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Reanimation of facial palsy following tumor extirpation in pediatric patients: Our experience with 16 patients

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Summary The aim of this study was to present our experience with reanimation of facial palsy (FP) following tumor extirpation in pediatric patients and to analyze the functional outcomes based on different types of procedures performed considering demographic and electrophysiological data of the patients. Sixteen patients with FP post-tumor extirpation who underwent facial reanimation were reviewed. Three independent assessors evaluated the preoperative and postoperative videos using the Terzis' grading scale for eye closure, smile, depressor and overall esthetic and functional outcomes. Preoperative and postoperative electromyographic interpretations and the effect of demographic variables were also evaluated. There was significant improvement in all the patients regarding overall esthetic and functional outcomes ($p < 0.0001$). Good and excellent overall esthetic and functional outcomes were observed in 62.50% of the patients ($n = 10$). The difference between preoperative and postoperative EMG results was of statistical significance ($p < 0.0001$ for each target re-innervated). Better results were observed in younger patients ($\leq$10 years) ($p = 0.014$) and in early cases (denervation time $\leq$2 years) ($p = 0.033$).

Functional results were significantly better if surgery was performed within 2 years and the patient was younger than 10 years. Augmentation of the paretic facial musculature in pediatric patients with post-tumor FP was feasible with the use of dynamic and/or static procedures. Advanced microsurgical techniques, such as the use of free muscle transfers, should be kept in mind in late cases (denervation time over 2 years).

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Introduction

Facial nerve (FN) paralysis is an uncommon but emotionally and physiologically devastating condition. Although the incidence of facial palsy (FP) is 15-40/100.000 inhabitants,[1] its incidence in pediatric patients is even lower (0.02%).[2] Regardless of the cause of FP, it affects facial expression, oral competence, verbal communication, social interaction, taste, and potentially vision.[3]

Primary tumors of the FN are uncommon and can arise from Schwann cells, the fibroblast support cells of the endoneurium, and the epithelial-like cells of the perineurium or the blood vessel.[4] Despite the existence of high resolution imaging studies, they are often ignored or misdiagnosed because of subtle, slowly progressive, protean clinical manifestations. Depending on its location FN tumors can be divided into intracranial (e.g. acoustic neuroma) and extracranial (e.g. parotid pleomorphic adenoma). Even if FN preservation in vestibular schwannoma surgery is possible in 80%–100% of cases, 50%–90% of these patients develop FP after the surgery.[5]

Decision-making for dynamic facial reanimation is multifaceted in the pediatric population, largely because parents and caretakers face the difficult dilemma of committing their children to long-standing and multi-staged operations. It is critical that appropriate and timely treatment be offered and executed in a way that ensures functional recovery.

The aim of this study was to present our experience with reanimation of FP following tumor extirpation in pediatric patients and to analyze the functional outcomes based on different types of procedures performed in consideration of the demographic and electrophysiological data of the patients.

Material and methods

Patients' demographics

From 1978 to 2006, 16 patients underwent facial reanimation for post-tumor extirpation FP. Inclusion criteria included: (1) age <18 years old; (2) FP was post-tumor extirpation; (3) follow-up ≥2 year. This study conforms to the World Medical Association Declaration of Helsinki and subsequent amendments. The Institutional Review Board Committee of the Eastern Virginia Medical School approved the protocol of this retrospective review. Demographic characteristics of the patients are summarized in Table 1. The distribution of tumors types (benign/malignant) according to the anatomic location is summarized in Table 2. In 5 patients with intracranial tumors either chemotherapy ($n = 1$) or radiotherapy ($n = 4$) was performed. The mean age of the patients was 10.9 years. The mean follow-up was 3.09 years. The mean denervation time was 6.07 years.

Preoperative evaluation

Evaluation included thorough history, detailed clinical examination, electrophysiological testing which included needle electromyography (EMG) and nerve conduction studies and documentation of facial movements, using standardized videos and photographs according to a time tested protocol. Similar testing took place during postoperative office visits for comparative purposes. Bilateral high resolution CT or MRI scans of the VII canals were performed as needed.

