Original Investigation

Objective Outcomes Analysis Following Microvascular Gracilis Transfer for Facial Reanimation
A Review of 10 Years' Experience

Prabhat K. Bhama, MD; Julie S. Weinberg, BA; Robin W. Lindsay, MD; Marc H. Hohman, MD; Mack L. Cheney, MD; Tessa A. Hadlock, MD

IMPORTANCE Objective assessment of smile outcome after microvascular free gracilis transfer is challenging, and quantification of smile outcomes in the literature is inconsistent.

OBJECTIVE To report objective excursion and symmetry outcomes from a series of free gracilis cases and investigate the predictive value of intraoperative measurements on final outcomes.

DESIGN, SETTING, AND PARTICIPANTS A retrospective medical chart review was undertaken of all patients who underwent microvascular free gracilis transfer for smile at our institution over the past 10 years.

MAIN OUTCOMES AND MEASURES Outcome measures included the following: smile excursion, angle of smile with respect to the vertical midline, and facial symmetry during repose and with smile. Measurements were obtained using an automated tool for assessment of facial landmarks (FACE-Gram). An exhaustive set of intraoperative parameters including degree of recoil of the gracilis muscle following harvest, the degree to which the muscle foreshortened during stimulation of the obturator nerve, final stretched length of the inset muscle, surgeon assessment of neurorrhaphy and pulse pressure, ischemia time, number of sutures used during neurorrhaphy, nerve used to innervate the flap, and surgeon assessment of oral commissure overcorrection were recorded and placed into a linear regression model to investigate correlations with smile.

RESULTS From March 2003 to March 2013, 154 microvascular free gracilis transfers were performed for facial reanimation at our institution, 14 (9%) of which were deemed failures. Of the remaining 140 flaps, 127 fulfilled inclusion criteria and constituted the study cohort. Smile excursion, angle excursion, and symmetry of the oral commissure at repose and with smile all improved following gracilis free flap ($P < .05$). Associations between selected outcomes measures and intraoperative gracilis measurements were identified.

CONCLUSIONS AND RELEVANCE Facial reanimation using free gracilis transfer results in quantifiable improvements in oral commissure excursion and facial symmetry both at rest and with smiling. Associations between contractility and internal recoil of the flap and final outcome were identified.

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Author Affiliations: Division of Facial Plastic and Reconstructive Surgery, Department of Otolaryngology, Harvard Medical School, Massachusetts Eye and Ear Infirmary, Boston (Bhama, Weinberg, Lindsay, Cheney, Hadlock); Harvard School of Public Health, Boston, Massachusetts (Bhama); Madigan Army Medical Center, Tacoma, Washington (Hohman).

Corresponding Author: Prabhat K. Bhama, MD, Division of Facial Plastic and Reconstructive Surgery, Department of Otolaryngology, Harvard Medical School, Massachusetts Eye and Ear Infirmary, Harvard School of Public Health, 243 Charles St, Boston, MA 02114 (pbhama@gmail.com).

Since its introduction in 1976 by Harii et al,[1] gracilis free tissue transfer (GFTT) has become the gold standard for dynamic reanimation of the oral commissure and is performed at many centers worldwide. Outcomes data following GFTT is sparse in the literature despite the frequency with which it is used. The most important barrier in advancing our understanding of outcomes following GFTT has been the lack of an objective, comprehensive tool to measure facial function following surgical intervention.[2]

Because of the lack of available objective outcome measures for smile, predicting outcomes based on specific intraoperative events and parameters has been impractical. To meet these challenges, we recently developed an automated software tool (FACE-Gram) that can be used to analyze zonal facial movements with accuracy and precision[3] and have also meticulously recorded intraoperative parameters that may be predictive of flap outcome. In this study, we demonstrate the use of FACE-Gram to analyze smile outcomes in a large series of patients and investigate relationships between intraoperative parameters and outcomes.

Methods

Selection Criteria

Institutional review board approval was obtained from the Massachusetts Eye and Ear Infirmary (MEEI) Human Studies Committee prior to beginning this study. All patients who underwent GFTT at the Massachusetts Eye and Ear Infirmary (MEEI) from March 2003 to March 2013 were initially included in this study. Patients who underwent revision surgery or had necrosis of the flap because of infection or vascular insufficiency were excluded, as GFTT was counted as having failed in these patients. Patients with missing data or in whom outcomes data were not acquired following a sufficient recovery period were excluded.

