Dynamic Reconstruction of Eye Closure by Muscle Transposition or Functional Muscle Transplantation in Facial Palsy

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For patients with facial palsy, lagophthalmus is often a more serious problem than the inability to smile. Dynamic reconstruction of eye closure by muscle transposition or by free functional muscle transplantation offers a good solution for regaining near-normal eye protection without the need for implants. This is the first quantitative study of three-dimensional preoperative and postoperative lid movements in patients treated for facial paralysis. Between February of 1998 and April of 2002, 44 patients were treated for facial palsy, including reconstruction of eye closure. Temporalis muscle transposition to the eye was used in 34 cases, and a regionally differentiated part of a free gracilis muscle transplant after double cross-face nerve grafting was used in 10 cases. Patients' facial movements were documented by a three-dimensional video analysis system preoperatively and 6, 12, 18, and 24 months postoperatively. For this comparative study, only the data of patients with preoperative and 12-month postoperative measurements were included. In the 27 patients with a final result after temporalis muscle transposition for eye closure, the distance between the upper and lower eyelid points during eye closing (as for sleep) was reduced from 10.33 ± 2.43 mm (mean ± SD) preoperatively to 5.84 ± 4.34 mm postoperatively on the paralyzed side, compared with 0.0 ± 0.0 mm preoperatively and postoperatively on the contralateral healthy side. In the resting position, preoperative values for the paralyzed side changed from 15.11 ± 1.92 mm preoperatively to 13.46 ± 1.94 mm postoperatively, compared with 12.17 ± 2.02 mm preoperatively and 12.05 ± 1.95 mm postoperatively on the healthy side. In the nine patients with a final result after surgery using a part of the free gracilis muscle transplant reinnervated by a zygomatic branch of the contralateral healthy side through a cross-face nerve graft, eyelid closure changed from 10.21 ± 2.72 mm to 1.68 ± 1.35 mm, compared with 13.70 ± 1.56 mm to 6.63 ± 1.51 mm preoperatively. The average closure for the healthy side was from 11.20 ± 3.11 mm to 0.0 ± 0.0 mm preoperatively and from 12.70 ± 1.95 mm to 0.0 ± 0.0 mm postoperatively. In three cases, the resting tonus of the part of the gracilis muscle transplant around the eye had increased to an extent that muscle weakening became necessary.

Temporalis muscle transposition and free functional muscle transplantation for reanimation of the eye and mouth at the same time are reliable methods for reconstructing eye closure, with clinically adequate results. Detailed analysis of the resulting facial movements led to an important improvement of the authors' operative techniques within the last few years. Thus, the number of secondary operative corrections could be significantly reduced. These qualitative and quantitative studies of the reconstructed lid movements by three-dimensional video analysis support the authors' clinical concept of temporalis muscle transposition being the first-choice method in adult patients with facial palsy. In children, free muscle transplantation is preferred for eye closure, so as not to interfere with the growth of the face by transposition of a masticatory muscle. In addition, a higher degree of central plasticity in children might be expected. (*Plast. Reconstr. Surg.* 114: 865, 2004.)

Functional problems around the eye are usually a first priority for the patient with facial palsy. The reduced or missing protection of the vulnerable cornea leads to a continuous need for artificial tears, ointment, or occlusion with a wet chamber. Impaired vision, corneal ulceration, conjunctivitis, tearing, and an increased sensibility of the eye to light, wind, or sun may impair the quality of everyday life. Working capacity is usually limited if dust, intensive light, wind, and sun play a role, and

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even working at a computer is not possible for long periods. For long-standing and irreversible facial palsy, we use temporalis muscle transposition to the eye[1,2] or part of a free gracilis muscle transplant with one of its fascicular territories reinnervated by an additional cross-face nerve graft supplied by branches of the orbicularis oculi muscle of the healthy side.[3–5] Implants[6] are considered only if muscle transposition is not possible due to loss of temporalis muscle function, or if the surgical intervention must be kept to a minimum because of general conditions or the patient's wishes.

Since exact quantitative and qualitative analysis of facial movements became possible when Frey et al.[7,8] introduced three-dimensional video analysis in 1999, different surgical procedures can be evaluated and compared for their functional output in reanimation of the paralyzed face. This analysis allows for comparison of the functional result of eye closure, the static and dynamic symmetry achieved, the occurrence of synkinesia, and the relief from symptoms, and it may lead to an optimized concept for treatment of the problems in the orbital region of the paralyzed face. The purpose of this article is to present the results of our clinical study, which is the first quantitative and three-dimensional study of preoperative and postoperative lid movements in patients treated for facial palsy.

Patients and Methods

Patients

Between February of 1998 and April of 2002, 44 patients were treated for facial palsy, including reconstruction of eye closure, at our unit. The causes of the facial palsy are listed in Table I. All patients undergoing dynamic reconstructions had irreversible lesions. The irreversibility had been proven by diagnostic measures or the lesion had been present without any onset of recovery for more than 2 years. Temporalis muscle transposition was used for reconstruction of the eye sphincter in 34 patients, and a regionally differentiated part of a free gracilis muscle transplant after cross-face nerve grafting was used in 10 patients. In this study, 27 of the 34 temporalis transposition patients and nine of the 10 free gracilis muscle transplant patients had results 12 months postoperatively. The mean age ($\pm$SD) of the patients in the temporalis group at the start of surgery was 42.8 ± 15.4 years (17 women and 10 men). The mean age in the gracilis muscle transplant group was 30.7 ± 20.2 years (six female patients and three male patients).

