The surgical management of facial nerve injury

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Historical review

Although the concept of repairing injured peripheral nerves is centuries old, it was not until 1821 when Sir Charles Bell demonstrated the loss of facial expression with transection of the seventh cranial nerve that surgical restoration of the facial nerve was attempted [1]. In 1879, Drobnik diverted axons from an intact spinal accessory nerve to the distal end of a transected facial nerve, thus affecting the first nerve transfer to reinnervate the mimetic muscles of the face [2]. The affects of nerve transfers on the cerebral cortex were critically reviewed by Kennedy in 1901 [3], and in 1903, Ballance et al [4] published a case series documenting their experience with end-to-side neurorrhaphy of the transected facial nerve into an intact spinal accessory nerve and suggested a hypoglossal-to-facial nerve transfer. Initial attempts to reinnervate the facial musculature through myoneurotization were met with limited success by Lexer in 1911 [5], but by 1927, Sterling Bunnell reported excellent results after primary neurorrhaphy of a transected facial nerve within the temporal bone [6]. In 1936, the Scottish neurosurgeon Norman Dott used a sural nerve graft extending from the intracranial to extratemporal facial nerve to span an intratemporal defect created by acoustic neuroma resection [7].

Over the past 30 years, the advent and refinement of microneurosurgical techniques and free tissue transfers has significantly improved treatment options for extensive or long-standing facial nerve injuries. In 1970, Tamai described free tissue transfer of innervated muscle flaps in canines [8], and, in 1971, Thompson reported inserting free muscle grafts first in canines and then in the clinical setting to restore facial mimetic function [9,10]. The use of the intact contralateral cervical branch of the facial nerve to reanimate the territory of the injured ipsilateral facial nerve was first presented by Scaramella in 1970 and was later modified to involve sural nerve grafts and branches of the cervical plexus [11,12]. In 1976, the microneurovascular transfer of the gracilis muscle to restore facial animation was described by Harii [13] and was followed by reports of successful free tissue transfer and reinnervation of the latissimus dorsi [14,15] or pectoralis minor [16] to restore facial animation. To produce a more symmetric and natural-looking result, these techniques have undergone multiple refinements as more attention is paid to the fascicular territories within a given muscle [17], the tonicity of various facial muscles [18], and differences in the distribution of motor endplates on facial compared with skeletal muscles [19].

Anatomic overview

The complex anatomy of the facial nerve is summarized here and can be thoroughly reviewed in other texts [20]. The branchial motor fibers constitute the largest component of the facial nerve and provide efferent innervation to the stapedius, stylohyoid, posterior belly of digastric, and the muscles of facial expression. The remaining three components of the
The intratemporal course of the facial nerve consists of a labyrinthine segment extending approximately 5 mm from the internal auditory canal and includes the geniculate ganglion. The intratemporal facial nerve is particularly susceptible to compression in the relatively narrow labyrinthine segment and to shearing as it makes a sharp turn, or genu, to enter the tympanic segment. The tympanic segment extends 8 to 11 mm to a second genu located between the posterior auditory canal wall and the horizontal semicircular canal of the middle ear. The nerve travels vertically another 10 to 14 mm through the mastoid segment before exiting the stylomastoid foramen [21–24].

The intraneural topography of the intratemporal facial nerve has been studied extensively. Clinical reports of consistent deficits of facial animation associated with nerve injuries at a particular level after mastoid [25], glomus tumor [26], and decompressive surgeries at the cerebellopontine angle suggested that the intratemporal facial nerve had a reliable spatial arrangement [27]. These clinical findings were temporarily corroborated in pathophysiological studies [28] and by May in a feline model [25]. May later noted, however, that the reproducible facial nerve topography that he had observed histologically was at least in part due to the presence of a branch of the trigeminal nerve found in cats but not in humans and not to a consistent branch of the facial nerve [20]. It is widely accepted that the intratemporal facial nerve possesses a variable intraneural topography [29–31] and that its spatial relationship to other intratemporal structures, such as the sigmoid sinus and carotid artery, are also variable [32].