Preoperative Data Collection

Demographic data including age and sex were recorded. Preoperative photographs and videos were used to measure baseline oral commissure excursion and angle of the oral commissure with respect to the vertical midline of the face at repose and with smile (**Figure 1**) using FACE-Gram software, an automated tool for measuring facial landmarks.[3]

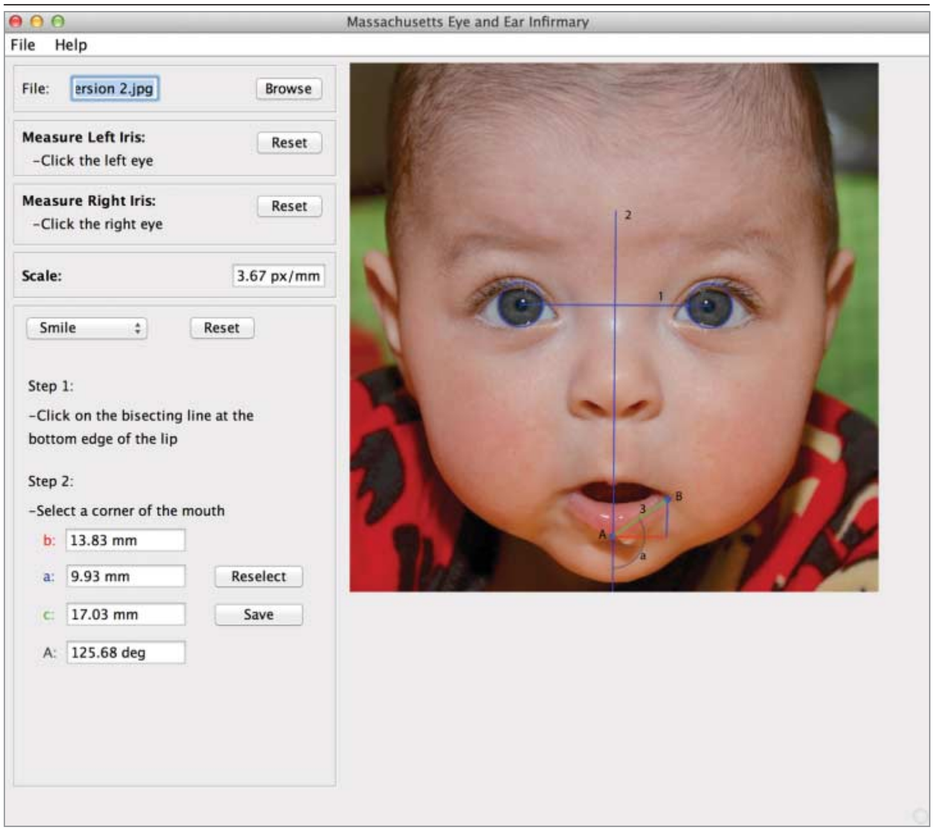
Operative Procedure and Intraoperative Data Collection

All operations were performed as previously described.[4] Briefly, a segment of gracilis muscle was harvested from a medial incision in the thigh along with the adductor artery, its venae comitantes, and the obturator nerve. The muscle was trimmed on the back table and inset into the face as described in the following subsection (**Figure 2**).

Gracilis Parameters

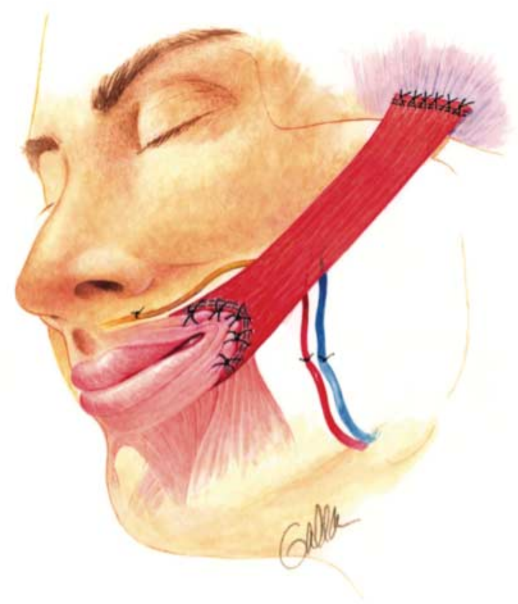
Prior to harvest, the gracilis muscle length was measured and recorded as the “marked length.” The muscle foreshortens to

