REVIEW

Facial reanimation: evolving from static procedures to free tissue transfer in head and neck surgery

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Purpose of review
The purpose of this article is to review and evaluate the surgical options for treating patients with facial paralysis, covering primary neurorrhaphy to facial reanimation, with microvascular free tissue transfer.

Recent findings
In recent years, free tissue transfer has been increasingly common for rehabilitating the paralyzed face, providing a more dynamic and aesthetic outcome, than has been possible prior to microvascular surgery in facial plastic and head and neck surgery.

Summary
Although primary facial nerve repair attains the best results, nerve grafting with the sural nerve and commercially available motor nerve allografts can be used alone, or in combination with masseteric nerve grafts to attain facial tone and protect eyelid function. The workhorse for reanimation is the gracilis free tissue transfer innervated by the masseteric nerve or contralateral facial nerve using a cross-face nerve graft. The orthodromic temporalis tendon transfer has minimal donor site morbidity acceptable reported outcomes. Static procedures continue to be used alone and in combination with other paradigms for facial nerve reanimation.

Keywords
cable nerve graft, facial paralysis, gracilis free flap, masseter nerve, orthodromic temporalis tendon transfer, reanimation

INTRODUCTION

The cause of facial nerve paralysis is varied, but its consequences are universal. Facial nerve paralysis is perhaps one of the most devastating diagnosis for a patient due to both its significant emotional and functional consequences [1,2▪,3,4] (level 5 evidence) (Table 1). Lack of a spontaneous social smile or sign of emotion often causes patients to feel isolated, and obvious asymmetry leads to embarrassment [2▪,5▪,6,7]. Additionally, the physical consequences of oral incompetence, nasal valve collapse, and dysfunctional lacrimation lead to a myriad of problems, such as drooling, poor speech and oral intake, nasal obstruction, and corneal ulcerations [3] (level 5 evidence).

Historically, the focus of facial rehabilitation is reanimation of the oral commissure. A study by Dey *et al.* [2▪] recently proposed a novel eye-tracking system to determine where observers focus on a paralyzed face. In addition to the mouth, onlookers also spent time looking at the eyes and nose, indicating the importance of treating these areas as well [2▪] (level 5 evidence). Given the significant consequences of facial nerve paralysis, rehabilitation and reanimation has been the focus of many reconstructive surgeons, and new techniques have been introduced throughout the years. When choosing the appropriate technique, it is essential to have a thorough understanding of the mechanism of nerve injury, extent of injury, time since onset, viability of facial musculature, patients' overall health, and patients' goals for rehabilitation [4]. It is well established that primary neurorrhaphy, when available, is the preferred method of treatment, especially in the setting on trauma and early intervention [8,9]. Interpositional nerve grafts and cross-over

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Table 1. Levels of evidence

Level I	High-quality, properly powered and conducted randomized controlled trial (RCT); systematic review or meta-analysis of these studies
Level II	Well designed controlled trial without randomization; prospective comparative cohort trial
Level III	Retrospective cohort study, case-control study, or systematic review of these studies
Level IV	Case series with or without intervention; cross-sectional study
Level V	Expert opinion; case reports; or bench research

Adapted from Oxford Centre for Evidence Based Medicine (http://www.cebm.net/index.aspx?o = 1001).

techniques also offer adequate outcomes, with the majority of patients obtaining at least a grade III on House–Brackmann grading system [3,8,10,11]. There are many limitations, however, that make these techniques not feasible. Several techniques, both static and dynamic, have evolved. Muscle transposition and free tissue transfer provide a dynamic option for more symmetry. The objective of this article is to review recent literature on surgical options for facial paralysis. Topics to be covered include static and dynamic procedures, including nerve repair, grafting, muscle transposition, and free tissue transfer, with emphasis on dynamic facial reanimation and advancements in free muscle transfer.

