Blink Restoration in Adult Facial Paralysis

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Background: Impaired eyelid function in facial paralysis patients is a serious disability that can even threaten vision. Eye reanimation techniques and specifically blink restoration reinstates the cornea's protective mechanism and recovers a more natural appearance and eye function. Both dynamic and static procedures have been used to augment eye closure, but only dynamic procedures can lead to blink restoration. In this study, the experience of a single surgeon (J.K.T.) with dynamic procedures addressing the challenge of blink restoration is presented.

Methods: A retrospective review of 95 adult patients who underwent dynamic procedures for blink restoration was performed. The patients were divided into two groups. Group A ($n = 75$) included patients who underwent nerve transfers, including cross-facial nerve grafting and subsequent microcoaptations, mini-hypoglossal nerve transfers, and direct orbicularis oculi muscle neurotization. Group B ($n = 20$) included patients who underwent eye sphincter substitution procedures, including pedicled frontalis or mini-temporalis transfers, free platysma, occipitalis, gracilis subunits, extensor digitorum brevis, and a slip of adductor longus transfer. Objective blink ratios were measured according to a protocol established by the senior author (J.K.T.).

Results: The patients included 34 men and 61 women. Mean age was 34.9 ± 9.8 years. Denervation time ranged from 7 months to 42.12 years, and the mean denervation time was 13.02 years. Blink improvement was noted in all of the patients. Blink scores and ratios were consistently better in group A than in group B.

Conclusion: Dynamic procedures provide the functional substrate on which subsequent static procedures can be performed and aid blink return. (*Plast. Reconstr. Surg.* 126: 126, 2010.)

Facial paralysis has detrimental effects for patients, including severe facial deformities, impairment of the function of the eyelids, and loss of the protective mechanism of the blink reflex. Corneal exposure and lack of protection of the globe lead to serious complications such as corneal abrasions, exposure keratopathy, epiphora, and loss of vision. Initial treatment aims at preserving vision, followed by eyelid function restoration.[1]

Static and dynamic procedures have been described for eyelid function restoration. Although static procedures have no effect in restoring the physiologic mechanism of the blink reflex,[2–9] they comprise a significant alternative that improves blink and eye closure in cases of partial return of blink after initial reanimation stages and in aged, noncompliant patients with modest expectations.[9] Dynamic procedures are used to restore the reflex pathway or as a substitute for the muscular substrate involved in blinking. They consist of cross-

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facial nerve grafting, direct neurotization of the orbicularis oculi muscle, various nerve transfers, and local and free muscle transfers.

A retrospective review of patients who underwent dynamic procedures was performed to evaluate their effect on blink restoration and to present evidence-based recommendations and surgical planning. Dynamic blink reflex restoration comprised a part of multistage facial reanimation procedures. However, smile and depressor restoration procedures are not considered in this study.

HISTORICAL REVIEW

Gordon in 1951[10] described eyelid function in detail, and Rushworth in 1962[11] published his work on the analysis of blink reflex evoked by different stimuli. Zappella in 1967[12] studied the light-evoked blink reflex in newborns, providing the basis for further electrophysiology studies such as that of Shahani in 1970.[13] Bender et al.[14] in 1969 described the use of the blink reflex in the diagnosis of facial paralysis.

Penders and Delwaide published in 1971 their electromyographic study of the blink reflex in patients with parkinsonism and facial paralysis.[15] Armington in 1978[16] described a means of diagnosing facial paralysis using blink reflex recordings. Kilimov and Linke in 1978[17] showed in patients who had undergone facial-to-hypoglossal anastomosis that the first component of the blink reflex is not monosynaptic and that the second component is most strongly influenced by alteration of the intrabulbar and efferent parts of the reflex circuits. Berardelli et al.[18] studied the second component of the blink reflex in 1985. Catalano et al. in 1995[19] published their guidelines for the management of paralyzed eyelids in facial paralysis. In 2002, Terzis and Bruno[20] published the outcomes of a large series of patients who underwent eye reanimation procedures, offering additional insight into the management of patients with facial paralysis.

Findings from animal models have also increased understanding of the physiology of the blink reflex. Lindquist and Mårtensson[21] in 1970 described the blink reflex mechanism in a cat model, whereas Black-Cleworth et al.[22] in 1975 demonstrated a conditioned blink obtained by using electrical stimulation of the facial nerve in a similar cat model. Martin and Biscoe in 1977[23] presented their extended physiologic studies in rat models. Otto et al. in 1986[24] described a method of electrical restoration of the blink reflex in the rodent model. In 1992, Hockman et al.[25] compared the use of the contralateral orbicularis oculi muscle flap and the neuromuscular pedicle flap technique for restoring the function of the orbicularis oculi muscle in a cat and a dog model. In 1992, Salerno et al.[26] demonstrated a method of restoration of the paralyzed orbicularis oculi muscle using a controlled electrical current in dogs.

In 1994, Terrell and Terzis[27] introduced an experimental model for studying the blink reflex in which findings were correlated to methods of current clinical practice, leading to useful evidence-based suggestions. Thanos and Terzis[28] in 1995 reported a comprehensive motor endplate analysis of denervated and reinnervated orbicularis oculi muscle in rats, and in 1998, Kalantarian et al.[29] presented the superior results of the "babysitter" procedure, introduced by Terzis in 1984.[30]

PATIENTS AND METHODS

A retrospective review of the charts of 140 patients with facial paralysis between January of 1981 and January of 2007 was performed. Only patients who underwent eye closure and blink restoration procedures with adequate follow-up (2 years) were included. Patient demographics and cause of facial paralysis are listed in Table 1.