Before starting treatment at our institution, five of the 27 temporalis transposition patients and four of the nine gracilis muscle transplant patients had undergone an operation to correct lagophthalmus, with no useful functional result (Table II).

Operative Techniques

Two different methods were used for dynamic reconstruction of eyelid closure: temporalis muscle transposition was used in adult patients, and a territorially differentiated part of a free gracilis muscle transplant in combination with a cross-face nerve graft was used mainly in children with congenital lesions and in adults with no further possibility of using the temporalis for eye sphincter reconstruction.

The technique described by Gillies and Millard[1] was used, with some modifications (Fig. 1), as described here. The temporalis muscle is exposed by a preauricular skin incision, which is elongated into the hair-bearing temporal area vertically with a bow-like incision toward the hairline. In a complete, irreversible lesion, no care has to be taken with the branches of the facial nerve, and subcutaneous fat tissue is removed onto the lateral orbital rim to prevent

TABLE I
Causes of Facial Nerve Palsy

Cause of Palsy	Type of Treatment: Temporalis Muscle Transposition (n = 27)	Type of Treatment: Gracilis Muscle Transplantation (n = 9)
Idiopathic	5	2
Congenital	0	3
Posttraumatic	2	0
Tumor (central nervous system)	12	2
Tumor (peripheral)	6	1
Infection	2	1

TABLE II
Previous Operative Treatment

	No. of Patients
Temporalis transposition group (n = 27)	
Gold implant (upper eyelid)	1
Functional gracilis muscle transplant	1
Cross-face nerve grafting + spring implant	2
Neurotization of VIIth by XIth cranial nerve	1
Gracilis muscle transplantation group (n = 9)	
Myocutaneous latissimus dorsi flap	1
Temporalis transfer	3

a bulging deformity by creating space for the transposed part of the muscle. A 2- to 2.5-cm-wide central strip of the temporalis is mobilized by cutting the temporal fascia and the muscle with two parallel vertical incisions down to the temporal bone. The posterior incision has to be somewhat longer than the anterior incision to keep the transposed muscle fibers under the same resting tension. The anterior fibers have to go a shorter distance than the posterior fibers, and it is very important that the ventrally neighboring temporal fascia is maintained intact. It can then function as a hypomochlion for the muscle fibers of the transposed part. Otherwise, the fibers altering their direction of pull by about 90 degrees will not be effective to the eyelids during contraction. At this point, a 1-cm strip of temporal fascia is taken from its anterior part just next and parallel to the hypomochlion. It is taken in maximal length from the temporal line down to the zygomatic arch, where it separates to the superficial and deep layers of the temporal fascia with some fat tissue in between. This procedure again creates additional space for the muscle to be transposed. The fascial strip is divided into two equal strips about 5 mm wide. The central part of the temporalis is mobilized subperiosteally and divided for 2 cm at the end into equal slips. The two slips of the muscle are elongated with the prepared fascial strips, which are sutured to the ends by nonabsorbable 4-0 sutures. Two tunnels are created by blunt dissection. A thread of silk is pulled through each tunnel in the upper and lower eyelids using special scissors with a hole in the tip. The tunnel in the upper eyelid should be made bow-like, with some distance from the lid edge. That way, the lateral pull of the transposed temporal muscle will push down the upper eyelid more efficiently. Complete closure is realistically obtained. In contrast, the tunnel in the lower lid has to be as near to the

