facial synkinesis, are devastating to the afflicted patient's function and quality of life. For chronic facial palsy (>1 year) reconstruction, debate persists between local muscle transfers[1–3] and functioning free muscle transplantation[4–10] (Table 1). With advanced microsurgery, functioning free muscle transplantation is now becoming the mainstream option for long-standing facial paralysis reconstruction.

For postparalysis facial synkinesis, past treatments are still inadequate. The current treatment proposed by the author (D.C.C.C.)[11] has become a standard strategy at our center. For mild postparalysis facial synkinesis (type I) with good smile quality and mild synkinesis, conservative treatment is preferred. For severe types (type III with

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Received for publication March 27, 2018; accepted December 18, 2018.
See Appendix for details of meeting presentations.

DOI: 10.1097/PRS.0000000000005871

Disclosure: *None of the authors has financial interests to declare in relation to the content of this article.*

Table 1. Comparison between Local and Distal Muscle Transfer

	Local Muscle Transfer	Functioning Free Muscle Transplantation
Example	Labbe procedure; Viterbo procedure; Rubin procedure; masseter muscle transfer	Muscle: gracilis, pectoralis minor, latissimus dorsi, serratus anterior, rectus abdominis, and others Nerve: facial nerve branch (ipsilateral, contralateral), spinal accessory nerve, masseter nerve, and others
Learning curve	Technique demanding	Technique demanding; neurovascular anastomosis technique
Advantages	One stage; shorter operative time (<4 hr); short rehabilitation time; quick result (<1 yr)	Little face scar; independent smiling; potential spontaneous smiling; with or without involvement of movement; predictable result
Disadvantages	NLF scar and deep fold; not completely independent; not full spontaneous smiling; with or without involvement of smiling; uncertain results	Might be two-stage procedure; long operation time (6–10 hr); long rehabilitation time (1–3 yr)

NLF, nasolabial fold.

unacceptable smile and severe synkinesis, and most type II with acceptable smile but severe synkinesis), extensive myectomy and neurectomy of the synkinetic muscles and nerves followed by functioning free muscle transplantation in a one- or two-stage procedure is the treatment of choice.

At least 10 muscles have been described for functioning free muscle transplantation for facial smile reanimation in the literature.[12,13] The gracilis, however, remains the muscle preferred by most reconstructive surgeons. Limited nerves were used for the motor neurotizer of the functioning free muscle transplant in the literature also. The cross-face nerve graft,[4–11] the spinal accessory nerve,[14] and the masseter nerve[15] have been the most popular at our center. The purpose of this article was to investigate and compare the long-term outcomes of these three groups of patients at a single center.

PATIENTS AND METHODS

This study was approved by the Chang Gung Medical Foundation Institutional Review Board (no. 201800629B0). Between 1985 and 2017 (33-year period), 392 patients were enrolled: 321 with true facial paralysis (82 percent) and 71 with postparalysis facial synkinesis (18 percent). Eight patients with bilateral Möbius syndrome treated by bilateral gracilis transplantation, and three patients with failed primary gracilis transfer treated by a second gracilis transfer were included. Patients with functioning free muscle transplantation innervated by either the ipsilateral facial nerve (eight patients) or the contralateral facial nerve as a one-stage procedure (four patients), or incomplete history or follow-up (10 patients), were excluded. In total, 403 functioning free muscle transplantations were performed by the senior surgeon (D.C.C.C.). For cause, nearly half (47 percent) were after tumor resection, one-third (29 percent) were viral, and one-fifth were caused by trauma or were congenital (Table 2).

Two hundred ninety-nine functioning free muscle transplantations in 299 patients [299 of 403 (74 percent)] were innervated by cross-face nerve grafts, 68 functioning free muscle transplantations in 60 patients were innervated by the spinal accessory nerve (17 percent), and 33 functioning free muscle transplantation in 30 patients were innervated by the masseter nerve (8 percent). Ninety-eight percent of functioning free muscle transplantations were gracilis. Mean duration of palsy before functioning free muscle transplantation was 16.8 years (range, 0.5 to 52 years) in the cross-face nerve graft group, 10.0 years (range, 0.5 to 52 years) in the spinal accessory nerve group, and 9.9 years (range, 1 to 27 years) in the masseter nerve group (Table 2). Eight patients had bilateral Möbius syndrome: six underwent bilateral spinal accessory innervation and two underwent bilateral masseter innervation of the gracilis muscle.

Classic Two-Stage Cross-Face Nerve Graft Innervation of the Gracilis

Stage 1: Short Cross-Face Nerve Graft

A short sural nerve (<12 cm) was placed from the healthy side facial nerve branches to the dermis of the paralyzed side face nasolabial fold, which has been described before.[8] Mean operative time was approximately 3 hours.