Preoperative Evaluation

All patients were evaluated meticulously before any decision and planning. A detailed medical and surgical history, physical examination, neurologic assessment of all cranial nerves, and the specifics regarding the onset and cause of the paralysis, obstetric history, and previous treatments were prerequisites for patient inclusion.

Table 1. Patient Demographics and Cause of Facial Paralysis

	Group A	Group B	Total
Total patients	75	20	95
Male	21	13	34
Female	54	7	61
Mean age, years	23.8 ± 5.3	45.8 ± 4.4	34.9 ± 9.8
Mean DT, years	6.42	19.72	13.02
LFP	27	14	41
RFP	45	6	51
BFP	3	0	3
Trauma	16	6	22
Developmental	10	5	15
Posttumor extirpation	39	9	48
Bell palsy	3	2	5
Idiopathic	1	0	1
Secondary to infection	1	0	1
MS	2	1	3

DT, denervation time; LFP, left facial paralysis; RFP, right facial paralysis; BFP, bilateral facial paralysis; MS, Möbius syndrome.

Needle electromyography and nerve conduction studies were also inclusion criteria. When indicated, additional investigations, including computed tomography of the facial nerve canal in the temporal bones bilaterally and magnetic resonance imaging, were performed.

Preoperative evaluation included continuous video and photographic documentation according to an established standardized protocol. Each patient was videotaped in a seated position, with a custom-made head restrainer for stabilization of the head and avoidance of lateral movements. The patients were then asked to look straight at the camera and to perform a specific series of functions including closing their eyes lightly and then tightly several times. To study involuntary blinking, each patient was asked not to blink deliberately or close their eyes for 4 minutes while the video camera was recording.

Postoperative Evaluation

The same videotape recording and documentation of blinking was also performed postoperatively and in every follow-up visit using the same established protocol, under the same conditions. Involuntary blinking was similarly measured using the Terzis and Bruno methodology,[20] and blink ratios were also obtained (Fig. 1).

Four independent investigators reviewed the preoperative and postoperative video recordings of all the patients and rated the preoperative blink impairment and the postoperative blink return according to the established grading system shown in Table 2.

The independent investigators did not participate in any stage of patient care. The senior author (J.K.T.) did not participate in the scoring of functional outcomes.

Study Groups

Patients were divided into two groups. Group A ($n = 75$) included patients who underwent nerve transfers alone. In this group, 49 cross-facial nerve grafting procedures and subsequent microcoaptations with eye sphincter branches of the involved side were performed, in addition to 11 mini-hypoglossal nerve transfers and 26 direct orbicularis oculi muscle neurotization procedures (Table 3).

Group B ($n = 20$) included patients who underwent eye sphincter substitution procedures. In this group, eight pedicled frontalis transfers, three pedicled temporalis transfers, four free platysma transfers, two free gracilis subunits transfers, one free extensor digitorum brevis transfer, one free occipitalis transfer, and one free adductor longus transfer were performed. Six corneal neurotization procedures[31] were also included in this study (Table 4).

Seventy-five patients underwent a single dynamic procedure, 16 underwent two procedures, and one patient underwent three dynamic procedures. The most common dynamic procedure was cross-facial nerve grafting.

Statistical Analysis

The Wilcoxon signed rank test was used in the analysis of preoperative and postoperative scores (Table 2). These scores comprise ordinal, Likert-type scale data. Paired t tests were used in the analysis of preoperative and postoperative blink ratios. When comparing blink improvement between more than two groups, analysis of variance was performed. Values of $p < 0.05$ were considered statistically significant.

RESULTS

Postoperative improvement in blink scores was significant for all the dynamic procedures ($p < 0.023$). Sex, age, and the cause of facial paralysis were among the factors with no statistically significant effect on blink improvement. There was a statistically significant negative correlation (Spearman's rank correlation coefficient $r_s = -0.32$ for $\alpha = 0.05$) between the number of dynamic procedures performed in each patient and preoperative blink scores.

In group A, cross-facial nerve grafting and concomitant mini-hypoglossal transfer was the procedure that yielded higher improvement in blink scores and ratios compared with the rest of the dynamic procedures. Direct orbicularis oculi muscle neurotization achieved a fair blink improvement in patients with the highest preoperative ratio. The aforementioned findings were statistically significant (Table 3).

In group B, frontalis transfer achieved higher improvement in blink return in patients with the second lower preoperative ratio. The highest preoperative and postoperative blink ratio was observed in patients who underwent temporalis transfer (Table 4).