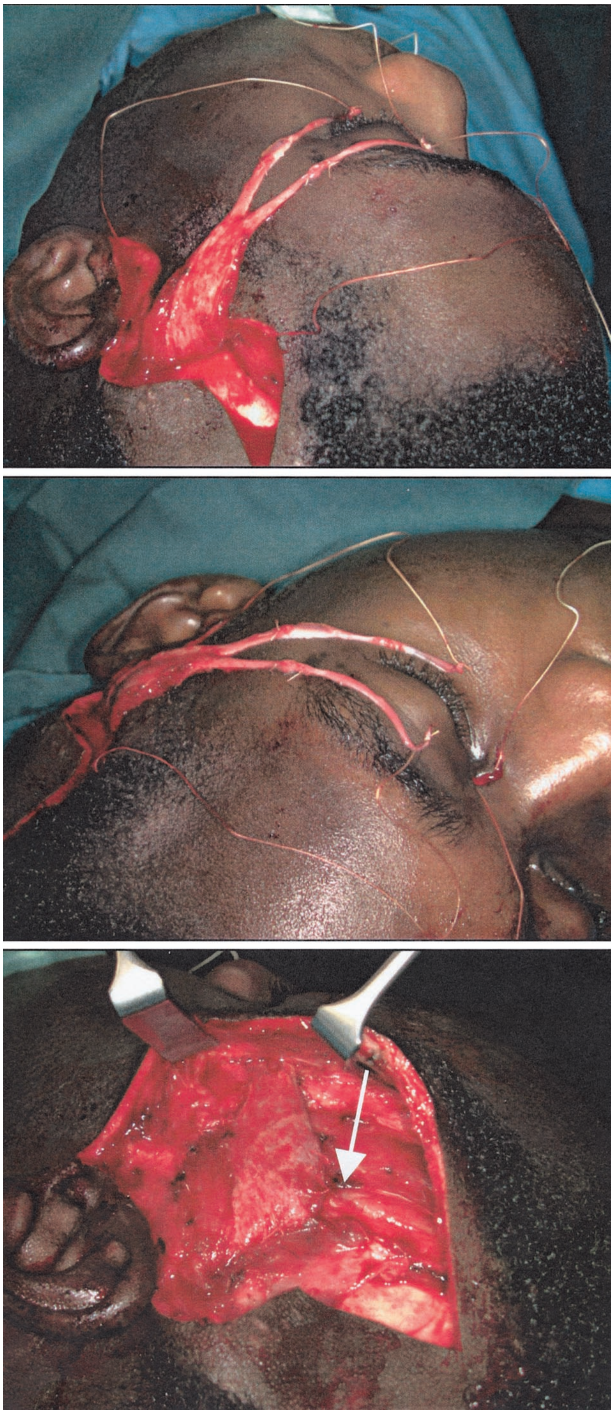

FIG. 1. Modified technique of temporalis muscle transposition to the eye to restore eye closure on the irreversibly paralyzed left side of an adult patient. (*Above*) Transposition of the central part of the muscle, distally split and elongated by strips of temporal fascia. The ends of the strips are pulled through the tunnels prepared in the upper and lower eyelids and behind the anterior part of the medial palpebral ligament, where the ends are fixed with nonabsorbable sutures. (*Center*) The fascial strips rest on the skin to demonstrate the course of the tunnels. (*Below*) The muscle is transposed over a hypomochlion, which is formed by the remaining anterior part of the temporal fascia (*arrow*). The correct tension and the direction of pull in the transposed muscle are fixed.

lid edge as possible to prevent or correct ectropion of the lower lid as much as possible. The anterior crus of the medial palpebral ligament is exposed by a small angled incision of the overlying skin. The elongated muscle slips are pulled through the tunnels. The fascial strips are both brought behind the ligament and sutured carefully to the ligament with nonabsorbable 4-0 sutures. The tension of the two slips of transposed temporalis is of crucial importance. The lower slip needs overcorrection for good lasting support of the lower eyelid, which has a tendency to sag because of gravity. The upper slip is at risk of too much tension, which can cause an asymmetrically narrow lid fissure if it is too tight, or of too little tension, which can cause ineffective sphincter function during contraction of the transposed temporalis. Some fine-tuning of the resting tension is still possible by placing some stabilizing fixation sutures between the rims of the temporal muscle and the fascial strip serving as hypomochlion in the temporal region. This is probably the most important part of the operation, as it has a great impact on the functional result. The remaining posterior part of the temporalis is now mobilized, leaving the temporal fascia behind, and the mobilized part of the muscle is used to fill up the depression at the donor site of the transposed part. In that way, a donor-site deformity is prevented. In the majority of patients, temporalis transposition is combined with a cross-face nerve graft during the same operation to prepare for a free gracilis muscle transplant to the cheek for smile reconstruction 8 to 10 months later.

Free gracilis muscle transplantation is shown in Figure 2. One of the two functional territories of the gracilis muscle is used for eye sphincter replacement, while the other muscular territory is used for reanimation of the mouth region. Muscle transplantation with microneurovascular anastomoses is performed 8 to 10 months after double cross-face nerve grafting between a zygomatic branch and a temporal branch of the facial nerve on the contralateral healthy side and the paralyzed side of the face. Eight to 10 months are necessary for the regenerating facial nerve fibers to reach the distal ends of the cross-face nerve grafts. The Tinel sign is an excellent tool to clinically monitor the progress of nerve regeneration. The possibility of separating the gracilis muscle into two functional territories was first described by Manktelow and Zuker in 1984.[3] Soon after this report, we used both territories of innervation of the gracilis muscle to reconstruct the eye sphincter and the levator muscles of the mouth region at the same time as the gracilis transplant. We prefer to use this procedure when treating children. In our opinion, masticatory muscles should not be touched at this young age, so as to prevent negative effects on the growth of the facial skeleton. In adults, we use a free gracilis muscle transplant for eye closure if the temporalis muscle is no longer available for transposition.