Stage 2: Cross-Face Nerve Graft Innervation of the Gracilis

The second-stage procedure was performed after a 6- to 9-month waiting period. On the paralyzed face, three incisions were made (Fig. 1, *left*). The first incision was along the upper lip white line between the philtrum and oral commissure to identify the previous cross-face nerve graft. Four 4-0 Dexon anchoring sutures were placed behind

Table 2. Patient Demographics*

	Total (%)	CFNG-Gracilis (%)	XI-Gracilis (%)	V3-Gracilis (%)
Sex				
Male		118	28	15
Female		181	32	18
No.				
Total	392	299	60†	33‡
FFMT	403	299 (74.2)	68 (17.4)	36 (9.4)
Age at day of FFMT, yr				
Mean		30.9	37.5	30.4
Range		3–68	4–68	4–72
Cause				
Virus infection (Bell palsy, herpes zoster)	115 (29)	94	16	5
Suppurative otitis media (cholesteatoma)	25 (6)	20	4	1
After tumor resection	159 (41)	132	14	13
Trauma	54 (14)	43	9	2
Congenital	39 (10)	10	17	12
Duration of facial paralysis, yr				
Mean		16.8	10.0	9.9
Range		0.5–52	0.5–52	1–27
Onset of muscle contraction after transplantation, mo				
Mean		9	5	3
Range		6–18	3–12	2–6

CFNG, cross-face nerve graft; XI, spinal accessory nerve; V3, masseter nerve; FFMT, functioning free muscle transplantation.
*Period: 1986 to 2017.
†Sixty-eight functioning free muscle transplantations in 60 patients after spinal accessory nerve–innervated gracilis: six patients, bilateral plus reoperation in two patients.
‡Thirty-three patients undergoing 36 functioning free muscle transplantations after masseter nerve–innervated gracilis: two patients bilateral plus one reoperation.

the orbicularis oris. The second incision on the lower lip white line was made for gracilis tail attachment. The third long incision was preauricular for subcutaneous face lift. Under the face-lift flap, four 3-0 Dexon anchoring sutures were placed transversely along the inferior zygomatic arch

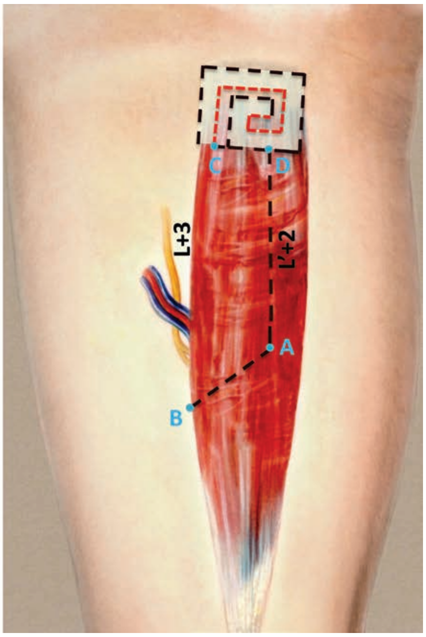

Fig. 1. (*Left*) Three incisions for recipient face preparation: *1*, upper lip white line incision, *2*, lower lip white line incision, and *3*, preauricular long incision. These three incisions are for regular muscle inset. (*Right*) Four lengths of proposed trapezoidal muscle dimensions were drawn over the upper gracilis. Additional lengths were added to avoid consequent lip contracture deformity with 2 cm on the vessel opposite and 3 cm on the vessel sides. A gracilis tail was created on the gracilis aponeurosis with 1 cm in width for lower lip suspension.

periosteum. For complete facial paralysis, soft tissue between the infrazygomatic margin down to the upper lip, including the zygomatic major muscle, buccal fat pad, and facial nerve branches was removed to create a recipient pocket. The Stensen duct was identified and protected. For postparalysis facial synkinesis, the resection was more involved, including all zygomatic, buccal, nasal, and platysma muscles and their innervated nerves. For incomplete facial paralysis, the soft-tissue removal was only above the muscles and nerves. The proposed trapezoidal muscle dimensions were measured and drawn. Based on our experience, 2 cm on the vessel opposite and 3 cm on the vessel side were added (Fig. 1, *right*) to avoid consequent lip contracture deformity.

On the contralateral medial thigh, the proposed measured trapezoidal dimensions were drawn on the exposed upper gracilis and its aponeurotic origin, with the distal edge drawn two fingerbreadths distal to the neurovascular pedicle. The proximal aponeurosis, with 1-cm width in continuity with the muscle, was trimmed into a long tail (Fig. 1, *right*). Maximal length of the vessel and nerve pedicles was obtained before division. The trimmed gracilis was harvested and inset in reverse polarity: the proximal aponeurosis was fixed to the upper lip, and the distal end was fixed to the zygomatic arch by way of the prior anchoring sutures. The gracilis aponeurotic tail was sutured to the lower lip wound under tension. After vessel anastomoses (one artery and one vein), the obturator nerve passing under the gracilis was coapted to the cross-face nerve graft in the upper lip wound.

Single-Stage Spinal Accessory Nerve–Innervated Gracilis

The spinal accessory nerve dissection anterior to the trapezius muscle should be long enough (usually >10 cm) to reach the mandibular angle for nerve coaptation. Recipient face and donor thigh gracilis preparation were similar to the cross-face nerve graft–innervated gracilis.[14]

Single-Stage Masseter Nerve–Innervated Gracilis

The masseter origin was divided from the zygomatic arch, cleaned downward to the deep muscle surface. The masseter nerve was identified with a nerve stimulator. The masseter nerve was 1 to 2 mm, located one fingerbreadth below the zygomatic arch and one fingerbreadth anterior to the condylar process. Under microscopy, the main branch of the masseter nerve was dissected distally for length, divided, and reflected upward for nerve coaptation. Recipient and donor preparation were similar to the cross-face nerve graft–innervated gracilis.