Several common branching patterns have been described for the voluntary motor component of the extratemporal facial nerve [33], with special attention given to the marginal mandibular [34] and frontal nerve branches [35–38]. Given the variability in location of the facial nerve branches and the overlap of facial nerve branches to any given group of facial muscles [39], careful dissection and a nerve stimulator should be used to confirm the presence of nerve fascicles and to decide which may be sacrificed in cross-facial nerve grafting procedures.

The parasympathetic division of the facial nerve is compromised of visceral motor fibers whose cell bodies are influenced by the hypothalamus, are located in the pontine tegmentum, and are collectively known as the superior salivatory nucleus. These visceral motor fibers contribute to the nervus intermedius, penetrate the temporal bone, and then divide into the greater petrosal nerve that innervates the lacrimal gland and the chorda tympani, which innervates the submandibular and sublingual glands. Cell bodies for the general sensory component that provides sensation to the conchal skin and the special sensory component of the facial nerve that travels along the lingual and chorda tympani nerves and provides taste to the anterior two thirds of the tongue reside in the geniculate ganglion. Postsynaptic afferent impulses are transmitted from the petrous temporal bone through the nervus intermedius and synapse with the general sensory trigeminal nucleus in the rostral medulla or with cell bodies modulating taste afferents within the gustatory nucleus of the pontine tegmentum. These impulses are propagated to thalamic nuclei before projecting to the sensory cortex.

Surgical management of acute facial nerve injuries

Primary neurorrhaphy

Acute injuries to the extratemporal facial nerve should be repaired under magnification and with adequate lighting and microsurgical equipment (Fig. 1). A nerve stimulator may be used to confirm the location of the distal end of the transected facial nerve for approximately 72 hours after nerve injury [40]. Beyond this period, the neurotransmitter stores necessary to depolarize the motor end plates are depleted and cannot be replenished given the disruption of antegrade axoplasmic transport after nerve injury [41–46]. Thus, early surgery is important and should be done within the 72-hour period when the appropriate operating room, surgical team, and equipment are available.
Ipsilateral nerve grafts are indicated in the reconstruction of segmental defects of the facial nerve when both ends of the transected nerve can be reliably identified and when it is not possible to do a primary repair (Fig. 1). In preparation for nerve grafting, neurolysis and dissection of the transected facial nerve stump to the level of clearly defined healthy fascicles proximally and equally judicious dissection of the distal facial nerve stump out of the zone of injury must occur. Once the facial nerve stumps are ready for grafting, the sural nerve, the greater auricular nerve, and the medial antebrachial cutaneous nerves are most commonly used. Our preference is to use medial or lateral antebrachial cutaneous nerve grafts.

Although surgical technique is an important consideration in performing primary neurorrhaphy or nerve grafting of the facial nerve, it is its variable spatial arrangement that most significantly affects the success of the repair [20,25,28]. Although the senior author has acutely repaired transected buccal and zygomatic branches of the facial nerve medial to a perceived line drawn from the lateral corner of the eye to the lateral corner of the lip with excellent success, injuries in this region are commonly observed, and facial mimetic function tends to recover. As the facial nerve ramifies in its peripheral extent, its topography becomes less complex, and subsequent repairs are more successful, although even its distal branches may not be committed to a single muscle group [39]. Also, unlike skeletal muscle (which possesses a single, centrically located motor end plate innervated by a single motor nerve), individual facial muscle fibers can possess multiple eccentrically located motor end plates innervated by multiple facial nerve branches [19,47]. The various facial muscles...
The distal end of the graft is banked subcutaneously in the upper lip and delivered to the contralateral side. The grafts are first tunneled subcutaneously across sectored donor facial nerves on the nonparalyzed side. Neurorrhaphy is performed between sural nerve graft and the transected, and relative expendability. Neurorrhaphy is used as the donor nerve graft because of its length, function of the nonparalyzed side. The sural nerve is perioral musculature, are protected to preserve the branches to the zygomaticus major and other prominent branch motorizing upper and lower lids. Branches that preserve eyelid function, including a branch causing elevation of the corner of the mouth, upper lip, and ala are taken for nerve grafting. Branches that preserve need to manipulate their tongues to contract their muscles with voluntary or involuntary facial expression. Synkinesis or dyskinesis becomes more common as the site of facial nerve injury becomes more proximal from the stylo-mastoid foramen and into the temporal bone.