REVERSIBLE VS. IRREVERSIBLE FACIAL PARALYSIS

One of the most important initial assessments in rehabilitation potential is to determine the mechanism and whether or not the paralysis is reversible or irreversible. Reversible facial muscles have viable muscle fibers and intact motor units [4]. The functionality of motor end units can be tested with electrophysiologic studies such as electroneurography (ENoG) [8]. With intact motor units, nerve grafts can be effective in restoring tone and movement to the facial musculature. Atrophic and fibrotic musculature will not respond to nerve grafting, often due to an old nerve injury. With this permanent or irreversible paralysis, static procedures may restore resting tone. Otherwise, muscle transposition or free muscle transfer is required to restore facial reanimation [4,11]. Once the type of injury has been established, it is easier to determine the timing of intervention. If there is a change for spontaneous recovery, reanimation procedures are delayed. If the injury is anticipated, or is considered to be reversible with intervention, procedures are generally performed within a few weeks to months. For irreversible paralysis, however, timing can be delayed to strategize and optimize the surgical outcome [4].

IMMEDIATE OR EARLY RECONSTRUCTIVE TECHNIQUES

Neurorrhaphy and grafting

Primary end-to-end anastomosis of the facial nerve stump at the time of injury provides the best recovery outcomes [8,9,11]. Technical limitations of its use include lack of neuronal length, unavailable nerve stump, or atrophy of distal musculature. Ideally, primary reanastomosis should occur within 3 days of injury to reapproximate the epineurium using 9-0 monofilament suture. The goal is to maximize the number of regenerating axons, and to minimize the potential for synkinesis [9]. Expected recovery after neurorrhaphy can range from 4 to 9 months, although patients can continue to regain function up to years later.

Neurorrhaphy is most effective when the anastomosis is free of excess tension [9] This is not always feasible, and therefore requires an interposition graft. A cable nerve graft can be harvested from 'sensory' [3] (e.g. great auricular nerve, sural nerve, or median antebrachial cutaneous nerves) or 'motor' donor nerves (e.g. nerve to vastus lateralis). Motor nerves have shown some evidence of improved outcomes over sensory nerve grafts, but harvest of motor nerves may have unacceptable side effects [4,12,13]. Each option has different advantages. The length of the sural nerve is helpful for long gaps, whereas the median antebrachial cutaneous nerve can include sensory innervation [11]. Limitations of the procedure include a double anastomosis site, often contributing to the greater length of time before results are seen, and availability of both proximal and distal stumps. In many oncologic resections or traumatic disruptions, this is not always feasible [9].

Advantages of cable nerve grafting include not only restoration of resting muscle tone but also spontaneous facial expression. Options for nerve grafting include ipsilateral VII, contralateral (cross-over), hypoglossal to facial nerve transposition, and most recently, the masseteric branch of the trigeminal nerve [14–16]. Transposition, or

Table 2. Terzis' Smile Function Evaluation Scale and Mehta's Synkinesis Evaluation Scale

Grade	Terzis' Smile Evaluation	Mehta's Synkinesis Evaluation
5	Symmetrical smile with teeth showing, full contraction	All of the time or severely
4	Symmetry, nearly full contraction	Most of the time or moderately
3	Moderate symmetry, moderate contraction, mass movement	sometimes or mildly
2	No symmetry, bulk, minimal contraction	Occasionally or very mildly
1	deformity, no contraction	Seldom or not at all

Adapted from Wang *et al.* [17].

nerve cross-over, is a reasonable option when the proximal stump is unavailable, but the distal segment remains intact with functioning motor endplates.

The 'hypoglossal-to-facial nerve transposition' provides facial movement and tone, but with downsides. The hypoglossal nerve provides robust motor function, but requires training to create spontaneous emotive facial movement [11]. The reported success rates range from 42 to 95%, with some voluntary motion and resting tone appearing as early as 6 months [11,14]. Major disadvantages include significant synkinesis and atrophy of the ipsilateral tongue, leading to dysphagia and dysarthria [3,4,14]. Given the morbidities associated with this procedure, various modifications have been described, including a partial hypoglossal-to-facial jump graft. In this technique, a cable graft usually provided by the sural nerve is used to connect the distal end of the facial nerve to a notch in the hypoglossal nerve. There have been fewer complications associated with this procedure, but recovery time is significantly longer. Most patients were without any return of function for 9–12 months, and only 41% obtained good movement [11,14]. These limitations have driven surgeons to seek other options.