Postoperative Care and Rehabilitation

Cross-Face Nerve Graft–Innervated Gracilis

In the second stage, patients were extubated after surgery and admitted to our microsurgical intensive care unit for 3 to 5 days. The total hospital stay was 7 days.

Rehabilitation began at week 4 postoperatively, including massage and muscle electric stimulation. "Induction exercise"[16] was initiated at month 4, when the innervated muscle began to move (M1 muscle strength). Resistance was placed with a hand over the healthy side of the cheek while attempting frequent large smiles. The exercise can induce or stimulate the transferred muscle. Follow-up visits were scheduled every 2 to 3 months.

Spinal Accessory Nerve–Innervated Gracilis

A premade neck splint was applied for neck immobilization immediately after surgery for 3 weeks. Postoperative care and rehabilitation were similar to those for the cross-face nerve graft–innervated gracilis. Specific induction exercise was initiated earlier, 3 months postoperatively, using active shoulder elevation against resistance to trigger functioning free muscle transplantation movement. Once dynamic functioning free muscle transplantation contraction allowed for exposure of the lateral incisor (6 to 12 months), the induction exercise was weaned and stopped. Instead, mirror smile training was advised to adjust and control the movement of the functioning free muscle transplant to achieve symmetry, independence, and spontaneity.

Masseter Nerve–Innervated Gracilis

Postoperative care and rehabilitation were similar to those for the spinal accessory nerve–innervated gracilis but without neck immobilization. Specific induction exercise was initiated earlier, at 2 months postoperatively, using jaw clenching to trigger functioning free muscle transplantation movement. Similarly, once functioning free muscle transplantation contraction allowed for lateral incisor exposure (3 to 5 months), the exercise was weaned and stopped, and mirror smile training was started.

Outcome Assessment

Postoperatively, all patients were evaluated clinically to confirm the function of functioning free muscle transplantation without electromyography. All patients were followed for at least 1 year. Patients were photographed and videotaped during preoperative and postoperative visits in standardized fashion, including facial repose and mild, moderate, and maximal smile; in addition, the "tickle-and-joke test" was used to examine the spontaneity of the smile. Five independent reviewers reviewed the photographs and videos and graded the functional and aesthetic outcomes.

The Smile Excursion Score[14,17] (score 0 to 4) is a simple measurement method to check muscle strength based on the exposure of denture during maximal smile. The score is graded with greater than or equal to 4 teeth seen yielding the highest score; a score of greater than or equal to 2 is considered acceptable.

The cortical adaptation staging system[14,18] includes five stages of movement: none (stage I), dependent (stage II), independent (stage III), spontaneous with synkinesis (stage IV), and spontaneous movement with less or absent synkineses (stage V). The tickle-and-joke test assessed smile spontaneity by either tickling the patient's axilla or telling a joke(s) to induce smile. Stage III is an acceptable result, stage IV is a good result, and stage V is an excellent result.

Hadlock's Smile Measurement of Improvement in Lip Excursion scale was used to quantitatively measure paralyzed lip excursion[19] (Fig. 2). Horizontal movement was given the x value, and vertical movement was given the y value. The final Z value was calculated by the equation $\sqrt{x^2 + y^2}$, with the larger values indicating better excursion.

The Terzis Functional and Aesthetic Grading System[4] for also used for general evaluation. Grade 1 (poor) and grade 2 (fair) were unacceptable. Grade 3 (moderate) showed asymmetric muscle contraction. Grade 4 (good) and grade 5 (excellent) were considered acceptable results.

For a more qualitative evaluation, we applied a patient-based questionnaire that has been developed at our center since 2012[14,20] to investigate the patient's subjective complaints, the use of the smile in daily activities, and what the patient thinks of the smile appearance. The questionnaire was performed by means of phone interview or mailed written response. A satisfaction score of 5 was used.

Statistical Analysis

Statistical analysis was performed using IBM SPSS Version 22.0 software (IBM Corp., Armonk, N.Y.). We do have a large total number of patients. Data are presented as mean ± SD. The Mann-Whitney U test was used for comparison between two independent samples, and the Kruskal-Wallis test was used for more than two independent groups. The nonparametric test was applied for unequal patient numbers in different groups with skewed distributions. Values of $p < 0.05$ were considered statistically significant.

RESULTS

Denervation Time

Denervation time was defined as the number of days between functioning free muscle transplantation date and the onset of muscle contraction. Average denervation time was 9 months (range, 6 to 12 months) in the cross-face nerve graft group, 5 months (range, 3 to 12 months) in the spinal accessory nerve group, and 3 months (range, 2 to 6 months) in the masseter nerve group. Denervation times for the masseter and spinal accessory nerve groups were significantly shorter than for the cross-face nerve graft group (Table 2).

Fig. 2. (*Left*) Patient photograph preoperatively. (*Right*) Total lip excursion length (Z length) after functioning free muscle transplantation, derived by $Z = \sqrt{x^2 + y^2}$. The larger the better.