Surgical treatment

First stage

In patients with denervation time ≤6 months or >2 years, two to four cross-facial nerve grafts (CFNGs) are coapted in an end-to-end fashion to selected distal branches of the unaffected VII.[6] The number of CFNGs depends on the degree of FP and the individual patients' needs. Both the sural nerves are used as CFNGs. Rarely, if additional grafting material is needed, one saphenous nerve can be added. Selection of FN fascicles on the normal side represents a dual challenge of finding an adequate number of motor donors to ensure reinnervation of the paralyzed side but without downgrading the normal side. The peripheral branches of the facial nerve, along with extensive intraoperative microstimulation studies and 'mapping' of each branch's distal innervation, make this selection possible, without measurable loss of function.

In patients with denervation time between 6 months and 2 years the 'Babysitter' procedure is utilized in which 40% of the ipsilateral hypoglossal nerve is coapted to the

Table 1 Demographic characteristics.

Variable		Patients	Mean ± SD	Range
Age	Male	5 (31.25%)	11.8 ± 5.6 years	3–17 years
	Female	11 (68.75%)	10.6 ± 5.3 years	1–17 years
Tumor location	Intracranial	11 (68.75%)		
	Extracranial	5 (31.25%)		
Denervation Time			6.07 ± 4.8 years	1–17.08 years
Side	Right	10 (62.50%)		
	Left	6 (37.50%)		

Abbreviation: SD: Standard Deviation.

Table 2 Tumor types and anatomic locations.

Location	Tumor type	Patients	Benign	Malignant
Intracranial	Astrocytomas	6	6	5
($n = 11$)	Ependymomas	2		
	Other	3		
Extracranial	Cystic hygromas	2	5	
($n = 5$)	Hemangioma	2		
	Lymphangiomas	1		
Total		**16**	**11**	**5**

affected VII with concomitant placement of 3–4 CFNGs.[6,7] In late cases (≥2 years), when the facial musculature has atrophied, CFNGs are used in combination with muscle transfers. In patients with either incomplete recovery of the depressor muscle function after CFNG neurotization, or in patients with evidence of remaining depressor muscle after needle EMG, a mini-XII transfer to either the cervicofacial branch of the affected VII, or via direct neurotization to the depressor muscle, is performed.[8]

Second stage

During this stage, free or regional muscle transfers take place in combination with secondary microcoaptations or direct neurotizations of dysfunctional targets. The term 'secondary microcoaptations' pertains to the coaptations between selected branches of the affected VII with the CFNGs, which usually take place 9–12 months after the first stage. Thus, the distal ends of the previously placed CFNGs are used for direct neurotization of either native facial or transferred musculature of the eye sphincter, levator and depressor respectively. The aim of muscle transfer is to substitute or augment a specific target.

Third stage (revisions)

At this stage, ancillary procedures are used, as needed, for enhancement of the dynamic procedures that took place in the previous stages of reanimation. Our Center has developed detailed algorithms of the ancillary and revisional procedures for compensation of common infirmities of dynamic reanimation.[9] An algorithm for facial reanimation is provided in Table 3.