Another option for cable grafting is a direct facial-to-facial cross-face graft, which involves sacrifice of contralateral branch and anastomosis to the affected cut distal nerve with a cross-face sural nerve graft. Multiple anastomoses from segmental branches to segmental branches are possible, allowing individual facial divisions to be innervated simultaneously [4,11]. The sural nerve is often used, due to the ability to harvest up to 25–30 cm of graft. Often a buccal branch of the contralateral side is chosen. Limitations include weakening of the uninvolved side and lack of power, making this procedure less common unless used in conjunction with free muscle transfer [3,11].

In recent years, the masseter nerve has become a favorable choice for innervating facial musculature, given its anatomic location, relative ease of dissection, and low donor site morbidity [15,16]. Originally described by Bermudez and Nieto in 2004, the ipsilateral masseteric branch of the trigeminal nerve was sewn to distal facial nerve branches. They reported complete return of function by 6 months. In other early studies, patients undergoing reanimation with the masseter-to-facial nerve transfer regained oral competence, resting tone, and nearly symmetric smile at an average of 5.6 months [16] (level 4 evidence). More recently, Wang *et al.* [17] described their experience ($n = 14$) undergoing facial reanimation with masseteric nerve following resection of cerebellopontine angle tumors (level 4 evidence). Facial movement was noted at a median of 87 days postoperatively, and grade 4 or 5 in 56% of patients on the Terzis' Smile Functional Evaluation Scale (Table 2). Disadvantages include slight weakness with mastication; this did not interfere with oral intake [17].

Other disadvantages to using the masseteric nerve for grafting are lack of spontaneous smile and it is no longer an option for free gracilis muscle transfer in a future reanimation procedure.

DELAYED RECONSTRUCTION

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Muscle transposition

When cable grafting is not possible, the next viable option for dynamic restoration is muscle transfer. Patients with permanent, irreversible facial paralysis are candidates for either masseter, but more commonly temporalis muscle transfers [11].

Masseter transfer

The use of the masseter muscle for facial reanimation was first described in 1908, and popularized by Rubin, and Baker and Connolly in the late 1970s [14,18]. Since that time, many modifications have been made, and it is now one of the preferred methods for rehabilitating the oral commissure and buccal complex for smile. Due to its location and anatomic pull, the masseter applies a posterosuperior pull on the lower mid-face [11,14]. The limitations of its use include asymmetry postoperatively and occasional difficulty with mastication, making this option less favorable than the temporalis muscle transfer [3,14].

Orthodromic temporalis tendon transfer

While the masseter provides adequate reanimation of the oral commissure, the temporalis muscle is still the preferred choice for muscle transposition [11,14]. Not only is it effective in rehabilitating the oral commissure, it can also provide support to the upper cheek and lower eyelid (prone to paralytic ectropion and retraction). The senior author of this review prefers to use a divided fascia lata graft to the tendon insertion into the upper and lower lips (Fig. 1). Additionally, newer techniques have made it possible for the reanimation to occur in a single stage [4]. The anatomy of the temporalis muscle, with its fan-shaped fibers arising from a single muscle belly and short tendon from the coronoid process, provides diversity in its use for reanimation [11]. Labbé and Huault [19] originally described the lengthening myoplasty technique in 1997, in which the temporalis muscle is elevated, mobilized, and tunneled under the zygoma, and the tendon, which is still attached at the coronoid process, is transferred to the oral commissure. After postoperative physical therapy, lateral lip commissure movement of at least 1.5 cm and improved symmetry with the contralateral face were found. They also reported minimal adverse effects. The orthodromic movement of the temporalis muscle tendon also minimized the muscle bulge that was seen over the zygoma when the traditional temporalis muscle was folded over from origin to lateral lip [19].

With incremental improvements, Labbé and Huault modified his technique to avoid a zygoma osteotomy, and also improved the maximal lengthening ability of the transferred muscle and tendon. Most recently, in a cadaveric study, they further defined the technique and noted the seven most critical steps in order to achieve the maximal results [20▪]. In his most recent study, Labbé further described his technique and indications. He also described a case report showing excellent excursion 8 months postoperatively [21].