Functioning Free Muscle Transplantation Ischemic Time

Ischemic time was usually within 1 hour for all cases, with no difference among the three groups.

Complications

Acute complications included hematoma (one patient), saliva accumulation (three patients), and flap loss (four patients). The four flap failures were in the cross-face nerve graft group: one declined further intervention, and the other three received a second gracilis (two innervated by the spinal accessory nerve and one by the masseter nerve) 1 year after initial débridement. Transection of facial nerve branches or spinal accessory or masseter nerve did not cause significant motor deficits or symptoms and signs.

Secondary Surgery

Most patients were satisfied with the final results. Nearly half of all patients (49 percent) had a secondary operation, either revision surgery to correct secondary deformity after functioning free muscle transplantation, or aesthetic surgery to enhance the results, performed usually at 1 year postoperatively (Tables 3 and 4). Revision operations included contracture release and/or fat or dermofat grafting, fat grafting for abnormal wrinkles or folds, thinning of widened vermilion, cheek debulking, lower lip wedge excision and/or contralateral lower lip myectomy for symmetry, and so forth. Weak lip elevation caused by insufficient functioning free muscle transplantation strength was infrequent and treated with minitemporalis muscle transfer. Aesthetic operations included brow lift, midface lift, fat grafting, blepharoplasty, and botulinum toxin type A injection.

Table 3. Sequelae Deformities following Functioning Free Muscle Transplantation

Location and Deformity	Incidence of Surgery (%)
Middle face (cheek)	43.8
Bulkiness	
Significant depression outside the transferred muscle	
Abnormal facial wrinkles, dominant nasolabial fold and/or marionette line	
Upper lip mouth angle	32.8
Weak lip elevation	
Upper lip contracture with abnormal fold	
Mouth angle contracture with fold	
Wide exposure of the lip width	
Notch or dimpling of upper lip	
Eyelid	14.5
Lagophthalmos	
Asymmetry	
Brow	5.1
Drop	
Lower lip neck	3.4
Hypertrophy (too strong) on the normal side	
Paralysis on the affected side	
Entropion (inverted)	
Contracture band caused by plantaris tendon	
Drooling	
Others	0.4
Ugly scars	

Table 4. Secondary Surgery after Functioning Free Muscle Transplantation

Revision procedure
Releasing contracture and fat graft
Releasing contracture and dermofat graft
Thinning procedure for the wider upper lip
Debulking
Temporalis transfer
Widening procedure for the lower lip width
Scar revision
Aesthetic procedure
Brow lift
Face lift (midface)
Blepharoplasty (upper /lower eyelid)
Fat grafts
Contralateral selective neurectomy
Botulinum toxin type A injection

Smile Excursion Score

In the first 2 years postoperatively, the spinal accessory and masseter nerve groups both showed significantly greater scores than the cross-face nerve graft group. However, in the third year, there was no difference among the three groups, with all three scoring 3 or higher (Table 5 and Fig. 3). Preoperatively, the cross-face nerve graft group had better dental show because of a higher percentage of synkinetic patients with incomplete paralysis.

Cortical Adaptation Stage

In the cross-face nerve graft group, nearly all achieved stage IV or V spontaneous smile (Table 6). In the spinal accessory nerve group, all achieved at least stage III (independent) smile, and nearly half of patients showed a potential upgrade to spontaneous smile over time. In the masseter nerve group, most achieved stage II or III smile, but none had spontaneity except for two cases of bilateral Möbius syndrome who received bilateral masseter nerve–innervated gracilis.

Satisfaction Score

To achieve similar patient samples sizes, we randomly chose 50 cross-face nerve graft patients, 30 spinal accessory nerve patients, and 15 masseter nerve patients. They all had undergone

Table 5. Mean Smile Excursion Score ± SD*

	CFNG	XI	V3	*p* < 0.05
Preoperatively	0.550 ± 0.076	0.325 ± 0.038	0.132 ± 0.047	CFNG:XI, XI:V3, CFNG:V3
First year postoperatively	2.183 ± 0.048	2.910 ± 0.161	3.111 ± 0.205	CFNG:XI, CFNG:V3
Second year postoperatively	2.567 ± 0.112	3.687 ± 0.150	4.014 ± 0.224	CFNG:XI, CFNG:V3
Third year postoperatively	3.083 ± 0.108	3.333 ± 0.135	3.500 ± 0.190	
>3 yr (>36 mo)	3.160 ± 0.093	3.835 ± 0.060	3.600 ± 0.245	CFNG:XI

CNFG, cross-face nerve graft; XI, spinal accessory nerve; V3, masseter nerve.
*Tooth visible score (range, 0 to 4).