Preoperative and postoperative blink scores in each group are shown in Table 5. Blink ratios, improvement, and denervation time in each group are shown in Table 6. There was one case of residual right upper eyelid edema that was treated conservatively. Representative cases are

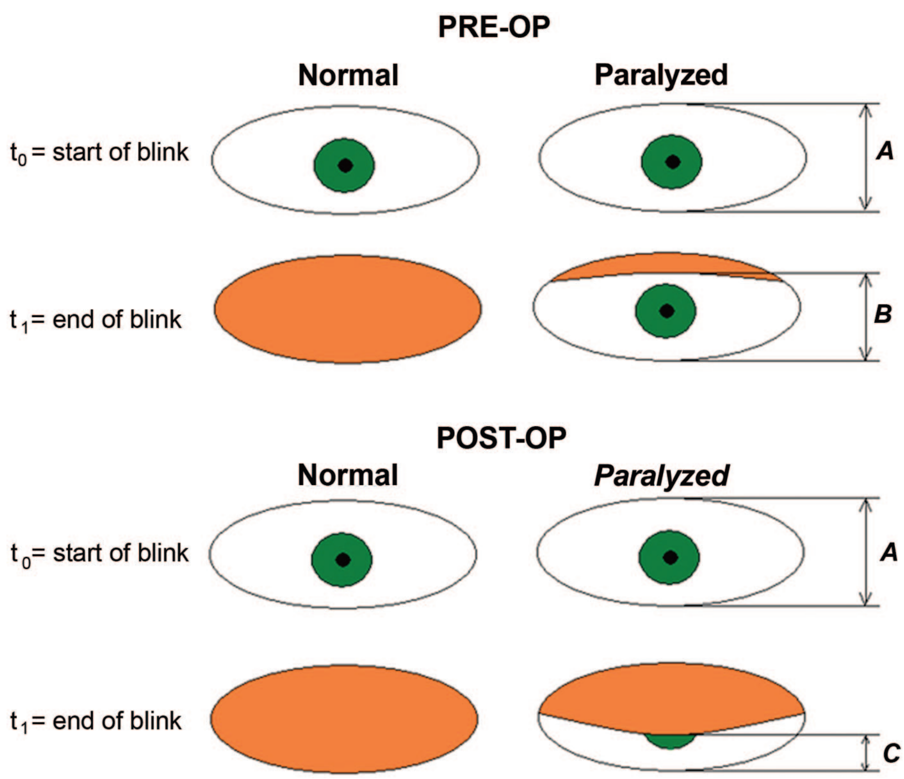

Fig. 1. Interpalpebral distance ratios measurement: t_0 = blink reflex start; t_1 = blink reflex end, before the normal upper eyelid reopens; A = the interpalpebral distance at rest; B = the preoperative interpalpebral distance at t_1; C = the postoperative interpalpebral distance at t_1. Ratios: $(A - B) \times 100/A$ = preoperative ratio percentage; $(A - C) \times 100/A$ = postoperative ratio percentage; blink improvement percentage = postoperative ratio percentage – preoperative ratio percentage. During frame-by-frame reviewing of the videos, in the first frozen frame, the interpalpebral distance of the paralyzed eye at the midpupillary line is measured using a metric ruler on the video monitor, with the patient looking forward. By advancing the video frame by frame, the point where the normal eye begins the blink phase is noted. Advancing proceeds until the normal eye achieves full closure and right before it reopens. At this point, the interpalpebral distance of the paralyzed eye is measured again. These measurements are performed three times for each preoperative and postoperative blink video and the mean values are obtained. Errors attributable to differences in distances between the patient and the video camera, and in variable zoom and video analysis, are eliminated by reporting blink ratios instead of millimeters. Each ratio is calculated by dividing the measured interpalpebral distance at the point of complete blink attempt by the same distance at rest and is converted into a percentage. Improvement in blink ratios was also calculated by subtracting the preoperative from the postoperative blink ratio.

Table 2. Scoring System for Eye Closure and Blink*

	Grading of Blink		
Group	Grade	Designation	Description
I	1	Poor	No blink
II	2	Fair	Minimal blink (contraction)
III	3	Moderate	Initiation of blink present but only one-third amplitude
IV	4	Good	Some coordinated blink but only two-thirds amplitude
V	5	Excellent	Synchronous and complete blink present

*From Terzis JK, Bruno W. Outcomes with eye reanimation microsurgery. *Facial Plast Surg.* 2002;18:101–112.

Table 3. Dynamic Procedures, Motor Donors, Preoperative and Postoperative Ratios, and Improvement in Group A in the Adult Population*

Procedure	Motor Donor	Preoperative Ratio (%)	Postoperative Ratio (%)	Improvement (%)†	No. of Times Performed	p
CFNG	VII (cOOM)	19.35	40.68	21.33	43	0.03
XII-VII plus CFNG	XII (ips) and VII (cOOM)	17.12	39.24	22.12	6	0.049
XII-VII plus direct OOM neurotization	XII (ips) and VII (cOOM)	20.15	35.67	15.52	5	0.049
Direct OOM neurotization	VII (cOOM)	22.9	38.15	15.25	18	0.04
	VII (c mandibular)	21.8	36.25	14.45	2	
	XII (ips)	22.7	34.95	12.25	1	
Total					75	

CFNG, cross facial nerve grafting; XII-VII, hypoglossal-to-facial nerve transfer; OOM, orbicularis oculi muscle; VII (cOOM), contralateral facial nerve (branches for the OOM); VII (c mandibular), contralateral facial nerve (mandibular branch); XII (ips), ipsilateral hypoglossal nerve.
*Group A consisted of the patients who underwent various nerve transfers for blink restoration.
†Improvement is the mean difference between the objective postoperative and preoperative blink ratios and represents the percentage gain in blink using each nerve transfer procedure (statistically significant results for $p < 0.05$).