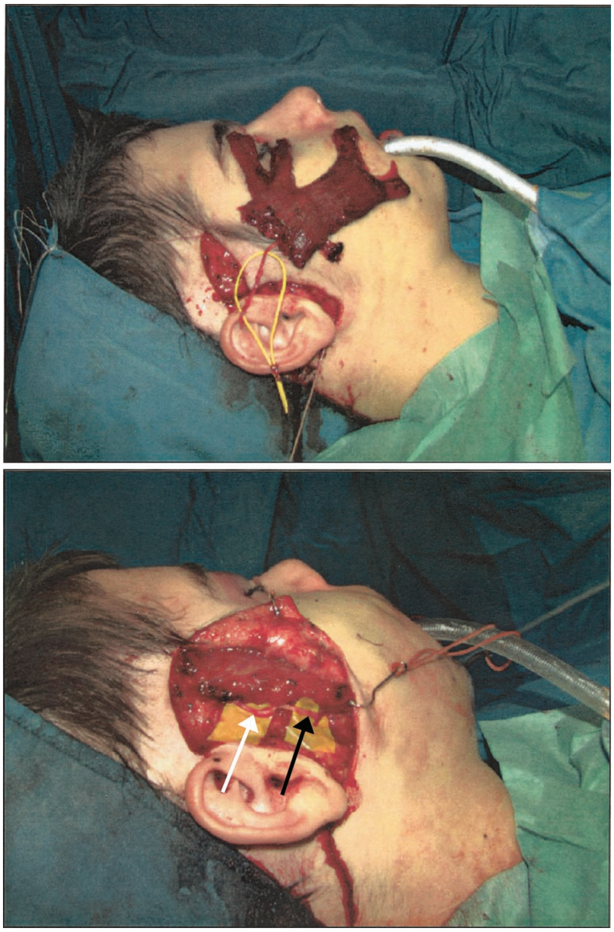

FIG. 2. Gracilis muscle transplantation for eye closure. At 10 months after double cross-face nerve transplantation, one territory of the gracilis muscle supplied by one of the two nerve fascicles of the motor nerve of the muscle transplant is used to reconstruct the eye sphincter in a child with congenital facial nerve palsy. (*Above*) The gracilis muscle transplant is carefully designed with three fingers for the upper lip, the corner of the mouth, and the lower lip and with two fingers for the upper and lower eyelids. (*Below*) The muscle graft is well perfused after neurovascular microanastomoses to the superficial temporal vessels and the distal ends of the two prepared cross-face nerve grafts (*white arrow*, cross-face nerve graft to the eye; *black arrow*, cross-face nerve graft to the mouth).

The gracilis muscle is exactly tailored while still in situ and under the original resting tension at the medial thigh. Anesthesia should be carried out without muscle relaxation. After identification of the dominant proximal vascular pedicle and the muscle nerve as a branch of the obturatorius nerve, the muscle nerve is separated into two fascicles. The territories innervated by the two fascicles are identified by electrostimulation. The degree of overlapping of the two territories of innervation will influence the degree of synkinesia of the muscle parts used for the eye and mouth region. Clearcut territories will make the movements of both regions independent and only controlled by their own cross-face nerve graft. About two thirds of the width of the muscle is used for transfer; the length depends on the needs of the recipient site in the face. The greater territory is split distal to the muscle hilus into three strips, which are exactly planned before division according to the face measurements. The shortest strip is used for the corner of the mouth, the midsize strip is used for the upper lip, and the longest strip is used for the lower lip. The other territory is split into two strips, a thin one for the upper lid and a thicker one for the lower eyelid. This should prevent a too strong closure of the upper lid during rest. At the same time, the strip for the lower eyelid should give good support against gravity and prevent ectropion. Documentation of the resting tension by using a stretched silk thread sutured to the surface of the muscle gives the chance to put the muscle transplant under the same resting tension in the recipient area after transfer.[9] The recipient bed in the face has to be prepared before ligation of the vascular pedicle of the gracilis muscle graft. From a preauricular face lift incision, tunnels are dissected toward the upper and lower eyelids. The medial palpebral ligament is exposed by an angular incision, and two long threads are pulled through the tunnels. When the gracilis muscle is transferred to the face, the two muscle strips are carefully pulled through the prepared tunnels in the upper and lower eyelids. The muscle origin is attached at the temporal fascia with 2-0 nonabsorbable sutures. The muscle strips are then positioned behind the palpebral ligament and fixed there with 4-0 nonabsorbable sutures under correct tension. At the end of the operation, slight overcorrection is intended. After fixation of the other muscle parts to the perioral region, the vascular anastomoses are performed on the superficial temporal vessels under the microscope. Finally, the distal ends of the two cross-face nerves are coapted to the two fascicles of the gracilis muscle nerve. Great care has to be taken that the cross-face nerve graft connected to the zygomatic nerve branch at the healthy side is sutured to the correct nerve fascicle supplying the territory used for the eye sphincter reconstruction. Marking of one of the fascicles with a 10-0 suture at the donor site is recommended for correct matching later on in the recipient area.

Documentation of Clinical Symptoms

The outcome of surgery was evaluated using the following clinical parameters: need for an eye chamber, ointment, or artificial tears for protection; susceptibility to wind or sun; incidence of conjunctivitis; and tiring while reading.

Three-Dimensional Video Analysis of Facial Movements and Functional Assessment

Since opening the Laboratory for Image and Movement Analysis at the Division of Plastic and Reconstructive Surgery, University Hospital of Vienna, in January of 1998, all patients treated for facial paralysis have been documented systematically in a prospective study design. The details of this documentation system were published together with its statistical methods in 1999[7]; they are also part of the International Registry for Neuromuscular Reconstruction in the Face. In all patients, three-dimensional video analysis of the standardized facial movements was performed preoperatively and 6, 12, 18, and 24 months postoperatively. For this comparative study, only the data of patients with measurements preoperatively and 12 months postoperatively were included. The study was performed under the strict ethical guidelines for clinical studies of the medical faculty of the University of Vienna. All recordings of facial movements were performed with the informed consent of the patients.