A minimally invasive approach to temporalis tendon transposition was described by Boahene *et al.* [22] (level 4 evidence). They made a 2-cm incision along the melolabial crease and using blunt dissection through the buccal space, identified the mandibular ramus and notch, thereby providing access to the coronoid process. A reciprocating saw was then used to divide the coronoid process, being careful not to disrupt the tendinous attachments on the medial mandible. The tendon was then transposed through the previously dissected buccal space

FIGURE 1. (a) Preoperative photograph of a 60-year-old with adenocarcinoma of the parotid with temporal bone involvement up to the skull base. The resulting irreversible facial paralysis was treated with an orthodromal temporalis tendon transfer to create improved oral symmetry and support the lower eyelid. (b) One-year postoperative photograph demonstrating the elevated lateral commissure and symmetry [patient photographs used with permission from senior author (T.T.) photograph library].

and sutured to the lateral commissure's modiolus and extended to the orbicularis oris and zygomaticus muscles. Additionally, they inserted electrodes to stimulate the temporalis and determine the ideal tension and length on the muscle intraoperatively [22]. This last step is critical in achieving maximal force generation and excursion [4]. All 17 patients included in the study achieved symmetry at rest, oral commissure competence and mobility, and some improvement in articulation [22]. As with the procedure described by Labbé, the authors noted the importance of physical therapy postoperatively to maximize results, especially if spontaneous smile is desired.

Free tissue transfer

Permanent facial paralysis with nonfunctioning motor end plates requires free muscle transfer to restore function, if dynamic reanimation is desired [4]. Microvascular free tissue transfer for facial reanimation was originally introduced in the 1970s, and is often performed in combination with cross-face nerve graft [11]. Cross-face nerve grafting provides the possibility of spontaneous and coupled movement with the contralateral side.

Latissimus dorsi

The latissimus dorsi free flap is a single-staged muscular transposition for facial reanimation, which can provide improved facial symmetry, muscle tone, and expression as compared with the traditional temporalis muscle transfer [3]. The procedure was initially described as a two-stage technique, but the single-stage approach became popularized by Harii *et al.* [23] in 1998. In 2009, Biglioli *et al.* [1] described their experience ($n = 33$) with the single-stage latissimus dorsi flap technique and found an average time to reinnervation of 8.9 months. Appropriate contraction during smiling was found in 61% of patients. Donor site morbidity, bulk of flap, and other better options limit the utility of this flap [1] (level 4 evidence).

Recently, Leckenby *et al.* [24] report their experience using the latissimus dorsi flap through an axillary approach. The flap was traditionally harvested from the back with the patient in prone or lateral decubitus position. Although this allows great access to the muscle, it does not allow a simultaneous two-team approach. The axillary approach allows one team to prepare the implant site at the face, whereas another team can harvest the flap, but has not gained significant popularity [24].

Gracilis

Gracilis free tissue transfer was initially described by Harii *et al.* in 1976 and has since become the gold standard for rehabilitating the oral commissure [4,14,25] (Fig. 2). Two large studies were recently published regarding the success of facial reanimation in both the adult and pediatric populations.