Cross-facial nerve graft

The cross-face nerve graft, as described by Anderl [51,52] and Scaramella [11,53], can be used when the proximal stump of the injured facial nerve is unavailable (Fig. 1). By diverting extratemporal axons from the contralateral facial nerve whose cortical origins match those of the injured side, the problems of synkinesis and involuntary muscular contractions can be avoided. Exposure is gained via a preauricular incision that is carried posterior to the auricle and then caudal to the mandibular angle. Branches of the contralateral facial nerve are exposed and identified with a nerve stimulator. Typically, one or two nerve branches causing elevation of the corner of the mouth, upper lip, and ala are taken for nerve grafting. Branches that preserve eyelid function, including a prominent branch motorizing upper and lower lids and branches to the zygomaticus major and other perioral musculature, are protected to preserve the function of the nonparalyzed side. The sural nerve is used as the donor nerve graft because of its length, caliber, and relative expendability. Neurorrhaphy is performed between sural nerve graft and the transected donor facial nerves on the nonparalyzed side. The grafts are first tunneled subcutaneously across the upper lip and delivered to the contralateral side. The distal end of the graft is banked subcutaneously in the preauricular area until free tissue transfer is undertaken. If cross-facial nerve grafting is performed shortly after the period of denervation, however, neurorrhaphy to the contralateral facial nerve can be considered. Using this model, the senior author has shown that, in instances where distal neurorrhaphy was completed at the time of the initial procedure, nerve fiber diameter, myelin thickness, and the density of neural tissue was greater than when the distal end was banked in the preauricular position [54]. When it is meticulously performed in patients with salvageable facial muscles who are capable of enduring a prolonged anesthetic and when there is sufficient donor nerve material, the cross-facial nerve graft with a distal repair is our preferred technique in restoring facial nerve function when the proximal stump is unavailable for ipsilateral grafting.

Nerve transfers

Defects of the facial nerve that are not amenable to primary repair, an ipsilateral nerve graft, or a cross-facial nerve graft can be reconstructed with a nerve transfer procedure. Axons from the transferred donor nerve may be delivered to the distal end of the transected facial nerve using direct neurorrhaphy or an interposition nerve graft to enable tension-free repair. Unfortunately, control of the facial mimetic musculature on the paralyzed side of the face relies upon activation of the donor nerve’s intended target. Patients treated with a hypoglossal-facial nerve transfer need to manipulate their tongues to contract their neurotized facial musculature and may develop dyskinetic facial movements with speech, chewing, and other tongue movements and hemiatrophy of the tongue on the paralyzed side. Like the hypoglossal-facial nerve transfer, other nerves transferred to the distal end of the transected facial nerve, including the trigeminal [55,56] and spinal accessory nerve, result in gross [4,57,58], unintended contractions of the facial musculature. Over time, however, a number of patients demonstrate some degree of motor re-education whereby similarly innervated facial muscles display the ability to contract independently after nerve [59] or muscle transfer procedures [60]. Some authors have suggested that this process of motor re-education is related to neuronal sprouting in the region of the pontine nuclei [60]. Others have suggested that instead of restoring facial nerve function, dormant branches of the trigeminal nerve may motorize denervated facial muscles, as suggested by rare instances of restoration of facial animation with no surgical intervention [61].
Surgical technique: partial hypoglossal-to-facial nerve transfer

To minimize the deficits caused when the ipsilateral hypoglossal nerve is sacrificed to enable an end-to-end hypoglossal to facial nerve transfer, end-to-side hypoglossal-to-facial nerve transfers have been described clinically [62–65], and a partial hypoglossal-to-facial nerve transfer is our preferred technique. Specifically, the ipsilateral hypoglossal nerve is identified proximally, where it is known to have a monofascicular pattern, and is followed distally where a polyfascicular pattern has been demonstrated in cadaveric dissections [66]. A nerve stimulator is then used to identify fascicles of the hypoglossal nerve innervating the posterior aspect of the tongue. These fascicles are carefully protected when a neurectomy involving 25% of the remaining hypoglossal nerve is performed and the transected distal end of the facial nerve is coapted end-to-side to the neuromatrixed hypoglossal nerve. End-to-side neurorrhaphy of the facial nerve to the hypoglossal nerve, usually with an interposition nerve graft obtained from the medial antebrachial cutaneous nerve, is associated with adequate reinnervation of facial nerve targets and usually without appreciable loss of tongue motion, ipsilateral bulk, or significant speech deficits.