Results

Additional Corrections

All 36 patients included in this study were evaluated prospectively and 12 months after the final operation. As we had recently described our three-stage concept of surgical treatment of irreversible facial palsy,[5] almost all of our patients took advantage of additional, final operative corrections some time after the functional reconstruction (Table III). The corrections around the eye were usually performed during the operation to improve the resting symmetry of the face or the dynamic symmetry of the smile.[5] The advantage of a further correction at the eye depended on the definite degree of functional recovery and the aesthetic appearance of the eye fissure.

Twelve of the 27 temporalis transposition patients obtained further improvement with additional surgery. In four patients, the dynamic sling around the eye had to be tightened up, a procedure which we combined with another to support the lower eyelid with a thin part of a palmaris longus tendon graft fixed to the medial palpebral ligament and the lateral orbital rim. Five lateral tarsorrhaphies were performed, mainly with the aim of reducing the scleral show and normalizing the form of the eye on the paralyzed side for aesthetic reasons. Further improvement of eye closure was obtained by implanting a gold weight in one patient, and in another patient, the preexisting extensive lateral tarsorrhaphy could be released because sufficient eye closure had been established by the temporal muscle transposition.

Five of the nine gracilis muscle transplant patients had additional corrections at the eye. Three reductions of the contracting part of the transplant at the upper eyelid had become necessary because function was too strong. One result was improved by a lateral tarsorrhaphy. One patient had further surgery 15 years after free gracilis muscle transplantation because tightening of the muscle transplant and blepharoplasty of both upper eyelids became necessary due to the changes of aging.

TABLE III
Operative Corrections after Surgical Treatment

	No. of Patients
Temporalis transposition group (*n* = 27)	
Gold implant (upper eyelid)	2
Lateral canthopexy	5
Tightening of reins, static sling (palmaris longus tendon)	4
Reversal of tarsorrhaphy	1
Gracilis muscle transplantation group (*n* = 9)	
Resection of muscle sling in upper eyelid	3
Lateral canthopexy	1
Tightening of muscle sling, blepharoplasty	1

Clinical Improvement of the Symptoms of Paralysis

All patients experienced significant improvement of their symptoms. None of the patients had to continue to wear a wet eye chamber, and all had a significant reduction in their use of artificial tears. Twenty of 27 temporalis transposition patients and all nine patients who underwent gracilis muscle transplantation for the eye had no more need of ointment to protect the cornea, and artificial tears were not used on a regular basis but only with strong wind or extreme light exposure. Seven patients in the temporalis transposition group did not achieve excellent improvement but had sufficient protection of the cornea and needed artificial tears two to three times a day. In addition, these patients found that the operation had significantly improved their daily lives and they were satisfied by the result and did not want further correction.

Three-Dimensional Video Analysis of Eye Closure

In the 27 patients with a final result after temporalis muscle transposition for eye closure, the distance between the upper and lower eyelid points during eyelid closure as for sleep was reduced from 10.33 ± 2.43 mm (mean ± SD) preoperatively to 5.84 ± 4.34 mm postoperatively on the paralyzed side, compared with 0.0 ± 0.0 mm preoperatively and postoperatively on the contralateral healthy side. In the resting position, preoperative values for the paralyzed side changed from 15.11 ± 1.92 mm preoperatively to 13.46 ± 1.94 mm postoperatively, compared with 12.17 ± 2.02 mm preoperatively and 12.05 ± 1.95 mm postoperatively on the healthy side (Fig. 3). Three-dimensional video analysis of eye closure movements revealed that the transposed temporalis muscle contributes significantly to closure during the submaximal movement of eye closure as for sleep, as well as during the maximal movement of eye closure (Figs. 4 and 5).

In the nine patients with a final result after a part of the free gracilis muscle transplant was used for eyelid closure, the distance between the upper and lower lids changed during movement from 10.21 ± 2.72 mm to 1.68 ± 1.35 mm postoperatively, compared with 13.70 ± 1.56 mm to 6.63 ± 1.51 mm preoperatively. The average closure values for the healthy side were from 11.20 ± 3.11 mm to 0.0 ± 0.0 mm preoperatively, compared with 12.70

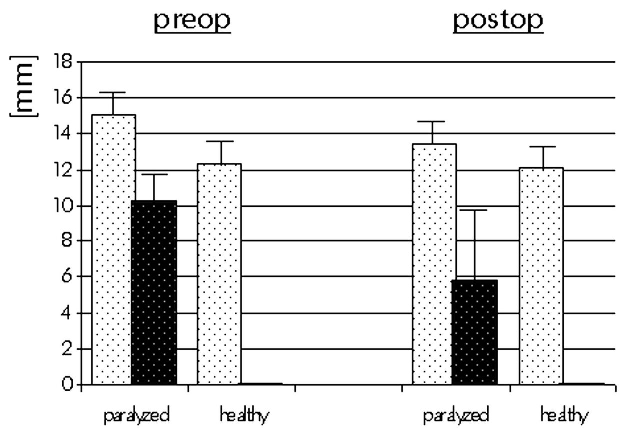

FIG. 3. Distance between the upper and lower eyelids during rest (□) and during closure of the eyelids as for sleep (■) (mean ± SD) in the temporalis muscle transposition group.