Table 4. Dynamic Procedures in Group B in the Adult Population*

Procedure	Preoperative Ratio (%)	Postoperative Ratio (%)	Improvement (%)†	No. of Times Performed	p
Frontalis	6.30	18.66	12.36	8	0.04
Temporalis	11.02	21.04	10.02	3	NS
Free platysma	8.45	16.21	7.76	4	NS
Free gracilis subunit	7.62	15.15	7.53	2	NS
Free extensor digitorum brevis	3.33	12.97	9.64	1	NS
Free occipitalis	7.72	14.97	7.25	1	NS
Free adductor longus	9.24	16.97	7.73	1	NS
Total				20	

NS, not statistically significant (statistically significant results for $p < 0.05$).
*Group B consisted of the patients who underwent various muscle transfers for blink restoration.
†Improvement is the mean difference between the objective postoperative and preoperative blink ratios and represents the percentage gain in blink using each muscle transfer procedure.

Table 5. Preoperative and Postoperative Blink Scores in Groups A and B

Procedures	Preoperative Blink Score	Postoperative Blink Score
Group A		
CFNG	2	4
XII-VII plus CFNG	1	4
XII-VII plus direct OOM neurotization	1	4
Direct OOM neurotization	2	4
Group B		
Frontalis	1	4
Temporalis	2	4
Free platysma	1	3
Free gracilis subunit	1	3
Free extensor digitorum brevis	1	2
Free occipitalis	1	3
Free adductor longus	2	3

CFNG, cross-facial nerve grafting; XII-VII, hypoglossal-to-facial nerve transfer; OOM, orbicularis oculi muscle.
Group A and B consisted of the patients who underwent various nerve and muscle transfers for blink restoration, respectively. The values are the median blink scores obtained by the four independent investigators according to the grading system shown in Table 2.

shown in Figures 2 through 9. (**See Videos, Supplemental Digital Content 1 through 16,** which demonstrate the preoperative and postoperative blink videos of patients shown in Figures 2 through 9; hyperlinks to view videos and descriptions are available in the Appendix.)

DISCUSSION

The blink reflex is an automated, involuntary, rapid movement of the eyelids elicited by stimulation of the cornea. One of the roles of the reflex is to protect the eye from foreign bodies and intense light.

Intense sounds greater than 40 to 60 dB can also evoke the blink reflex. Several types of stimuli, including corneal, cutaneous, acoustic, visual, and electrical, have been studied.[32–36] The orbicularis oculi muscle response, in particular, can be evoked both by mechanical stimulation of the cornea (corneal reflex) and by electrical stimulation of the skin overlying the supraorbital nerve (blink reflex). Mechanical stimuli to the cornea activate A delta and C free nerve endings of the corneal mucosa. Electrical stimuli to the supraorbital

Table 6. Preoperative and Postoperative Ratios and Achieved Improvement in Groups A and B in the Adult Population

Group*	Preoperative Ratio (%)	Postoperative Ratio (%)	Improvement (%)†	Mean DT (mo)
A	19.84	38.07	18.23	75.8
B	7.67	16.56	8.89	236.6

DT, denervation time.
*Group A consisted of patients who underwent various nerve transfers for blink restoration; group B consisted of patients who underwent various muscle transfers for blink restoration.
†Improvement is the mean difference between the objective postoperative and preoperative blink ratios and represents the percentage gain in blink using each nerve or muscle transfer procedure.

Fig. 2. A 34-year-old woman presented with right partial facial paralysis secondary to excision of a lymphangioma tumor in the right neck when she was 7 months old. A major portion of the facial nerve had to be resected at that time. At 7 years of age, she had a tensor fascia lata sling to the right commissure performed elsewhere. The patient is seen during her first office visit to our center (*above*). Note the absence of blink on the right side. The patient underwent a cross-facial nerve grafting procedure followed 1 year later by secondary microcoaptations of the upper cross-facial nerve graft carrying "eye" fibers of the left eye sphincter to eye branches of the right upper zygomatic nerve for reinnervation of the right eye sphincter. The patient is seen postoperatively 2 years after the completion of the cross-facial nerve grafting procedure (*below*). The preoperative blink reflex score was 2 and the postoperative score was 4.

nerve activate A beta, A delta, and C fibers of the nerve trunk.

Electrical stimulation of the supraorbital nerve evokes the trigeminofacial reflex, consisting of an early R1 (oligosynaptic) component on the ipsilateral side with an onset latency of 9 to 12 msec; R2, a bilateral (polysynaptic) polyphasic burst with a latency of 25 to 35 msec; and R3, a bilateral polyphasic component with a latency of 70 to 90 msec. Different methods of stimulus and response measurements are important in research.[32,33] R1 is a pontine component and R2 is a medullary–C1 component. R1 and R2 can be evoked by innocuous stimuli by means of A β-afferents, but the R2 response is also triggered by pain or heat, suggesting that the R2 is mediated by a wide, dynamic range of neurons of the spinal trigeminal nucleus.[33,34]

Stimulation of the cornea on one side would result in closing both eyelids. The pathways include sensory fibers in the ophthalmic division of the trigeminal nerve that pass into its chief sensory nucleus.[35,37] The result is the closing of both eyelids on stimulation of one cornea (Fig. 10).