Figure 1. FACE-Gram Software



1, Horizontal interpupillary line; 2, vertical line bisecting and perpendicular to horizontal interpupillary line; A, intersection of line 2 and vermilliocutaneous border of lower lip; B, oral commissure; 3, line with distance spanning points A and B; and a, angle between line 2 and line 3.

Figure 2. Gracilis Muscle Following Inset



a variable degree after the muscle cuts are made, and this new length was recorded as the "recoil length." The muscle was then stimulated with a Montgomery Nerve Stimulator (Boston Medical Products) at 2 V, and the length during stimulation was recorded as the "stimulated length." After the muscle was trimmed and prepared on the back table, the final length was recorded as the "harvest length." During inset, the muscle was stretched and sutured superiorly to the deep temporal fascia to create a neoorigin, and inferiorly to the modiolus to create a neoinsertion. This new length was recorded as the "inset length." Several parameters were calculated based on these measurements, as displayed in the **Box**, including stretch, recoil proportion, and contractility proportion. Thickness and width of the gracilis were also recorded before and after inset.

Operative Parameters

The nerve used to innervate the free flap was noted. During neurorrhaphy, a subjective surgeon neurorrhaphy grade was assigned on an ordinal scale to the repair based on absence or presence of tension at the coaptation site, nerve diameter mismatch, and extravasation of axonal contents from the suture line. The number of sutures used and the type of tissue sealant used during the neurorrhaphy was also noted. A subjective assessment of the pulse pressure of the donor artery and oral commissure overcorrection was also performed and recorded.

Postoperative Data Collection

Outcome assessment in the postoperative phase was performed after recovery stabilized—9 months for a flap innervated by the ipsilateral masseteric branch of the trigeminal nerve and 18 months for a flap innervated by the contralateral facial nerve via cross-face nerve graft. The postoperative assessment included photographs and videographs, which were used to obtain measurements with the FACE-Gram software as was done preoperatively. In several cases, recovery had stabilized prior to the expected recovery periods. These patients were included in the final analysis.

Box. Intraoperative Measurements and Variables

Prior to Gracilis Harvest

In vivo marked length

Internal recoil length

Stimulated length

After Gracilis Harvest

Harvested length

Harvested width

Harvested thickness

Harvested weight

Trimmed weight

During Gracilis Inset

Inset length

Inset width

Inset thickness

Surgeon neurorrhaphy grade

No. of sutures placed for neurorrhaphy

Type of tissue sealant used for neurorrhaphy

Nerve(s) used to innervate free flap

Surgeon assessment of pulse pressure of donor artery

Surgeon assessment of oral commissure overcorrection

Ischemia time

Variables

Stretch = (harvest length/inset length) × 100.

Internal recoil proportion = internal recoil length/in vivo marked length.

Contractility proportion = (marked length−stimulated length/marked length) × 100.

Excursion Analysis

Objective comparisons of preoperative and postoperative photographs were performed using FACE Gram software (Figure 1). FACE-Gram software scaled each photograph based on the size of the iris (approximately 11.8 mm).[3] After the operator outlined each iris, a horizontal line (line 1) was created by the software through the pupils, followed by a perpendicular line (line 2) bisecting the former. The user then marked the intersection of the perpendicular line with the vermilliocutaneous border of the lower lip (point A). The user then defined the oral commissure (point B), and the software was able to calculate the distance from point A to point B (line 3), which represents the distance from the midline of the vermilliocutaneous border of the lower lip and the oral commissure. The change in this distance between repose and smile is referred to as the "smile excursion." The change in angle "a" between repose and