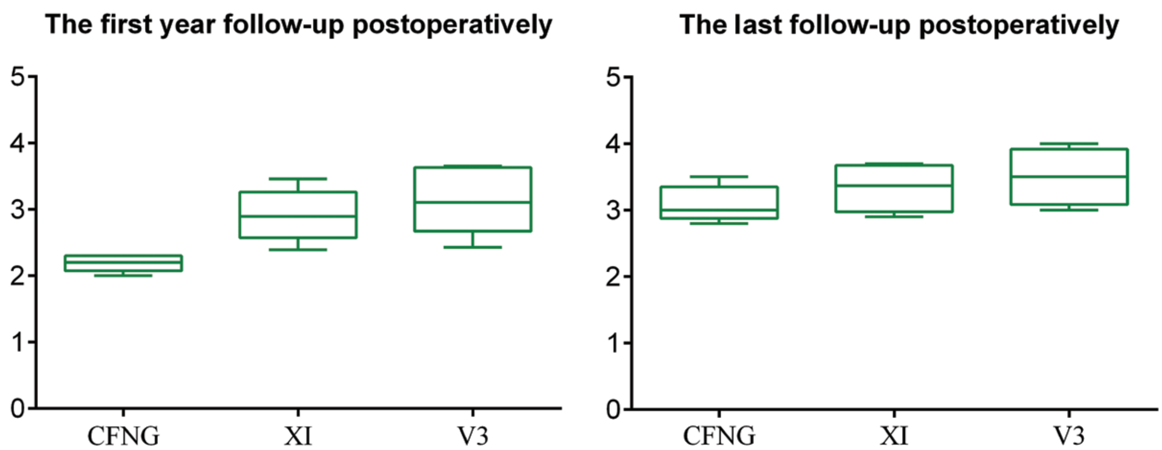

Fig. 3. Comparison of results of smile excursion score (teeth visible score) among cross-face nerve graft (*CFNG*), spinal accessory nerve (*XI*), and masseter nerve (*V3*) group patients (*left*) during the first year and (*right*) at the last (>3 years) follow-up (see text).

reconstruction within the past 10 years. A score greater than or equal to 3 (acceptable and satisfied) was reported in 86 percent of the cross-face nerve graft group and 90 percent of the spinal accessory nerve group. Both were significantly higher than the masseter nerve group at 67 percent (Table 7).

Hadlock Lip Excursion Scale

Similarly, we purposely chose similar samples sizes from each group: 30 cross-face nerve graft, 30 spinal accessory nerve, and 14 masseter nerve group patients. Regardless of time of follow-up, the cross-face nerve graft group demonstrated significantly better lip excursion compared with the spinal accessory and masseter nerve groups (Table 8 and Fig. 4).

Table 6. Cortical Adaptation Stage

Innervation	Stage
CFNG-gracilis	Stage IV–V; tickle-and-joke test (all passed)
XI-gracilis	Most stage III or higher; 33%, stage IV; 12%, stage V; tickle-and-joke test (most passed)
V3-gracilis	Most stage III; tickle-and-joke test for unilateral cases (failed to pass)

CNFG, cross-face nerve graft; XI, spinal accessory nerve; V3, masseter nerve.

Terzis Functional and Aesthetic Grading System

The cross-face nerve graft group demonstrated progressive improvement from an average score of 1.367 preoperatively to 3.117 after 1 year, 3.683 at 2 years, and finally 4.180 at last follow-up. The spinal accessory nerve group also had similar progressive improvement. In contrast, the masseter nerve group demonstrated significant improvement at 1 year (from 1.037 to 3.738),

Table 7. Satisfaction Score*

	CFNG-Gracilis	XI-Gracilis	V3-Gracilis
No.	50	30	15
Satisfaction score	3.46	3.40	3.2
Distribution (score)*			
5	6	3	0
4	22	9	2
3	16	15	13
2	6	3	0
1	0	0	0
≥3	86%	90%	67%

CNFG, cross-face nerve graft; XI, spinal accessory nerve; V3, masseter nerve.
*Range, 0 to 5.
†1, regret surgery; 2, unacceptable but does not regret surgery; 3, acceptable but need major improvement; 4, satisfied but need minor improvement; 5, completely satisfied without revision.

Table 8. Hadlock Smile Measurement of Improvement in Lip Excursion Scale

	No.	Median 1-Yr Follow-Up (IQR)	Median Last Follow-Up (IQR)	Median Follow-Up Time of Last Follow-Up (IQR) (mo)
CFNG	30	12.73 (10.52–15.80)	14.12 (12.66–16.26)	34 (24–42)
XI	30	7.25 (4.15–13.26)	7.4 (3.75–13.68)	15 (11.25–17.75)
V3	14	9.25 (2.49–16.40)	9.25 (1.81–18.05)	12 (7.75–27)
p		0.04	0.007	

IQR, interquartile range; CNFG, cross-face nerve graft; XI, spinal accessory nerve; V3, masseter nerve.