Nerve transfers can be used as a definitive procedure to reanimate the paralyzed face but may also be used to provide trophic support to the denervated neuromuscular junction if a cross-facial nerve graft and subsequent prolonged period of denervation is expected [67–70]. The hypoglossal and accessory nerves have been used to temporarily maintain the neuromuscular junction of denervated facial mimetic muscles [57]. Recent animal studies, however, challenge the utility of such a “baby-sitter” procedure, suggesting that repeated episodes of denervation followed by reinnervation leads to less muscle recovery than a single prolonged period of denervation followed by a single reinnervation [71].

Surgical management of established facial palsy

Regional muscle transfers

It is well known that periods of denervation in excess of 1 year in the extremities and 1 to 2 years in the face leads to the irreversible loss of functional motor end plates and muscle contraction in response to neural stimuli. As a result, reinnervation alone does not successfully restore muscle contraction. As shown in Fig. 1, regional muscle transfers using the temporalis or masseter [72], cross-facial nerve grafts combined with free tissue transfers in a one- or two-stage procedure, and various ancillary static procedures can be used when the motor end plates of the facial muscles are not salvageable. Regional muscle transfers are preferred in patients who do not desire a two-stage operation or are not medically suitable for a prolonged anesthetic or free tissue transfer. Some groups favor using a portion of or the entire masseter muscle alone or in combination with a temporalis muscle transfer for facial reanimation, particularly when the natural vector of the patient’s smile is in a more lateral direction [73,74]. We most frequently use a partial temporalis muscle transfer. The vector-of-pull for this transfer extends from the modiolus to the anterior zygomatic arch and resembles the vector created by contraction of the zygomaticus major muscle.

Surgical technique: partial temporalis transfer

Exposure for the temporalis muscle transfer begins with an incision extending from the preauricular skin cephalad over the temporoparietal muscle (Fig. 2). A skin flap is raised just superficial to the parotid fascia and is extended medially toward the nasolabial fold and above and below the oral commissure. If the patient has partial facial nerve palsy, care is taken to identify and preserve branches of the facial nerve that may be stimulated intraoperatively. Superiorly, the dissection continues to the deep fascia of the temporalis muscle. A superiorly based flap of deep temporal fascia, approximately 4 cm wide, is fashioned. The cephalic attachment of this fascia to the temporalis muscle is reinforced with nonabsorbable suture. This superiorly based fascial flap extends the reach of the muscle transfer and functions as a tendon that can be secured to the modiolus and orbicularis oris. After the fascial flap is mobilized, the middle third of the temporalis muscle is elevated from cephalad to caudal and is proximally based. Although care must be taken in elevating a portion of the temporalis muscle for transfer, a recent cadaveric study has confirmed that the temporalis is consistently well vascularized by three distinct arteries and in a majority of cases is simultaneously innervated by buccal, mandibular, and masseteric branches of the trigeminal nerve [75]. With the temporalis elevated to the superior border of the zygomatic arch proximally, the flap is transposed to the modiolus, where the flap is secured to match the vector of smile noted on the contralateral side. The repair of the transferred muscle flap around the corner of the mouth is the same as for inserting a free muscle transfer. Nonabsorbable clear sutures are placed in the orbicularis oris muscle above...
Fig. 2. Middle-aged woman with established facial palsy on the right side. (A) Preoperative photo while smiling. (B) Intraoperative photo demonstrating temporalis muscle transfer. (C) Two-year follow-up while smiling.
Zuker have recently reported a variation on their approach that avoids the cross-facial nerve graft. Manktelow and colleagues described a meticulous dissection superficial to the parotid fascia and superficial myoaponeurotic system that is maintained for 6 weeks postoperatively.