Table 1. Demographics and Operative Characteristics

Characteristic	Study Cohort (Flaps, n = 127; Patients, n = 124)	Failure Cohort (n = 14)
Demographics		
Sex, No. (%)		
Male	52 (42)	10 (71)
Female	72 (58)	4 (29)
Age, mean (SD) [range], y	35 (18) [6-80]	35 (12) [10-57]
Motor nerve, No. (%)		
Ipsilateral CN V	66 (52)	4 (29)
Contralateral CN VII	52 (41)	10 (71)
Ipsilateral CN V + contralateral CN VII	6 (5)	0
Ipsilateral CN VII	1 (1)	0
No. of neurorrhaphy sutures, No. (%)		
1	1 (1)	0
2	37 (29)	1 (7)
3	24 (19)	3 (21)
4	38 (30)	5 (36)
≥5	22 (17)	5 (36)
Not recorded	5 (4)	0
Measurements, mean (SD) [range]		
Preharvest		
In vivo length, cm	14.4 (1.11) [12-19]	14 (0) [14-14]
Cut recoil length, cm	9.2 (1.2) [6-12]	9.67 (0.6) [9-10]
Stimulated length, cm	5.4 (1.0) [3.5-8.5]	5.57 (1.0) [4.5-6.5]
Harvest		
Length, cm	7.99 (1.0) [6.0-13.0]	8.1 (0.6) [7.5-9.0]
Width, cm	3.99 (0.78) [2.4-6.0]	4.2 (0.6) [3.3-5.0]
Thickness, cm	0.95 (0.23) [0.2-1.5]	1 (0.1) [0.8-1.1]
Inset		
Length, cm	10.6 (1.16) [8.5-13.0]	11.2 (1.4) [10.0-13.0]
Width, cm	3.6 (0.62) [2.5-5.0]	3.8 (0.4) [3.5-4.6]
Thickness, cm	0.71 (0.17) [0.2-1.2]	0.69 (0.13) [0.45-0.80]
Weight, g	28.5 (10.1) [10.5-51.2]	33.7 (13.0) [2.0-53.3]
Operative variables, mean (SD) [range]		
Stretch	75 (8.0) [60-100]	71 (62) [62-78]
Contractility	59 (9.25) [44-85]	58 (7.6) [50-65]
Contractility proportion	0.448 (0.064) [0.29-0.63]	0.45 (0.02) [0.40-0.50]
Ischemia time, mean (SD) [range], min	132 (30) [60-262]	119 (22) [95-154]
Time from onset to operation, mean (SD) [range], d	3841 (5483) [328-38 166]	5825 (7071) [624-19 309]

Abbreviation: CN, cranial nerve.

smile is referred to as "angle excursion." The smile and angle excursions on both the affected and healthy sides were then calculated.

Symmetry Analysis

Symmetry was measured by calculating the difference in length of line 3 between the normal and affected sides, and the difference in angle "a" between the normal and affected sides. This calculation was performed at repose and with smile, both in the preoperative and postoperative setting. A perfectly symmetric smile yields a symmetry score of zero.

Hypothesis Testing and Regression Analysis

Differences between continuous variables were assessed using a 2-tailed paired *t* test for preoperative-postoperative comparisons. A Wilcoxon signed-rank test was used to compare continuous variables with a nonparametric distribution.

Linear regression models were used to assess the association of demographic and operative factors with postoperative angle and length excursion on the affected side and postoperative symmetry with smile. A robust empirical variance structure was used to overcome slight deviations from normality. Surgeon neurorrhaphy grade, number of sutures used for the neurorrhaphy, type of tissue sealant used for the neurorrhaphy, assessment of pulse pressure of donor artery, and assessment of oral commissure were analyzed continuously. Age, ischemia time, stretch, internal recoil proportion, and contractility proportion were individually divided into quartiles. All statistical analysis was performed using STATA/SE 12.1 (StataCorp).

Results

Patient and Operative Characteristics

A total of 154 free flaps were performed on 148 patients during the study period, of which 14 (9%) were failures. Flaps still within the predetermined recovery period that had not plateaued and those with lack of adequate data were excluded from the analysis, leaving 127 flaps performed on 124 patients in the study cohort.