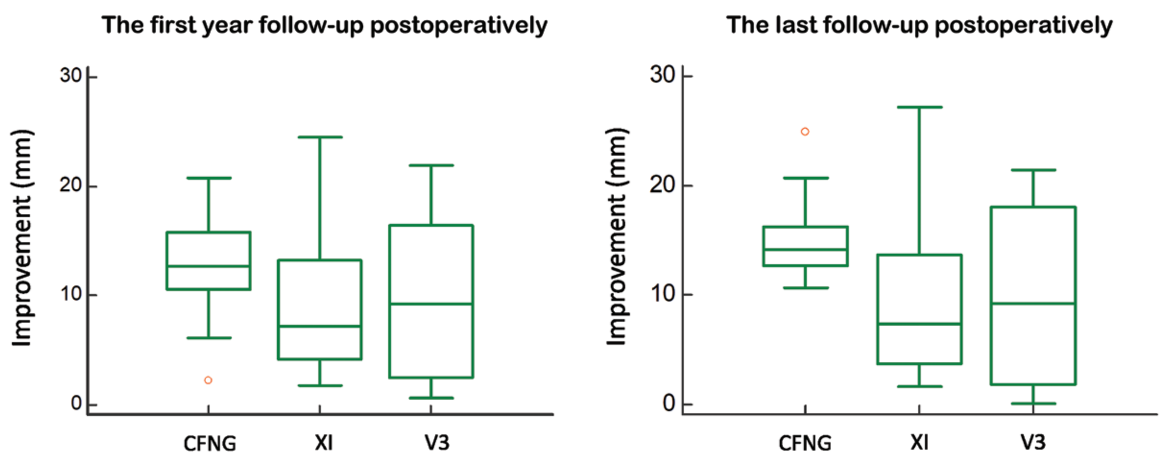

Fig. 4. Comparison of results of the Hadlock Smile Measurement of Improvement in Lip Excursion total lip excursion after functioning free muscle transplantation among cross-face nerve graft (*CFNG*), spinal accessory nerve (*XI*), and masseter nerve (*V3*) group patients (*left*) during the first year and (*right*) at the last follow-up.

but then decreased to 3.611 at 2 years, and then achieved a very slow improvement to 4.100 at last follow-up (Table 9 and Fig. 5).

DISCUSSION

Why Was Postparalysis Facial Synkinesis Included in This Series?

All postparalysis facial synkinesis patients in this series underwent extensive myectomy and neurectomy before functioning free muscle transplantation to remove synkinetic muscles and nerves. Their status before functioning free muscle transplantation is similar to that for true facial paralysis. Their reconstructive procedure, postoperative care, and rehabilitation were all the same as for true facial paralysis. However, postparalysis facial synkinesis patients after functioning free muscle transplantation have a higher revision rate than those with true facial paralysis, especially revision of upper lip contracture.

Cortical Adaptation

In 2006, Manktelow et al.[15] reported a series of 27 patients (18 with bilateral and nine with unilateral facial paralysis) with masseter-innervated gracilis, where 85 percent learned to smile without biting, and where spontaneity occurred routinely in 59 percent and occasionally in 29 percent. Cortical connection between the cortical centers of cranial nerves VII and V was hypothesized. In our series, brain plasticity occurred only in bilateral Möbius syndrome patients (eight patients). All achieved good results in spontaneity and symmetry. However, the majority of cases of masseter-innervated gracilis in our series were unilateral facial paralysis, of which 86.7 percent achieved stage III independent movement (similar to the 85 percent reported by Manktelow et al.), but none passed the tickle-and-joke test, indicating a lack of spontaneity.

Sequelae by Spinal Accessory Nerve Transection

Spinal accessory nerve transection and transfer has been extensively used at our center in more than 1000 cases for brachial plexus injury reconstruction.[16] Significant motor deficits, symptoms, or signs have not been observed. Although atrophy of the middle and lower trapezius was noted, the shoulder soreness was usually temporary and usually resolved within 1 month. The sternocleidomastoid and upper trapezius muscle were always preserved because of the sparing of the proximal

Table 9. Terzis Aesthetic and Functional Grading System

	CFNG	XI	V3	$p < 0.05$
Preoperatively	1.367 ± 0.049	1.347 ± 0.053	1.037 ± 0.023	XI:V3, CFNG:V3
In the first year postoperatively	3.117 ± 0.128	3.723 ± 0.163	3.738 ± 0.221	CFNG:XI, CFNG:V3
In the second year postoperatively	3.683 ± 0.130	4.040 ± 0.198	3.611 ± 0.200	
In the third year postoperatively	4.150 ± 0.115	4.140 ± 0.185	4.067 ± 0.245	
More than 3 yr (>36 mo)	4.180 ± 0.146	4.439 ± 0.202	4.100 ± 0.245	

CFNG, cross-face nerve graft; XI, spinal accessory nerve; V2, masseter nerve.