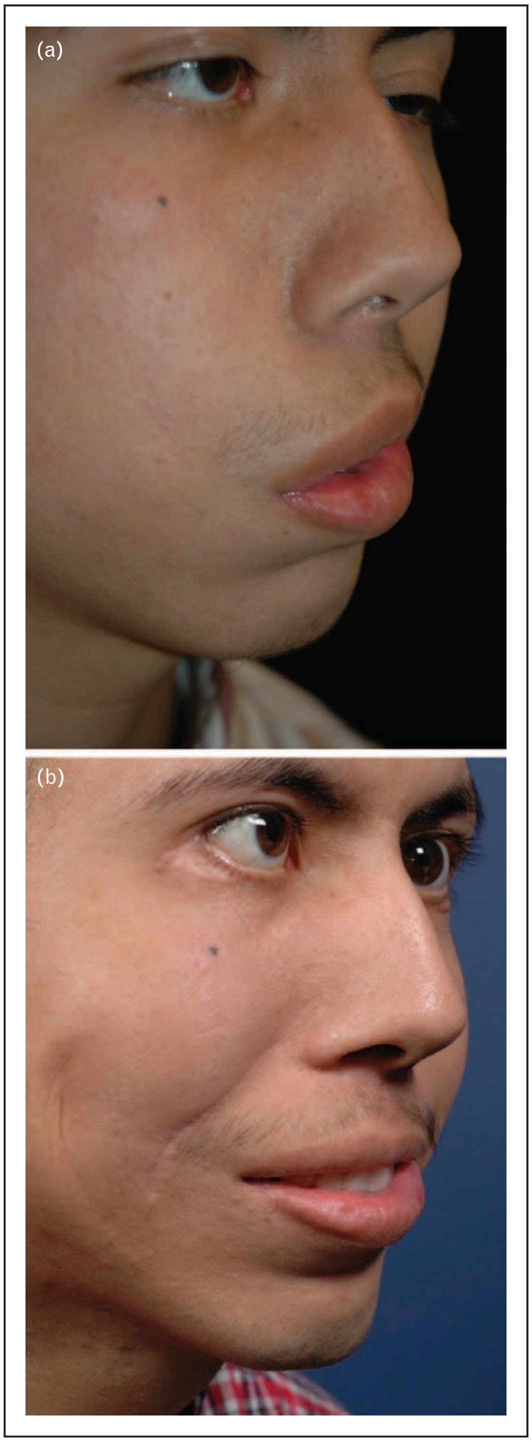

FIGURE 2. 16-year-old with Mobius syndrome treated with right gracilis muscle free tissue transfer with innervation to the masseteric nerve shown: (a) preoperatively, and (b) 9 months postoperatively [patient of senior author (T.T.), Dr Greg Farwell, and Dr Danny Ennepekides].

Snyder-Warwick *et al.* [26▪] report on 91 pediatric patients undergoing gracilis transfer, with innervation by either the cross-face nerve graft or masseteric nerve (level 3 evidence). They measured functional outcomes based on the Scaled Measurement of Improvement in Lip Excursion (SMILE) software. They also examined the axon density of the donor nerves histomorphometrically, noting a significantly greater number of axons in the masseteric nerve compared to the cross-face nerve graft. They reported that both innervation sources resulted in improvements in the oral commissure and smile symmetry, but there was a greater amount of contractility and excursion noted with the masseteric nerve.

There has been great success in the adult population as well. Maktelow *et al.* [27] reported that of 27 adult patients, 89% had a spontaneous smile. More recently, Bhama *et al.* [28▪▪] report their experience with the gracilis muscle transfer in 127 patients with facial paralysis, approximately half of which were innervated by the masseter and the other half by the contralateral facial nerve (level 3 evidence). They analyzed excursion and symmetry using their automated software tool (FACE-gram). They found that excursion on the healthy side decreased by 1.2 mm, whereas it improved by 8.66 mm on the paralyzed side, leading to an improvement in symmetry. They also found that patients innervated by the contralateral facial nerve had better postoperative symmetry during smiling [28▪▪]. To date, the microvascular gracilis transfer remains one of the most promising donor flaps for facial rehabilitation.

Other flap options

The anterolateral thigh (ALT) flap is versatile, bulky when needed, relatively straightforward to harvest, and has low donor site morbidity [29]. Following total parotidectomy, the flap can be coupled with orthodromic temporalis tendon transfer (OTTT). Revenaugh *et al.* [29] described a single-stage approach using a combination of ALT with the dynamic facial reanimation following total parotidectomy (level 5 evidence). In five patients, they reported 100% symmetry at rest, oral commissure excursion, and competence, and 'good' eye closure in 80% of patients.