More than half of the patients in the study cohort were female, whereas most in the failure cohort were male. The mean age of the study population was 35 years. Half of the free flaps were innervated by the masseteric branch of the trigeminal nerve, and just under half were innervated by the contralateral facial nerve. In 1 patient, a functioning branch of the ipsilateral facial nerve was used to drive the gracilis, and in 6 patients, both the masseteric nerve and contralateral facial nerve were used.

Typically, fewer than 4 sutures were used during neurorrhaphy. The marked length of gracilis for harvest was typically 14 cm, with a recoil length of approximately 9 cm. After stimulation of the obturator nerve, the cut gracilis contracted to a mean of 5 cm. Harvest and inset measurements are all also listed in the **Table 1**. Ischemia time averaged approximately 2 hours, but examination of the raw data revealed an obvious trend toward decreased ischemia time with increased surgeon experience (Table 1).

In 22% of cases, intracranial neoplasm was the cause of the facial paralysis. Vestibular schwannoma was the specific cause in another 22%. The remainder were congenital, temporal bone fracture, iatrogenic injury, malignant parotid neoplasia, and others (**Table 2**).

Outcome Assessment

Excursion on the healthy side decreased from 8.4 mm preoperatively to 7.2 mm postoperatively, while excursion on the affected side increased from −0.86 mm preoperatively to 7.8 mm postoperatively. Angle excursion decreased as well on the healthy side, and increased on the affected side following GFTT. Symmetry at repose with respect to angle improved following surgery. Symmetry during smile with respect to angle and length improved after GFTT (**Table 3**). Flaps innervated by the trigeminal nerve had a mean of 2.2 mm greater excursion than those innervated by the contralateral facial nerve. Those innervated by the contralateral facial nerve had better postoperative symmetry during smile with regard to length (**Table 4**). There was no statistically significant difference between the nerve used to innervate the flap and failure rate (**Figure 3**).

Regression analysis revealed an association between contractility proportion and excursion on the affected side. Specifically, those patients in the third quartile (75th percentile) had a higher excursion compared with those in the first quartile (25th percentile) (95% CI, 0.002 to 5.6). An association between internal recoil proportion and symmetry with smile using length as a measurement index was also identified. Similarly, patients in the third quartile had better symmetry compared with their first quartile cohorts (95% CI, −7.2 to −1.2). We found no correlation between age, ischemia time, stretch, neurorrhaphy grade and number of sutures used, type of tissue sealant

Table 2. Cause of Facial Paralysis

Cause	No. (%)
Intracranial neoplasm	33 (22)
Vestibular schwannoma	33 (22)
Congenital	20 (13)
Temporal bone fracture	10 (6)
Iatrogenic	10 (6)
Malignant parotid neoplasm	10 (6)
Bell palsy	9 (6)
Benign facial nerve neoplasm	8 (5)
Other	21 (14)

Table 3. Outcome Assessment in 74 Flaps

Outcome	Mean (SD) Preoperative	Mean (SD) Postoperative	*P* Value[a]
Excursion[b]			
Healthy side	8.4 (4.5)	7.2 (4.3)	.03
Affected side	−0.86 (3.6)	7.8 (3.3)	<.001
Δ Angle[c]			
Healthy side	8.5 (7.4)	6.0 (6.4)	.02
Affected side	3.9 (7.9)	6.0 (6.5)	.05
Symmetry (angle)[d]			
Repose	8.5 (6.3)	4.4 (2.9)	<.001
Smile	12.9 (9.6)	4.4 (3.8)	<.001
Symmetry (length)[e]			
Repose	5.2 (4.2)	4.3 (3.6)	.16
Smile	12.7 (6.9)	5.3 (3.8)	<.001

[a] The *P* values are based on a 2-tailed paired *t* test.

[b] Excursion refers to oral commissure, measured in millimeters.

[c] Δ Angle refers to change in angle with smile, measured in degrees.

[d] Symmetry refers to difference in angle between vertical midline of lower lip and oral commissure between affected and unaffected side, measured in degrees. Smaller values reflect more symmetry.

[e] Symmetry refers to difference in position relative to midline of lower lip vermillion-cutaneous border between affected and unaffected side, measured in millimeters. Smaller values reflect more symmetry.