± 1.95 mm to 0.0 ± 0.0 mm postoperatively (Fig. 6 and Figs. 7 and 8).

The variability of results was caused by the varying individual local situations and the different preoperative values for lagophthalmus.

Symmetry of Eye Fissure

Symmetry of the eye fissure, when the eyes are at rest and when they are open, is an important aesthetic quality of an eye sphincter reconstruction or of supportive static structures against the effect of gravity at the lower eyelid. The width of the eye aperture was 2.72 ± 1.55 mm wider preoperatively and 1.46 ± 2.28 mm wider postoperatively on the paralyzed side than on the healthy side in the temporalis transposition group; in the gracilis muscle transplantation group, it was 2.50 ± 1.40 mm wider preoperatively but 2.48 ± 1.02 narrower postoperatively on the paralyzed side than on the healthy side. The average difference between the two sides for a normal population without any facial nerve lesion is 0.79 ± 0.55 mm, as we reported recently.[10]

Synkinesia

During closure of the eyes as for sleep, synkinesia was found in that part of the gracilis muscle transplant used around the mouth for reconstruction of the smile in four of the nine patients. When smiling with teeth showing, none of the nine patients showed synkinesia in the part of the transplant used for eye sphincter function.

DISCUSSION

Although several operative techniques with static or dynamic aspects have been proposed to correct lagophthalmus, mainly two techniques of functional eye sphincter reconstruction were used in this study to treat longstanding facial paralysis. The dominance of these two techniques over the numberless techniques reported in the literature has been experienced by our facial paralysis patients for the last three decades. In this recent study, both techniques showed comparably good results, with significant improvement of symptoms in all patients. The free gracilis muscle transplant was somewhat more efficient than the transposed temporalis muscle. This was true with regard to both the clinical results and the measured excursions of the eye closure movements.

Not only was the part of the free muscle graft for the eye able to transmit contractions to the paralyzed eye sphincter, but the transposed part of the temporalis muscle was able to do so as well. We could clearly document this effect using three-dimensional video analysis. Whereas the transposed temporalis muscle has the advantage in the onset of immediate function after the operation, the gracilis muscle transplant achieves stronger functional long-term results. The patients in the latter group should expect symptoms of lagophthalmus for up to 1 year. In the final outcome, however, eye closure is more complete and has a higher amplitude of movement in the gracilis transplant group (Fig. 3). Residual lagophthalmus during eye closure (as for sleep) could be found in some patients in both groups, but a significant reduction of the width of the eye fissure during rest and closure was enough for relief of symptoms. Patients with a remaining lagophthalmus of even 6 mm did not report any complaints with being awake or asleep. There seems to be a critical level of lagophthalmus at which patient complaints increase. There are no studies on this subject in literature, and no data on remaining lagophthalmus have been reported. In our patients, 5 mm of lagophthalmus was the critical point with regard to the start of clinical symptoms.

In both groups, the eye fissure was wider on the paralyzed side than on the healthy side before treatment. Postoperatively, the corrected eye fissure was still somewhat wider during rest in the temporalis transposition patients. After gracilis muscle transplantation, the corrected eye fissure was on average narrower than the fissure on the normal side during rest. This is explained by the higher resting

FIG. 4. Representative example of eye closure function achieved by temporalis muscle transposition in an adult patient with irreversible facial paralysis on the left side after removal of an acoustic neuroma. The clinical result was videotaped using the mirror system, with the three views of the face during rest and closure of the eyes as for sleep. Significant improvement can be seen, with complete closure on the paralyzed side during maximal closure of the eyes. *CES*, closure of eyes as for sleep; *MCE*, maximal closure of eyes.