Only a small number of studies addressing blink restoration with dynamic procedures can be found in the current literature.[38,39] Willer et al.[38] described heterotopical sprouting of trigeminal neurons toward hypoglossal motoneurons in eight patients with complete unilateral facial paralysis who underwent hypoglossal-to-facial nerve transfers. All of the patients showed significant clinical recovery and the development of a short-latency trigeminal-hypoglossal R1 blink reflex, demonstrating the influence of the periphery in central nervous system remodeling. However, in another study by Willer et al.,[39] six patients with facial paralysis who had undergone hypoglossal-to-facial nerve transfer showed that this new short-latency trigeminal-hypoglossal blink reflex could not be facilitated by ipsilateral and contralateral infralaminar supraorbital nerve stimulation in the same way that the R1 blink reflex on the unoperated side was. These findings suggested partial

Fig. 3. A 22-year-old woman presented with complete left partial facial paralysis following operation on the left ear 8 years previously to remove a cholesteatoma. Two years later, the cholesteatoma recurred and she had repeated surgery performed elsewhere. At that time, the facial nerve was explored and a neuroma was found in the vertical canal of the facial nerve. Nothing was done for the nerve, but with time, there was some improvement in the facial paralysis. This improvement plateaued 5 years ago. The patient remained deaf on the left side. Preoperative needle electromyographs revealed partial innervation of each facial muscle, with the orbicularis oculi being primarily involved. Preoperative blink video revealed incomplete blink in the left eye (*above*). The patient had four cross-facial nerve grafts, and 1 year later, the patient had secondary microcoaptations of the distal ends of the cross-facial nerve grafts with selected branches of the left facial nerve. The preoperative blink reflex score was 3 and the postoperative score was 4. Note the improvement in the blink reflex (*below*).

Fig. 4. A 40-year-old man presented who 20 years earlier had experienced a slow loss of function of his right facial nerve. Five years later (i.e., 15 years before the patient presented to our center), he was operated on elsewhere by an ear, nose, and throat surgeon, who removed a fibroadipose tumor with calcifications at the level of the intramastoid vertical canal of the facial nerve. He was referred to our center 20 years after the onset of his symptoms, with a diagnosis of right facial paralysis secondary to extirpation of a facial nerve tumor. (*Above*) Preoperative blink video discloses minimal blink on the right eye. (*Below*) Postoperative blink video after cross-facial nerve grafting procedure and direct neurotization 2 years later of the orbicularis oculi muscle with the upper cross-facial nerve graft carrying "eye" fibers from the contralateral facial nerve. The preoperative blink reflex score was 3 and the postoperative score was 4. Note appreciable improvement of the blink reflex in the right eye.

restoration of the physiologic pathway of the blink reflex and the unpredictable nature of central connectivity remodeling that follows peripheral hypoglossal-to-facial nerve transfer.

In 1995, Danziger et al.[40] described the central mediation and return of the short-latency R1 blink reflex on the operated side of a patient who underwent surgical ablation of acoustic neuroma necessitating the removal of a large part of the facial nerve. One month later, the patient underwent peripheral spinal accessory–to–facial nerve transfer to provide reinnervation of the facial muscles using the spinal accessory motor axons. Their electrophysiologic study on the same patient 20 years later indicated heterotopic sprouting of axons of trigeminal neurons from the principal trigeminal

Fig. 5. A 32-year-old woman presented who was born as the ninth child to a 40-year-old mother after a full-term uncomplicated pregnancy. Outlet forceps were used. After visits to multiple centers for her left developmental facial paralysis, and after various suspension operations performed elsewhere with facial static slings, the patient was referred to our center. (*Above*) Preoperative blink video. Note nearly absent blink in the left eye. (*Below*) Postoperative blink video obtained after cross-facial nerve grafting and, 1 year later, direct neurotization of the left orbicularis oculi muscle with the upper zygomatic branch that supplied the eye. The preoperative blink reflex score was 3 and the postoperative score was 4. Note adequate return of the blink reflex, which is nicely synchronized with the blink of the right eye through the upper cross-facial nerve graft (*below*).

Fig. 6. A 42-year-old man presented who had first begun to notice a gradual right facial palsy when he was 14 years old. One year later, he had a complete right facial palsy. For 7 years, his diagnosis was right Bell palsy. Soon afterward, he underwent a fascia lata suspension of the mouth and lower lip performed elsewhere. A few years later, he had a face lift on the right cheek. Nine years after the onset of his symptoms, he was diagnosed with an intraosseous schwannoma of the facial nerve, and this was excised elsewhere. After several additional operations performed in various centers, he presented to our center. (*Above*) Preoperative blink video of the patient. Note incomplete blink in the right eye. (*Below*) Postoperative blink video obtained after cross-facial nerve grafting procedure and, 2 years later, pedicle transfer of the left frontalis to the right eye sphincter with neurotization of the frontal branch of the left facial nerve with the upper cross-facial nerve graft. The preoperative blink reflex score was 2 and the postoperative score was 4. Note improvement in the blink reflex (*below*).

nucleus toward the nearest motoneurons of the spinal nucleus of the accessory nerve. Although it was the first time these findings were reported, this was a single-patient study lacking confirmation from larger series.