Table 4. Postoperative Outcome Assessment With Respect to the Nerve Used

	Mean (SD)		
	Trigeminal (n = 43)[a]	Facial (n = 35)[b]	*P* Value[c]
Affected side			
Excursion[d]	8.7 (3.5)	6.5 (2.9)	.006
Δ Angle[d]	5.2 (6.3)	7.1 (5.5)	.39
Symmetry (angle)[d]			
Repose	4.7 (3.5)	4.5 (2.3)	.91
Smile	4.3 (4.3)	4.8 (3.1)	.21
Symmetry (length)[d]			
Repose	4.7 (3.9)	4.2 (3.5)	.47
Smile	5.9 (3.9)	4.1 (3.4)	.03

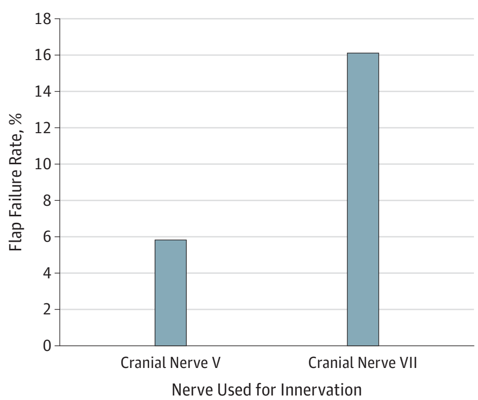
[a] Trigeminal refers to innervation via the ipsilateral masseteric branch of the trigeminal nerve.

[b] Facial refers to innervation from the contralateral facial nerve via a cross-face nerve graft.

[c] The *P* values are based on a Wilcoxon rank-sum test.

[d] See Table 3 footnotes for description.

Figure 3. Gracilis Flap Failures by Nerve



The y-axis shows the percentage of total flaps innervated by the nerve denoted on the x-axis that failed over the study period. *P* = .09 by Fisher exact test.

used, assessment of pulse pressure, oral commissure overcorrection, and outcome in the study or failure cohorts (**Table 5**).

Discussion

Our centers' goal was to perform an analysis of smile excursion, assess improvements in facial symmetry, and track different quantitative properties of the gracilis muscle and intraoperative clinical variables to determine if these factors are associated with clinical outcome. Herein, we present data demonstrating that in the experience at a single institution, smile excursion in the frontal plane reaches a mean of 8 mm following GFTT. This value does not represent total excursion because it fails to address Z-plane excursion; nonetheless, it is similar to smile excursion reported in the normal population.[3] The measure simply provides an objective 2-dimensional measure of outcomes and a gauge from which to assess success in the future. From a strictly anatomic and physiologic standpoint, excursion with smile presents a useful tool for measuring surgical success because gracilis contraction following transfer is dependent on the surgeon successfully performing a number of surgical steps, permitting revascularization and reinnervation of the muscle and eventually translation of muscle contraction to the modiolus and oral commissure. Although many of the outcome parameters improved significantly following GFTT, symmetry at repose with regard to length did not, though lack of statistical power may have masked a potential true difference in a larger population (Table 3).

The decrease in excursion with smile on the healthy side following GFTT is not surprising. In the flaccid face, the normal side of the face may contract unopposed by contralateral mimetic muscle contraction. However, following gracilis inset, the normal side of the face experiences the force of an opposing vector from the gracilis muscle, which results in decreased smile excursion on the normal side. A similar rationale explains the preoperative negative excursion with smile on the affected side. During smile, the normal side contracts, thereby displacing the contralateral oral commissure to the normal side. This displacement is considered negative because the vector of movement is toward the contralateral side of the face.

Patient-reported outcome measures such as the Facial Clinimetric Evaluation (FaCE) Scale may provide more clinically relevant indices[5] from which to measure success. In the future, we plan to analyze FaCE scores in patients following GFTT to determine if associations between the outcomes assessed in Table 3 and FaCE scores exists. Moreover, observer-based studies that show less ocular scrutiny of facial abnormalities following GFTT could also provide a sensitive measure of success.

Smile excursion may not be the most relevant outcome measure of smile reanimation. Facial anatomic differences and discrepancies in zygomaticus major muscle size may account for substantial differences in smile excursion between individuals. Cultural differences in smile appearance also exist and can account for measurable differences in smile excursion between individuals.[6] Nonetheless, studies have found an association between smile intensity and lifespan,[7] indicating that greater smile excursion may be confer a health benefit.