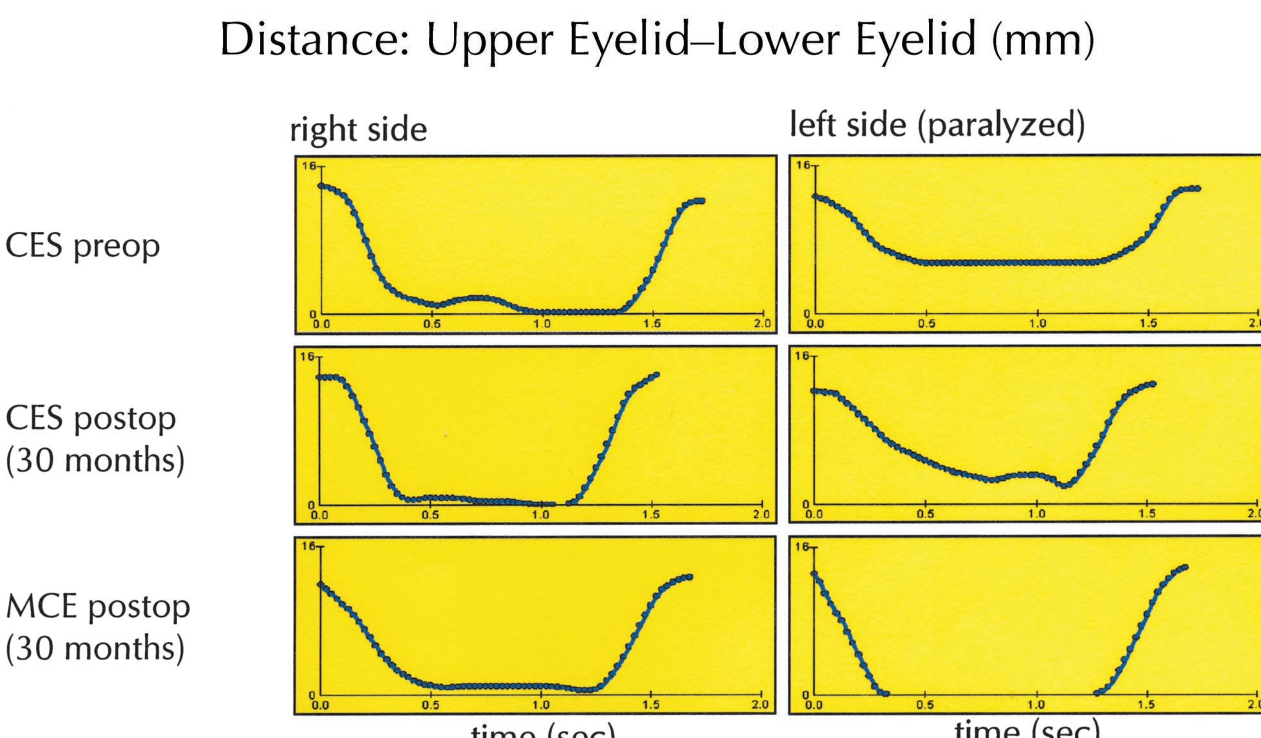

FIG. 5. Two-dimensional graph of the movement on the left paralyzed side and the right healthy side of the patient shown in Figure 4. Significant improvement was seen after temporalis muscle transposition. *CES*, closure of eyes as for sleep; *MCE*, maximal closure of eyes.

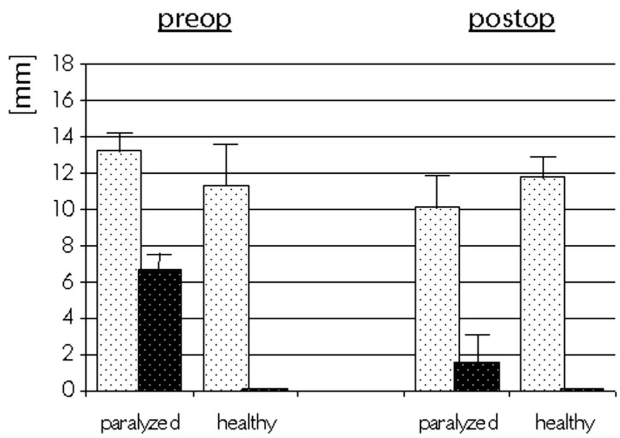

FIG. 6. Distance between the upper and lower eyelids during rest (□) and during closure of the eyelids as for sleep (■) (mean ± SD) in the free gracilis muscle transplant group.

tonus recovered after muscle transplantation. In three of nine patients, the hyperfunction had to be corrected by surgical muscle reduction. We prefer this small intervention in the case of overcorrection to the risk of a final unsatisfying result caused by undercorrection without the additional possibility of functional improvement. The incidence of additional corrections was similar for both techniques (Table III). The aims of further surgery were usually to optimize the new motor system around the eye and improve the symmetry of the eye fissures.

The frequent incidence of final corrections is not a sign of incompetence of the operative procedures under investigation, but is a consequence of the fact that all dynamic procedures are unpredictable in their final functional outcome and in their influence on the symmetry and aesthetic appearance of the eye fissure. This fact is inherent to all regenerative processes of the neuromuscular system. Final corrective procedures are therefore not disadvantages but chances for an optimized overall result. To patients sent to us after reconstruction attempts at other centers, we often had to state that further corrections could upgrade a clinically useless result to a useful result. Secondary corrections are a significant part of the overall outcome in this field of complex surgery.

Continued assessment of functional outcome by three-dimensional video analysis had a significant impact on our surgical techniques. In comparing the objective measurements of the facial movements with the corresponding video clip of the movement, we discovered several reasons for limited functional outcome, for unnatural aspects of the movement, and for aesthetically disfiguring deformities caused by the operative procedure that had been used for reanimation of the eye region. We could achieve maximal excursions of the movements and prevent disfiguring eye closure or deformities by making several modifications to the operative techniques on the basis of the video analysis. The actual modifications are described in detail in the Patients and Methods section (Figs. 1 and 2). Only the sum of many detailed operative techniques improved the final result to an extent that both techniques can offer reliable methods for eye sphincter reconstruction with progressive experience. In the future, the growing experience with the detailed analytic possibilities of the three-dimensional video analysis system will reduce the incidence of some of the secondary corrections (e.g., muscle reduction in the upper eyelid after gracilis muscle transplant). Terzis and Bruno[11] reported this to also be true for other techniques used in the difficult field of reanimation of the paralyzed face.