In all of the aforementioned studies,[38–40] electrophysiologic demonstration of significant R1 blink component return was provided. Nevertheless, there was no direct association of the outcomes with the type of the procedure in earlier follow-up stages and no comparison with outcomes of other procedures; and the results concerned patients with short-term, complete, unilateral facial paralysis alone. Conversely, in our center, a large number of patients with diverse facial palsy causes were included, and the appropriate procedure was decided depending on specific indications and according to a standard sur-

Fig. 7. A 51-year-old woman is shown who in 1975 was diagnosed as having a glomus jugular tumor. The tumor was resected and she had to have three more operations to resect the recurrences. The final operation was performed in 1978, and since then she has been tumor free. She was referred to our center 8 years after her last operation with a right facial paralysis. (*Above*) Preoperative blink video. Note absence of blink reflex in the right eye. (*Below*) Postoperative video after facial reanimation procedures that included cross-facial nerve grafting procedure, free pectoralis minor muscle to the right cheek, and a minitemporalis pedicle muscle transfer to substitute for the missing right eye sphincter. The preoperative blink reflex score was 2 and the postoperative score was 3. Note improvement in the blink video (*above*).

gical decision and planning algorithm specifically addressing blink restoration.[20]

The senior author (J.K.T.) explored the possibilities in eye sphincter substitution with other muscles by studying all of the available transplantable muscles in the body. The use of the frontalis and platysma for eye sphincter substitution has been described previously.[20,41,42] After the introduction of frontalis and platysma for eye sphincter substitution, the occipitalis muscle was attempted as part of this exploration, as were subunits of the gracilis, extensor brevis, and adductor longus.

The advantages of the free occipitalis muscle are that it shares the same type and morphology (excursion, tension, thickness, innervation density) with the frontalis, and it is available in facial trauma cases where the use of the frontalis is contraindicated. The harvest is challenging because of the complexity of the region and the variable dimensions of the posterior auricular nerve, and transfer requires preparation in the anatomy laboratory.

In the early 1970s, Thompson and Gustavson[43] used the extensor brevis as a free graft for eye closure without performing microvascular transfer. They initially positioned the muscle on top of the unaffected orbicularis oculi muscle to achieve neurotization and then tunneled its tendons to the contralateral paralyzed side to achieve eye clo-

Fig. 8. A 48-year-old man is shown who had experienced a sudden onset of facial paralysis in 1968 before resection of a left cholesteatoma. After this operation, he had no hearing in his left ear and a complete left facial paralysis. Nineteen years later, he was referred to our center. (*Above*, *left*) Preoperative blink video. Note complete absence of blink in his left eye. The patient had four cross-facial nerve grafts and, 1 year later, a free gracilis muscle for smile restoration. Two years later, the patient had medial canthoplasty and a microvascular transfer of the right occipitalis muscle for left eye sphincter substitution. (*Above*, *right*) The free occipitalis muscle after harvesting and after contouring it for orbicularis oculi substitution. (*Below*, *left*) The free occipitalis muscle on the left eye before insetting. Microvascular anastomoses took place between the superficial temporal vessels and the occipitalis vascular pedicle. The supplying nerve (a branch of the right facial nerve) was coapted to the upper cross-facial nerve graft, which was carrying "eye" fibers from the right facial nerve. (*Below*, *right*) Postoperative blink video. The preoperative blink reflex score was 2 and the postoperative score was 3. Note restoration of the left blink reflex.

sure. No reproduction of these results has been reported since then.

In group A, nerve transfer procedures appear to yield better results than the muscle transfer procedures in group B. One reason could be the fact that nerve transfers were performed in patients with considerably shorter denervation time (Table 6), implying that the orbicularis oculi muscle was not completely atrophied, nor was there excessive fibrosis or degenerative changes near the facial nerve lesion.[44] It could, therefore, be suggested that treatment has to be strictly individualized and surgical planning should rely primarily on detailed preoperative needle electromyographic and nerve conduction studies. Early cases where needle electromyography of the orbicularis oculi muscle elicits fibrillations are indicative of the presence of muscle, and a cross-facial nerve grafting procedure is indicated. In later cases, when there is electrical evidence of some muscle present but it is denervated, a mini–hypoglossal-to-facial nerve transfer is performed. In long-lasting facial paralysis with silent needle electromyographs and total orbicularis oculi muscle denervation, the initial cross-facial nerve grafting stage is usually followed by a muscle substitution procedure. The patient's health condition, age, and expectations are always important concerns during surgical planning.

Fig. 9. A 26-year-old man is shown who fell from 15 feet of scaffolding and landed on his head in 1986. He sustained a frontoparietal temporal bone fracture with an intracerebral and epidural hematoma. He also injured the left facial nerve and the left eighth nerve. He was referred to our center in 1987 for facial reanimation procedures. (*Above*) Preoperative blink video. Note complete absence of blink in his left eye. The patient had cross-facial nerve grafting procedure and a free segmental extensor brevis muscle transfer 1 year later to the left upper and lower eyelid for eye closure and blink restoration. The segmental extensor brevis was vascularized from the superficial temporal vessels and innervated by the upper cross-facial nerve graft. (*Below*) Postoperative blink video. The preoperative blink reflex score was 2 and the postoperative score was 3. Note appreciable improvement of the blink reflex.