In the present study, we observed that patient age, surgeon perception of quality of the neurorrhaphy, number of sutures used during the neurorrhaphy, flap ischemia time, and pulse pressure were not associated with excursion or symmetry outcomes. However, this study was limited by its sample

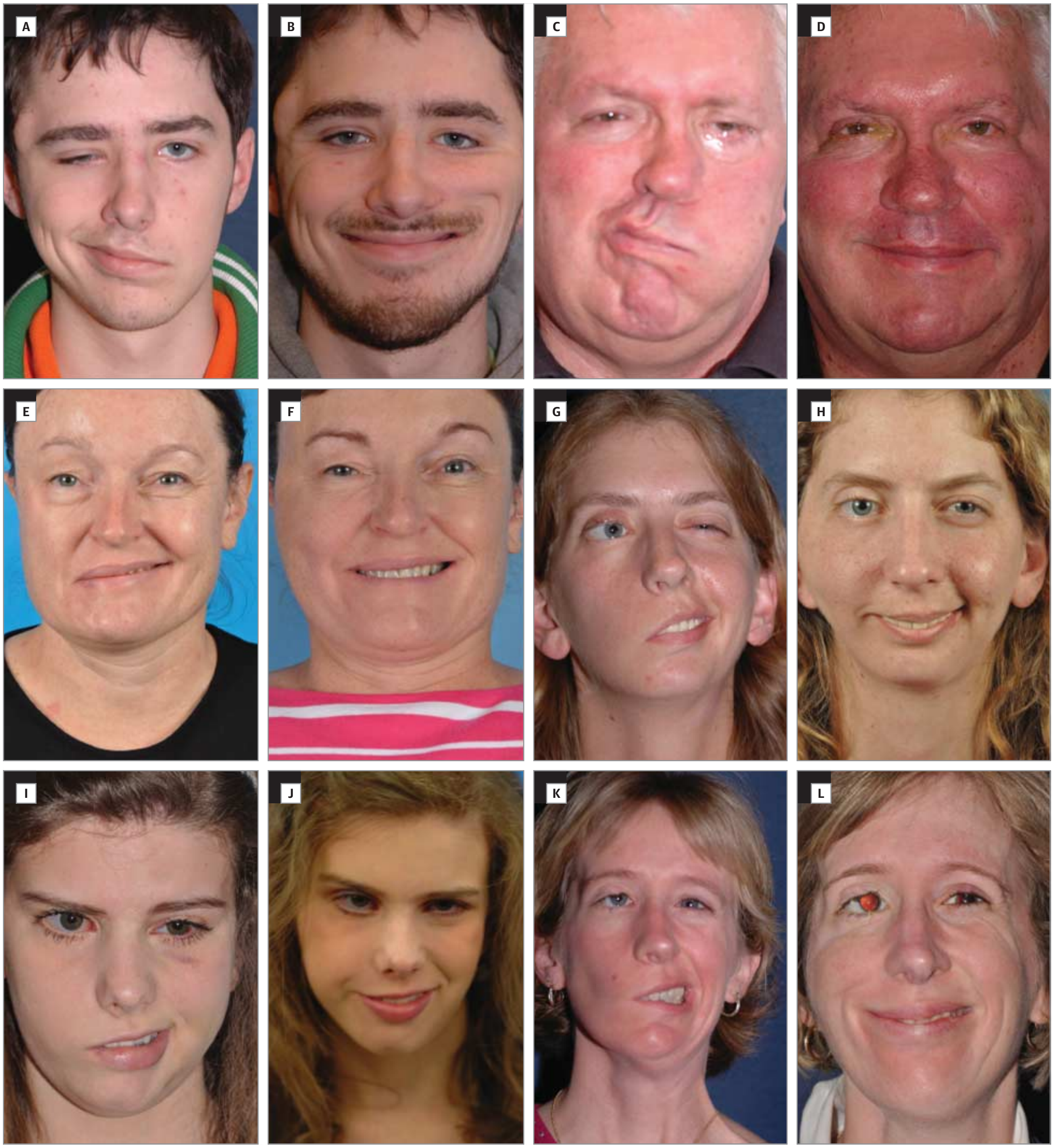
Table 5. Regression Analysis

Independent Variable	95% Confidence Interval[a]		
	Excursion, Affected Side	Δ Angle, Affected Side	Symmetry With Smile (Length)
Contractility proportion	0.002 to 5.6[b]	−3.3 to 5.6	−1.7 to 4.5
Internal recoil proportion	−2.7 to 3.3	−8.3 to 3.7	−7.2 to −1.2[b]