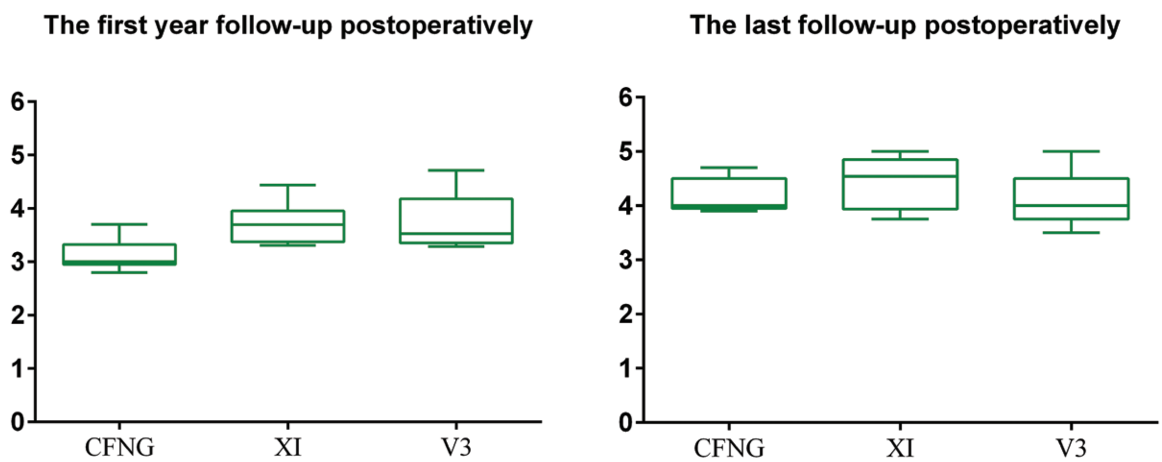

Fig. 5. Comparison of results of the Terzis Functional and Aesthetic Grading System among cross-face nerve graft (*CFNG*), spinal accessory nerve (*XI*), and masseter nerve (*V3*) group patients (*left*) during the first year and (*right*) at the last follow-up.

branches. The trapezius muscle is attached to the clavicle, acromion, and scapular spine, but not across the glenohumeral joint. Total palsy or total removal of the trapezius muscle purposely should not theoretically cause shoulder drop.

Result Evaluation

There is much debate regarding result evaluations in the fields of science, and no consensus or conclusion exists. This is especially true in peripheral nerve injury and reconstruction such as obstetric brachial plexus palsy, adult brachial plexus injury (especially on total root avulsion), facial palsy (especially on postparalysis facial synkinesis), and others (e.g., replantation versus amputation and prosthesis for major limb amputation).

Although some standardized evaluation systems for facial nerve paralysis and recovery have been established, such as the House-Brackmann, the Sunnybrook, or the Sydney system,[21] we found that none could comprehensively represent our patients' results after functioning free muscle transplantation reconstruction. On the contrary, our evaluation had a multiplicity approach: teeth exposure score to assess functioning free muscle transplantation strength, cortical adaptation system to evaluate muscle movement stage, Hadlock lip excursion to quantitatively assess total lip excursion, and Terzis grading system to quantitatively and qualitatively evaluate the overall result. The additional patient questionnaire provided patient-centered outcomes. The multiple approaches for facial palsy outcome assessment after functioning free muscle transplantation reanimation could comprehensively represent our patients' results.

Solved and Unsolved Challenges

Facial reanimation by functioning free muscle transplantation at our center has solved and unsolved challenges. Solved challenges include (1) functioning free muscle transplantation is better than regional muscle transfer; (2) smile reconstruction is the most important goal; (3) cross-face nerve graft–innervated gracilis is the preferred method for patients younger than 70 years; (4) a short cross-face nerve graft is better than a long cross-face nerve graft; (5) measuring the proposed muscle dimensions under the face-lift flap is more accurate; (6) a vertical vector of muscle axis is better than an oblique or a transverse axis; (7) plantaris tendon is better than gracilis aponeurosis for lower lip dynamic suspension in total palsy patients,[22] (8) spinal accessory– and masseter nerve–innervated gracilis provide

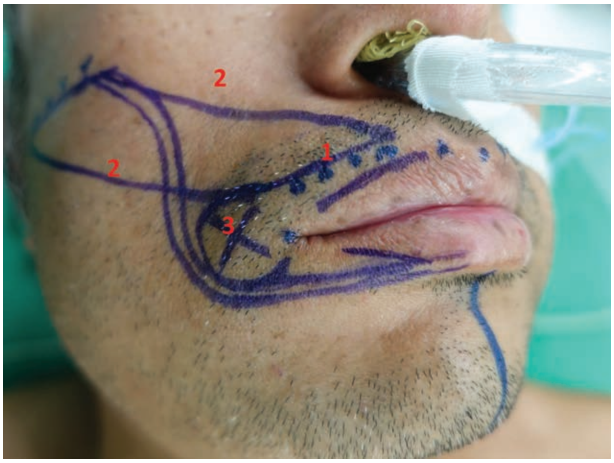

Fig. 6. Current modified techniques include the following: *1*, insetting the muscle lip attachment higher, along the gingival gum line, not posterior to the orbicularis oris; *2*, decreasing the length of the muscle on the nonvessel side, and increasing the length on the vessel side (because contracture is always seen at the lateral upper lip and commissure); and *3*, creating a soft-tissue cushion at the commissure for lower lip suspension.

a stronger smile at an earlier time point, but a cross-face nerve graft–innervated gracilis achieves the best final results; (9) for patients older than 70 years, patients who had failed primary reconstructions, or patients whose facial paralysis is caused by malignant tumor resection, a masseter nerve–innervated gracilis is better; and (10) the tickle-and-joke test is an easy and effective means of testing spontaneity.

We still have unsolved challenges, including (1) ideal muscle insertion site on the upper lip; (2) appropriate muscle length requirement, especially for synkinesis patients; and (3) overcoming progressive muscle shortening over time (i.e., because the transferred muscle has a fixed proximal attachment on the zygomatic bone, but a movable distal attachment on the upper lip). It will physiologically shorten over time. These unsolved challenges may be related to our high revision rate. Some new technical modifications have recently been attempted to decrease the revision requirement (Fig. 6).