In our study, improvement regarding the use of mini muscle transfers (subunits of free gracilis, extensor digitorum brevis, occipitalis, and adductor longus transfers) was not statistically significant. Nevertheless, to our knowledge, this is the first time that the successful use of a slip of the free extensor digitorum brevis, a segment of the free occipitalis, and a sliver of the free adductor longus for eye sphincter substitution has been reported.

The differences in outcomes among the various donor muscles used for transfer were not statistically significant. The negative correlation between the number of dynamic procedures performed in each patient and preoperative blink scores and the absence of significant correlation between postoperative blink scores and the total number of dynamic procedures are explained by the fact that the patients with the more severe cases of facial paralysis needed additional procedures, whereas the postoperative outcome was not affected by the total number of procedures. Blink improvement was noted in all patients.

To restore corneal sensibility in cases with unilateral facial paralysis and corneal anesthesia, a novel procedure was introduced by the senior author in which corneal neurotization is carried out using sensory branches of the supratrochlear and supraorbital nerves, which are tunneled across the bridge of the nose and inserted around the limbus of the contralateral eye.[31] Several patients underwent static procedures in subsequent stages, following dynamic procedures after the postoperative evaluation was performed and when the progress of blink return caused by dynamic procedures alone was considered complete (Table 7). Static procedures included the use of palpebral eye springs, gold weights, mini-tendon (palmaris longus) grafts, mini-tendon grafts and eye springs, and mini-tendon grafts and gold weights.[7,9]

Postoperative (poststatic) blink ratios were obtained using the Terzis and Bruno methodology[20] and compared with those from the dynamic procedures alone. Blink improvement was noted because static procedures augmented the results achieved by the dynamic procedures, and it ranged from 17 percent (mini-tendon group in group B_s) to 44 percent (mini-tendon graft and eye spring group in group A). Results were statistically significant only in group A_s.

It is important to note that the effect of static procedures depends largely on the dynamic procedures effect that they augment. Static procedures alone cannot achieve such improvement because they have no effect on the physiologic mechanism of the blink reflex.

CONCLUSIONS

It is apparent that dynamic blink restoration has been a rather neglected area in facial reanimation. Eye reanimation comprises an integral part in facial paralysis treatment. Dynamic procedures constitute the cornerstone of blink restora-

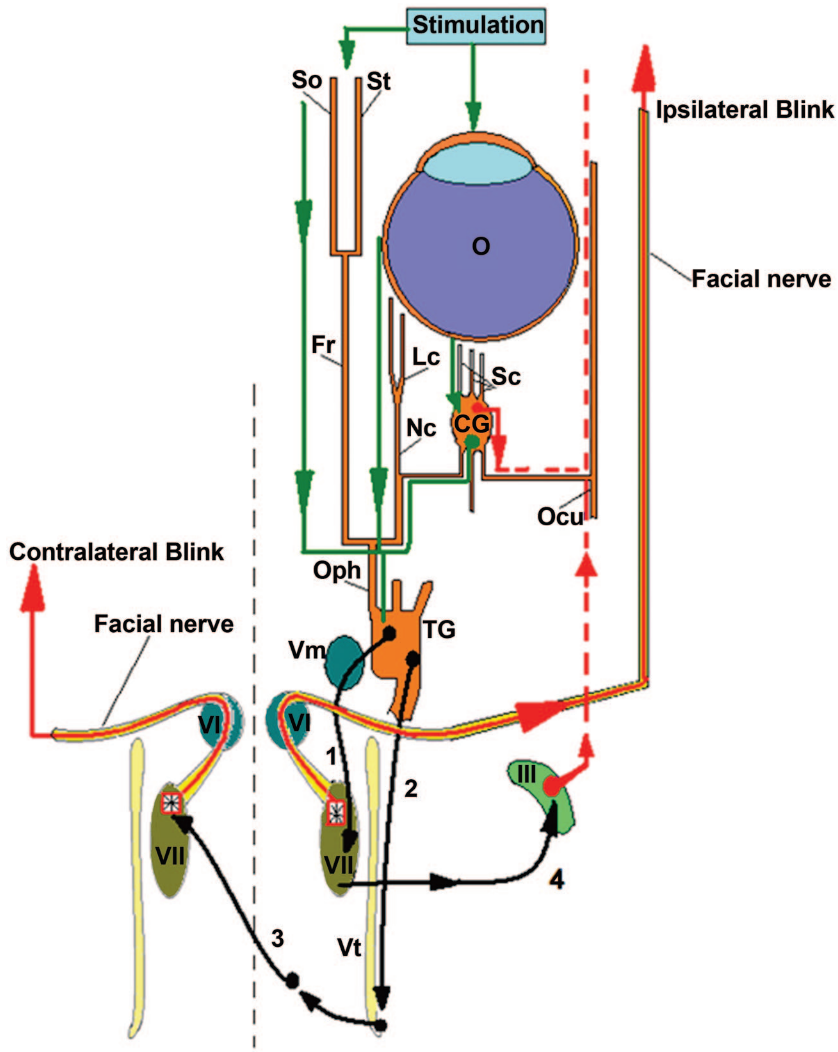

Fig. 10. Blink reflex pathway. *So*, supraorbital nerve; *St*, supratrochlear nerve; *O*, orbit; *Fr*, frontal branch of the ophthalmic branch; *Lc*, long ciliary nerves; *Sc*, short ciliary nerves; *CG*, ciliary ganglion; *Nc*, nasociliary branch; *Oph*, ophthalmic nerve; *TG*, trigeminal ganglion; *Ocu*, oculomotor nerve; *Vm*, trigeminal motor nucleus; *VI*, abducens nucleus; *VII*, facial nucleus; *Vt*, spinal trigeminal tract; *III*, oculomotor nucleus; *1*, trigeminal-to-facial internucleus neuron pathway; *2* and *3*, trigeminal-to-contralateral facial internucleus neuron pathway.