The ongoing quality control of the functional results of all reconstructive procedures has enabled us to establish a three-stage concept for facial reanimation, which was reported recently by Frey and Giovanoli.[5] To restore eye closure in the adult patient, temporalis muscle transposition is the first choice in the first operation of our three-stage approach. The reasons for this priority rest in the reliability of the method, the immediate postoperative effect, and the possibility of creating a functional unit around the eye. Furthermore, this method is independent of reconstruction in the mouth region and without the risk of synkinesia. Emotional coupling was shown to be not as important as in the mouth region. This disadvantage is far outweighed by the prevention of synkinesia, which was observed in almost half of our gracilis muscle transplant patients. Although two separate cross-face nerve grafts were used for reinnervation of the two territories of the gracilis muscle transplant for the eye and the mouth, overlapping of the territories of innervation caused synkinesia. Interestingly, in this group of patients, synkinesia was observed only during the blink reflex or during eye closure in the muscle transplant around the mouth and never in the eye region during smiling. There was so little synkinetic movement in all cases that the patients did not complain about it and did not even realize its existence. Therefore,

FIG. 7. Representative example of eye closure function achieved by free gracilis muscle transplant in a child with congenital facial palsy on the right side. The clinical result was videotaped using the mirror system, with three views of the face during rest and closure of the eyes as for sleep. There is wider eye fissure on the paralyzed side preoperatively, normalized eye fissure during rest, and complete closure 18 months postoperatively. *CES*, closure of eyes as for sleep.

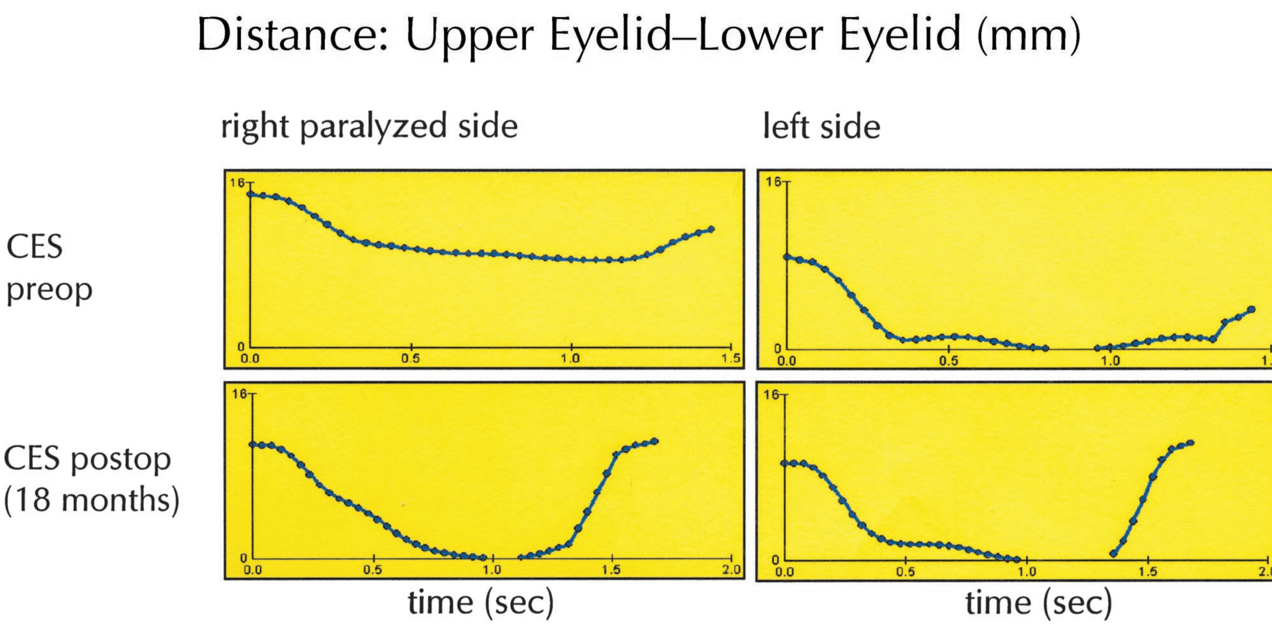

FIG. 8. Two-dimensional graph of the movement on the right paralyzed side and the left normal side of the patient shown in Figure 7. *CES*, closure of eyes as for sleep.

synkinesia should not be used as a principal argument against the use of a muscle transplant in the face with two territories reinnervated by two different cross-face nerve grafts.

In children, the use of masticatory muscles may impair regular skeletal growth, so use of a part of the free gracilis muscle transplant reinnervated by the contralateral healthy zygomatic branches through a separate cross-face nerve graft is preferred during the second-stage operation. In addition, the adaptive processes in the neuromotor system are more pronounced in children than in adults. In adults, if the temporalis muscle has been used before or has been destroyed by earlier surgery, one of the two territories of the gracilis muscle transplant can be used to achieve dynamic eye closure.

This study clearly shows that temporalis muscle transposition and free gracilis muscle transplantation are procedures that offer efficient dynamic restoration of eye closure in patients with facial palsy. They therefore deserve a fixed place in the spectrum of procedures to treat the irreversibly paralyzed face.

We prefer muscle transposition or muscle transplantation for eye closure to other techniques such as implants because of our clinical experience of better functional results and fewer late complications. In the coming years, a scientific comparison of muscle techniques and implants will be the subject of a running multicenter project using three-dimensional video analysis.

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