Indication and Contraindication

Transection of the spinal accessory nerve may possibly result in disability of shoulder abduction, which should be explained to the patient preoperatively. The spinal accessory nerve should be avoided in athletes, particularly those requiring a lot of shoulder abduction and external rotation exercises, which will result in an embarrassingly involuntary cheek movement. Communication difficulties are other relative contraindications for use of spinal accessory– and masseter nerve–innervated gracilis because of difficulties for smile training. The advantages and disadvantages of the three neurotizers are summarized in Table 10.

Table 10. Comparison of Functioning Muscle Transplantation with Different Donor Motor Nerves

	CFNG	XI	V3
Stage requirement	2	1	1
Nerve graft requirement	Yes	No	No
Scars	Face and leg	Face and neck	Face
Neurotizer power	+	++	+++
Time to reach smile excursion score 1, mo	6–12	6	2–6
Time to achieve smile excursion score ≥2, mo	12–24	<12	<6
Cortical adaptation stage	IV–V	III, IV, or V (getting better by time)	III
Tickle-and-joke test	Spontaneously, no latency	Spontaneously, but with latency (+)	Latency (++)
Smiling training requirement	+	++	+++
Satisfaction score	4–5	3–4	3
Disadvantages	May have synkinesis between eye closure on the normal side and cheek FFMT movement on the affected side	May have shoulder disability	Synkinesis between biting and FFMT movement
Indications and contraindications	Most no contraindication	Contraindication in (1) athletes with active use of upper limb exercise, and (2) patients with poor communication	Indications in (1) failed gracilis transplant innervated by CFNG or XI, (2) congenital facial palsy (unilateral or bilateral), (3) aged patient (>70 yr), (4) malignant tumor resection Contraindication in patients with poor communication

CFNG, cross-face nerve graft; XI, spinal accessory nerve; V3, masseter nerve; FFMT, functioning free muscle transplantation.

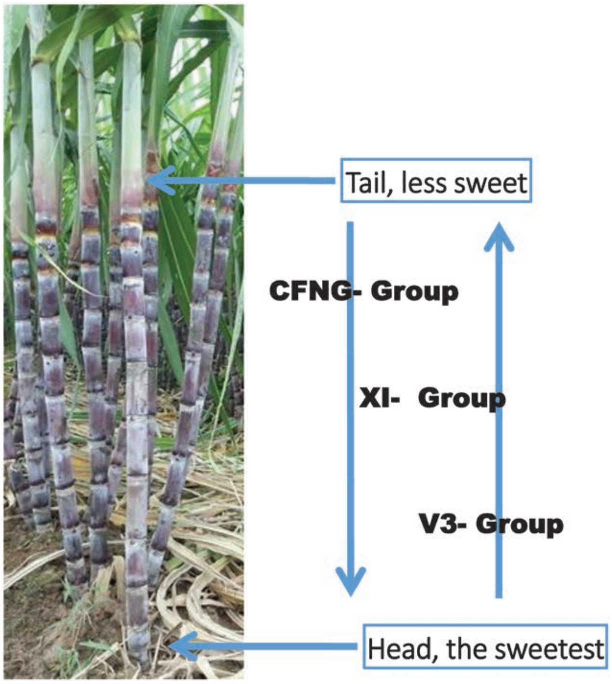

Fig. 7. The sugarcane chewing concept (see text).

The "Sugarcane Chewing" Concept

We first started using the two-stage cross-face nerve graft–innervated gracilis for facial reanimation in 1985, then adopted the single-stage masseter nerve–innervated gracilis in 1995, and then single-stage spinal accessory nerve–innervated gracilis in 2000. Our experience over three decades can be best summarized with the "sugarcane chewing" concept (Fig. 7). The sweetest portion of sugarcane is at the head on the ground and the least at the tail in the air. The result of cross-face nerve graft–innervated gracilis is akin to chewing sugarcane from tail to head, the initial "sweetness" is minimal, but becomes progressively sweeter over time. Although cross-face nerve graft–innervated gracilis has weaker excursion at an earlier stage, the best result is typically seen in the third year. Conversely, the masseter nerve–innervated gracilis result is comparable to chewing sugarcane from head to tail; the result is initially sweeter, but wanes over time. The result of the spinal accessory nerve–innervated gracilis falls between these two groups. This analogy can assist both surgeons and patients in weighing the benefits and drawbacks during motor neurotizer selection.

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APPENDIX

Presented at the 25th Annual Meeting of the Society of Plastic and Reconstructive Surgeons of Thailand, in Bangkok, Thailand, October 15 through 16, 2015; the 13th European Federation of Societies for Microsurgery, in Antalya, Turkey, April 21 through 24, 2016; the 5th World Congress for Plastic Surgeons of Chinese Descent, in Wuhan, China, November 18 through 20, 2016; the 5th Chang Gung-Mayo Symposium, in Munich, Germany, September 9, 2016; the 13th International Facial Nerve Symposium, in Beverly Hills, California, August 4 through 5, 2017; the 25th Taipei Society for Plastic Surgery, in Taipei, Taiwan, December 2, 2017; the American Society for Reconstructive Microsurgery Annual Meeting, in Phoenix, Arizona, June 13 through 16, 2018; the 41st Facial Nerve Research Meeting, in Yamagata, Japan, June 8, 2018; and the 6th Asian Society of Head and Neck Oncology, in Seoul, Korea, March 27 through 29, 2019.

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