[a] 95% Confidence intervals were obtained using robust regression and represent the change in the dependent variable associated with a change from quartile 1 to quartile 3 in the independent variable.

[b] $P < .05$.

Figure 4. Preoperative and Postoperative Images Following Gracilis Free Tissue Transfer



Preoperative (A, C, E, G, I, and K) and postoperative (B, D, F, H, J, and L) photographs. Patients 1, 2, and 3 (A-F) had innervation of the gracilis from the masseteric branch of the trigeminal nerve, and patients 5 and 6 (I-L) via a cross-face nerve graft coapted to the contralateral facial nerve. Patient 4 (G and H) had a gracilis innervated by both the masseteric branch of the trigeminal nerve and the contralateral facial nerve via a cross-face nerve graft.

size, therefore lacking power to detect small associations that may be statistically significant.

We identified 2 statistically significant associations between intraoperative measurements and outcome. Specifically, patients in the third quartile of contractility proportion had greater excursion with smile compared with those in the first quartile; flaps with more contraction during stimulation of the obturator nerve had increased postoperative smile excursion. Similarly, patients in the third quartile of internal recoil proportion exhibited better postoperative symmetry compared with those in the first quartile, indicating that less foreshortening of the gracilis following the muscle cuts (prior to nerve stimulation) is optimal.

The finding that smile excursion was greater in trigeminally innervated flaps is consistent with other reports in the literature.[8] The masseteric branch of the trigeminal nerve has a robust axon count, and increased throughput of these axons into the obturator nerve compared with those from a cross-face nerve graft likely accounts increased smile excursion. In addition, 2 neural coaptation sites are required when innervating the gracilis from a cross-face nerve graft, introducing more opportunity for axonal loss at the neurorrhaphy sites. The finding that smile symmetry was better in flaps innervated by the facial nerve is not surprising because the neural stimulus to both the zygomaticus major on the normal side and the gracilis on the paralyzed side arise from a common neural origin. However, this does not account for the differences in muscle characteristics between the zygomaticus major and the transplanted gracilis.

In this study, we were not able to identify a difference in flap failure rate based on the nerve used for flap innervation (Figure 3), although the tendency toward higher failure rates in cross-face innervated flaps is consistent with current observations regarding flap failure rates. **Figure 4** demonstrates several typical examples of outcomes following GFTT innervated by the trigeminal and facial nerves.

The number of GFTT performed on an annual basis has increased since the inception of the Facial Nerve Center at our institution. It appears that failure rates were higher on average during the first several years of our practice; the decrease in failure rate may be associated with the technological advances that we have used (venous couplers, color Doppler ultrasonography to monitor blood flow through the pedicle, illuminated retractors, and split operating beds for harvest of the flap). It would be interesting to investigate whether case volume and these technological advances are associated with improved outcomes. Multi-institutional collaboration and a larger sample size would be required for such studies.

Conclusions

Gracilis free tissue transfer is a reliable procedure for dynamic reanimation of the paralyzed oral commissure. Successful muscle transfers result in measureable improvements in smile excursion and oral commissure symmetry, and both muscle recoil and contractility parameters relate to final outcome. We were unable to discern a difference between failure rates based on the nerve used, but such a difference may exist. Larger, prospective studies are indicated to better define associations between intraoperative gracilis muscle parameters and outcomes.

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Study concept and design: Bhama, Weinberg, Lindsay, Cheney, Hadlock.
Acquisition of data: Bhama, Weinberg, Lindsay, Hohman, Cheney, Hadlock.
Analysis and interpretation of data: Bhama, Weinberg, Lindsay, Cheney, Hadlock.
Drafting of the manuscript: Bhama, Cheney, Hadlock.
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