tion by providing the functional substrate on which subsequent static procedures can be performed and aid the amplitude of blink return. Nerve transfers and reinnervation of the orbicularis oculi muscle offer the most desirable results. In late cases, muscle transfers can substitute for the lost function of the eye sphincter with acceptable results.

The aim of the study has not been to show which dynamic procedure is best for blink restoration in general but to investigate more advantageous surgical options for the adult blinkless patient. Neurophysiology and basic science advances have greatly enriched the perspectives of evaluating the outcome of surgical procedures and planning. Assessment of postoperative blink return based solely on dynamic procedures offers adequate evidence and support for further studies in this delicate area of eye reanimation. Static procedures and biofeedback considerably augment the final outcome.

Obtaining reliable measurements of blink improvement is constantly reviewed and addressed. Digital analysis and computation systems are continuously progressing. In addition, a rather immeasurable factor is the psychological effect that

Table 7. Patients Who Underwent Static Procedures in Subsequent Stages, following Dynamic Procedures*

	Group A_s (n = 33)				Group B_s (n = 6)			
Procedures	No.	Prestatic (%)	Poststatic (%)	p	No.	Prestatic (%)	Poststatic (%)	p
ES	10	36.7	71	0.03	1	10	34	NS
GW	8	35.2	60.2	0.035	1	7.5	28	NS
M	32	37.8	55.4	0.02	1	8.4	25	NS
M/ES	18	34.6	78.8	0.025	2	12.3	46.5	NS
M/GW	16	35.2	74.5	0.029	1	7.7	43	NS
Total procedures	84					6		

ES, palpebral eye spring; GW, gold weight; M, mini-tendon (palmaris longus) graft; M/ES, mini-tendon graft and eye spring; M/GW, mini-tendon graft and gold weight; NS, not statistically significant (statistically significant results for $p < 0.05$).
*Group A_s (33 of a total of 75 in group A) consisted of the patients who underwent various static procedures after undergoing nerve transfers for blink restoration. Group B_s (six of a total 20 in group B) consisted of the patients who underwent various static procedures after undergoing muscle transfers for blink restoration. Prestatic is defined as the mean blink ratio in patients who were scheduled for static procedures after the effect of dynamic procedures was complete and evaluated (prestatic ratio = postdynamic ratio). Poststatic is defined as the mean postoperative blink ratio in patients who underwent static procedures.

blink restoration has on the patient for whom corneal protection and improved health spell a far higher quality of life.

APPENDIX

Supplemental Digital Content 1, http://links.lww.com/PRS/A169. Preoperative blink video of patient shown in Figure 2.

Supplemental Digital Content 2, http://links.lww.com/PRS/A170. Postoperative blink video of patient shown in Figure 2.

Supplemental Digital Content 3, http://links.lww.com/PRS/A171. Preoperative blink video of patient shown in Figure 3.

Supplemental Digital Content 4, http://links.lww.com/PRS/A172. Postoperative blink video of patient shown in Figure 3.

Supplemental Digital Content 5, http://links.lww.com/PRS/A173. Preoperative blink video of patient shown in Figure 4.

Supplemental Digital Content 6, http://links.lww.com/PRS/A174. Postoperative blink video of patient shown in Figure 4.

Supplemental Digital Content 7, http://links.lww.com/PRS/A175. Preoperative blink video of patient shown in Figure 5.

Supplemental Digital Content 8, http://links.lww.com/PRS/A176. Postoperative blink video of patient shown in Figure 5.

Supplemental Digital Content 9, http://links.lww.com/PRS/A177. Preoperative blink video of patient shown in Figure 6.

Supplemental Digital Content 10, http://links.lww.com/PRS/A178. Postoperative blink video of patient shown in Figure 6.

Supplemental Digital Content 11, http://links.lww.com/PRS/A179. Preoperative blink video of patient shown in Figure 7.

Supplemental Digital Content 12, http://links.lww.com/PRS/A180. Postoperative blink video of patient shown in Figure 7.

Supplemental Digital Content 13, http://links.lww.com/PRS/A181. Preoperative blink video of patient shown in Figure 8.

Supplemental Digital Content 14, http://links.lww.com/PRS/A182. Postoperative blink video of patient shown in Figure 8.

Supplemental Digital Content 15, http://links.lww.com/PRS/A183. Preoperative blink video of patient shown in Figure 9.

Supplemental Digital Content 16, http://links.lww.com/PRS/A184. Postoperative blink video of patient shown in Figure 9.

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PATIENT CONSENT

Patients provided written consent for use of their images.

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