In the senior author’s experience, the temporalis muscle transfer is a reliable alternative to microsurgical techniques in restoring facial mimic function after prolonged denervation. In addition, some animal data suggest that muscle transfers may stimulate reinnervation of the facial musculature [76]. In a recent animal study, the retrograde tracer horseradish peroxidase was identified in the trigeminal nucleus of guinea pigs after injection of the facial nerve-innervated zygomaticus major muscle. Although the possibility of duel innervation of the facial mimetics by the trigeminal and facial nerve has been mentioned previously [61], these investigators suggested that their results may have been due to a phenomenon whereby temporalis muscle transfers may stimulate reinnervation of the facial mimetic muscles [76]. Clinically, however, the degree of success achieved with temporalis muscle transfers depends upon the patient’s ability to independently contract the temporals on the affected side to match the degree of facial muscle contraction on the normal side. Although involuntary facial contractions are rarely symmetric, in our experience patients do extremely well with motor re-education after these muscle transfers.

**Free tissue transfers**

To avoid synkinesis and asymmetric, unintended facial expressions in the individual with long-standing facial nerve injury, vascularized free tissue transfers motorized by an ipsilateral nerve, cross-facial nerve graft, or a long neural pedicle extending to a branch of the intact contralateral facial nerve may be used. Described free tissue transfers for facial reanimation include the gracilis [13], latissimus dorsi [14], pectoralis minor [16], and rectus abdominis [77]. Our current practice is to perform a vascularized, free tissue transfer of the gracilis muscle approximately 8 months after cross-facial nerve grafting (Fig. 3). The gracilis muscle remains our muscle of choice based on ease of harvest, its parallel fiber orientation, and a reasonable length of excursion with contraction. Preparation of the recipient site involves a meticulous dissection superficial to the parotid fascia and superficial myoaponeurotic system that avoids the cross-facial nerve graft. Manktelow and Zuker have recently reported a variation on their original cross-facial nerve graft technique, referred to as the “short-cross facial nerve graft” [78]. Instead of performing the neurorrhaphy in the preauricular area as occurred when a 20-cm long sural nerve graft was used, a graft measuring 7 to 8 cm is used and resides superior to the incisors in the upper buccal sulcus after the first stage of cross-facial nerve grafting. The anterior branch of the obturator nerve that innervates the gracilis extends approximately 6 cm so that the neurorrhaphy is performed within the dissected buccal mucosa.

**One-stage free tissue transfers**

Over the last decade, there have been a number of reports advocating one-stage free muscle transfers to reanimate the paralyzed face. The success of one-stage free tissue transfer of the abductor hallucis longus to restore facial animation in three patients was first reported in 1992 [79] and was later updated [80]. Koshima et al then described an innervated rectus femoris flap for facial reanimation [81]. Nerve grafting could be avoided secondary to the length of the femoral nerve pedicle—often reaching 20 cm—that could easily extend from the muscle flap to an intact buccal branch of the contralateral facial nerve. This group subsequently described a doubly innervated rectus femoris flap whereby lip elevation was provided via the long femoral nerve segment coapted to the contralateral facial nerve. The inferior segment of the rectus femoris muscle responsible for lip depression possessed a shorter motor nerve that was coapted to the ipsilateral masseteric nerve [82].

One-stage free tissue transfers possessing a long motor nerve that can be coapted to the contralateral side have also been described for the gracilis [83,84], latissimus dorsi, [85], and the internal oblique musculature [86]. Although advocates of a two-stage approach to facial reanimation with free tissue transfers do so primarily to minimize the period of muscular denervation, none of these groups performing one-stage operations report problems with muscle reinnervation clinically or with EMG confirmation [83]. Muscular recovery as early as 6 months after one-stage procedures has been reported, and one-stage procedures are used successfully to treat children with Moebius syndrome [87]. Harii gives two explanations for the paradoxical acceleration in muscle reinnervation that he has observed after one-stage transfers [85]. First, retrograde blood flows from the muscle and into its long vascular pedicle, converting it into a vascularized nerve graft. Second, a sural nerve graft possesses two suture lines, versus the single neurorrhaphy required for a one-stage transfer.
Perhaps the additional scar and technical considerations of a second neurorrhaphy limits the efficacy of a nerve graft versus the one-stage technique. One concern that we have had with the one-stage free tissue transfer technique relates to the frequent requirement of an additional anterior facial incision to gain exposure for the extended neural pedicle as it passes to the nonparalyzed side of the face [13,86]. Perhaps the buccal sulcus incision described by Manktelow and Zuker for two-stage, free tissue transfers [78] could be used to help pass the nerve graft to the contralateral side and could be combined with a contralateral facelift incision instead of a more anterior incision to gain exposure of the contralateral normal facial nerve. Although long-term follow-up and further study of the integrity of the neuromuscular junction in one-stage transfers is warranted, this technique is gaining favor for its shorter recovery period and reduced operative times.