In a separate study, Revenaugh *et al.* [30] described the potential use of the motor nerve to the vastus lateralis (MNVL) as a nerve cable graft, available while harvesting the ALT. The MNVL is commonly encountered near the vascular pedicle during ALT harvest, and it has been noted to have an abundant branching pattern. In this cadaveric study, they note that there was an average of 4.4 nerve branches supplying the vastus lateralis. The authors propose that this pattern would make it ideal for grafting multiple facial nerve branches simultaneously, and suggest it is particularly ideal for immediate reconstruction following total parotidectomy with facial nerve sacrifice, when motor units are still intact and identifiable [29,30] (level 5 evidence). To the best of our knowledge, no clinical studies describing this technique are available, but it holds promising future in this subset of patients.

Another recent cadaveric study was performed by Alam *et al.* [31▪] to describe a novel sternohyoid flap for potential facial reanimation (level 5 evidence). They found that the sternohyoid flap would be a promising donor muscle for free tissue transfer because of its reliable vascular pedicle by the superior thyroid artery, and its appropriate motor nerve length of 10.7 cm. They endorse this flap as an alternative to the gracilis muscle, noting its decreased bulk and more favorable anatomic location. The authors are currently conducting a clinical trial examining the sternohyoid flap in patients as an alternative to the gracilis, and as with ALT, it offers promising results [31▪].

Static and other procedures

Although dynamic reanimation is preferred, patients who are poor surgical candidates can still achieve some symmetry with static procedures. Static procedures are a good option for repairing specific cosmetic or functional deficits of the periorbital, perioral and to address nasal obstruction due to nasal valve collapse [13]. The fascia lata graft has been in use since the early 1900, and is more favorable than synthetic implants such as Gore-Tex due to its longevity and limited wound complications. In 2015, Lemound *et al.* [32] revisited their experience with the fascia lata sling in 15 cases of unilateral facial paralysis (level 4 evidence). The authors noted an immediate improvement in facial symmetry, speech, oral competence, and oral intake, with only a 7% complication rate [32]. These results were mainly subjective, however, which limits their applicability.

Rehabilitating the eye is one of the most important immediate needs in facial paralysis. Paralytic lower eyelid ectropion/retraction and lack of upper eyelid closure contribute to lagophthalmos. Complex processes such as lacrimal dysfunction, eyelid punctual eversion, and poor tear film movement by dysfunctional eyelid movement all affect the tear production and tear quality. This leads to simultaneous and paradoxical dry eye and epiphora. These common consequences of a paralytic eye are treated with conservative measures (e.g. moisture

FIGURE 3. Photograph of the 73-year-old with irreversible paralysis after reanimation and eyelid surgery. This oblique postoperative view highlights the right lateral canthus demonstrating the mini-Hughes tarsoconjunctival flap (black arrow) and the nasolabial fold elevated by an orthodromic temporalis tendon transfer (∗asterix) [patient photographs used with permission from senior author (TT) photograph library].

chamber, lubrication, lid taping), but other options are needed for expected persistent paralysis. The gold or platinum weight is a common technique to assist with eyelid closure.

Other techniques to improve the paralyzed eye include tarsorrhaphy and lateral canthopexy. Recently, Sufyan *et al.* [33■■] described a modification of the tarsoconjunctival flap to repair ectropion and lagophthalmos in a single-staged procedure. The authors of this review have found this to be very effective with low morbidity in recalcitrant cases (Fig. 3). Bhama *et al.* [7] also described refinements in nasolabial fold reconstruction as an additional means to improve aesthetic outcomes and quality of life in patients unable to undergo dynamic reanimation. The authors note that while static procedures are not ideal, they are an important component of the surgeon's repertoire when approaching a patient with facial paralysis. The study by Chu *et al.* [34] on the perception of symmetry in reconstruction can help guide us to using adjunct procedures to meet the threshold where the lay public will not perceive the facial paralysis.

CONCLUSION

Effective management of facial paralysis can be challenging due to the variety of patient presentation, and muscle and nerve viability. Additionally, due to the severe emotional and physical consequences, finding an adequate method to rehabilitate both the aesthetic and functional deficits is in and of itself difficult. In addition to traditional approaches, free muscle transfer powered by the masseteric nerve appears to be at the forefront of facial reanimation and is the most promising tool for the surgeon in the immediate future.

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