Gold weight for lagophthalmos

Injuries to the facial nerve, most particularly the zygomatic branch, interfere with lid closure because the levator palpebrae superioris and Mueller’s muscles elevate the upper lid unopposed. Exposure keratitis and tearing are common sequelae. Although static procedures involving magnetized rods [88] and dynamic procedures using palpebral springs [89] and slips of a regional temporalis muscle transfer have been described [90], we frequently use a gold weight to achieve eyelid closure [91,92]. This technique has been a reliable method for treating lagophthalmos in a number of series [93] and relies on the weight of the implant and gravity to produce eye closure with the patient in the upright or reclined position. Preoperatively, trial weights ranging from 0.8 to 1.6 g are placed on the upper lid to determine the lightest weight consistently capable of producing eye closure. Intraoperatively, the appropriately sized 24-carat gold weight, which usually weighs 1 g, is placed immediately superficial to the tarsal plate and centered over the pupils with the patient in centric gaze. To avoid implant visibility, the weight is placed sufficiently cephalad that the resultant bulge is not visible with the eyes open. In a retrospective review, Pickford et al [94] noted that although patient satisfaction was generally high, selection of an excessively large weight was the most common factor contributing to morbidity. Implant visibility, extrusion, downward migration, and ocular irritation are sequelae noted by us and others [95]. Fortunately, the gold weight can be downsized and repositioned as needed because this technique permits subsequent adjustments with little morbidity.

Other ancillary procedures

Reconstruction after facial nerve injury is not confined to a single or staged procedure but may require several ancillary procedures. Procedures that may improve facial aesthetics after facial nerve injury include debulking procedures (particularly when regional or free flaps are used), tightening or repositioning procedures, or selective denervations to restore symmetry. Static facial reconstructions with fascia lata or Gore-Tex [96] and common facial cosmetic procedures (eg, brow lift for eyebrow ptosis and rhytidectomy) are also implemented. Denervation of the perioral musculature may cause significant lip asymmetry, which can be restored with autologous reconstructions involving pure fat grafts [97], dermal fat grafts [98], and fascia lata grafts [99]; autologous forms of injectable collagen; or other alloplastic alternatives [100]. Occasionally, facial symmetry is best restored by limiting the function of the non-paralyzed side. When overpull by muscles such as the frontalis or depressor anguli oris distorts facial harmony, for example, botulinum toxin can be used judiciously to temporarily denervate them [101,102]. Typically, any touch-up procedures are performed 18 to 24 months after the last reconstructive procedure to provide sufficient time for wound healing and scar formation and to allow the patient to identify which aspects of their facial aesthetics and function they wish to change.

Summary

Treatment of facial nerve injuries depends upon a detailed understanding of its anatomic course, accurate clinical examination, and timely and appropriate diagnostic studies. Reconstruction depends upon the extent of injury, the availability of the proximal stump, and the time since injury and duration of muscle denervation. Although no alternative is perfect, these techniques, in combination with static and ancillary

Fig. 3. Boy with established facial palsy on the right side. (A) Preoperative photo while smiling. (B) Intra-operative photo demonstrating free tissue transfer of gracilis muscle 8 months after receiving cross facial nerve graft. (C) Two-year follow-up while smiling. (D) Seven-year follow-up while smiling.
procedures, can protect the eye, prevent drooling, restore the smile, and improve facial symmetry. New techniques (including single-stage free tissue transfers and bioengineered nerve grafts), further research on the characteristics of the facial musculature, and methods of preserving the neurovascular junction will undoubtedly manifest themselves as further refinements of established surgical techniques.

References

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