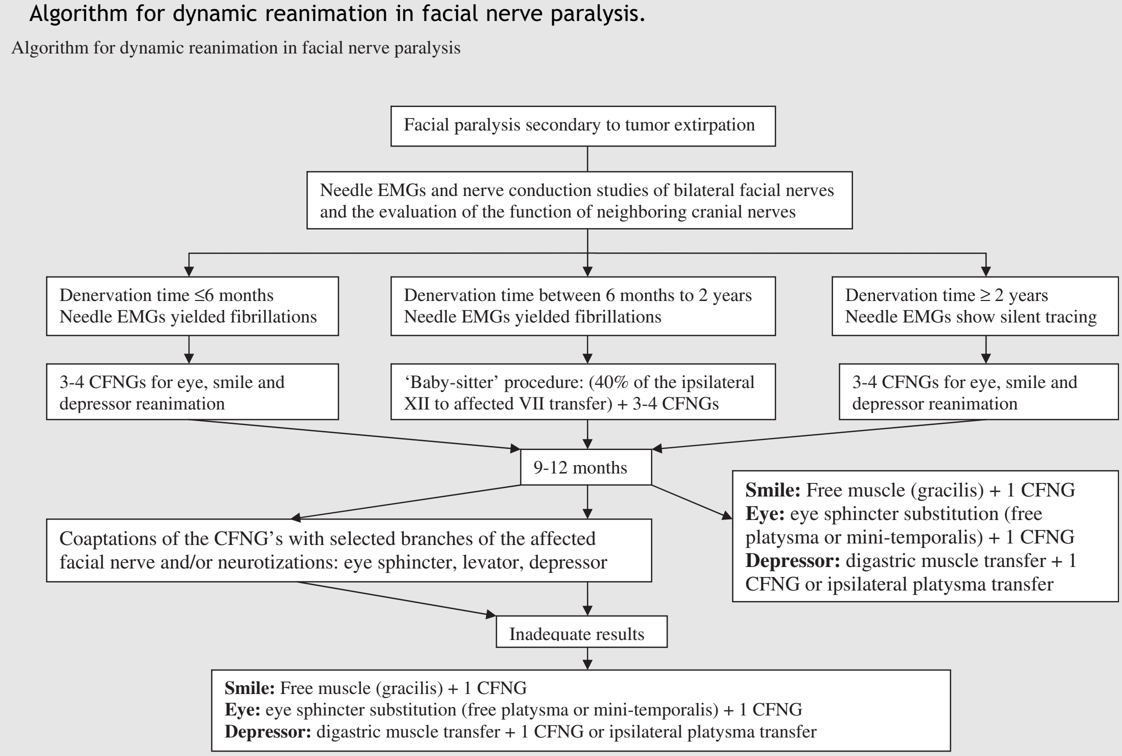
Postoperative care

At the sixth postoperative week, ultrasound therapy and massage are applied over the operated hemiface in order to prevent adhesions between either the nerve grafts or the transferred muscle and the overlying skin envelope. Each patient follows an exercise regimen in front of a mirror. A slow pulse stimulator ('The Liberson', J.D. Medical, California, USA) is used in cases of the 'Babysitter' procedure in order to maintain the bulk of the facial musculature and halt the denervation process. When a free muscle has been used to restore smile, no slow pulse stimulation is indicated, as there can be sequellae of too powerful contraction.

Data analysis

Preoperative and postoperative videos of each patient were reviewed separately by three independent investigators

Table 3 Algorithm for dynamic reanimation in facial nerve paralysis.



who are blinded to the study, under almost identical conditions, with the Terzis' grading scales for eye closure, smile, depressor and overall esthetic and functional outcome.[7,10–12] The authors did not participate in the evaluating process. Preoperative and postoperative electromyographic interpretations were evaluated by using a 4-scale (from 0 to 3) developed by our Center.[13] The needle electromyography interpretations scale, which is used by our Center, correlates the number of motor unit potentials, found by the EMG study, with muscle contraction. The more motor units elicited during needle insertion the better the motor function. According to this scale,[13] silent needle EMG studies are graded as 0, the beginning of reinnervation (1+) is graded as 1, the more advanced reinnervation (2+) is graded as 2 and the full electogenesis (normal muscle contraction, 3+) is graded as 3. The effect of demographic variables was also investigated in relation to the measured parameters.

Statistical analysis

Comparisons between preoperative and postoperative mean reviewers' scores were performed using the Wilcoxon signed rank test. The Mann–Whitney test was used to compare postoperative results according to age, denervation time and tumor location. All the analysis was performed in SAS 9.1.3 (Cary, NC). The significance level was set at 0.05.

Results

There was a late loss of a free pectoralis muscle transfer for smile in one patient secondary to a direct trauma. The patient underwent a second free muscle transfer using a free gracilis for smile restoration. There was significant improvement regarding preoperative versus postoperative outcomes for overall esthetics and function with good and excellent results achieved in 62.50% of the patients ($n = 10$) (Table 4). There was a statistically significant increase ($p < 0.0001$) in all the patients' mean scores at the postoperative evaluation.

Nerve transfers

The CFNGs procedure ($n = 12$) was utilized in the majority of the cases. In the remaining cases ($n = 4$) the 'Baby-sitter' procedure ($n = 3$) and the combination of masseteric nerve transfer with CFNGs ($n = 1$) were used. The mean reviewers' scores for overall function and esthetic results per type of nerve transfer are summarized in Table 4.

Eye

In 9 cases eye reanimation was achieved with direct neurotization of the eye sphincter. The combination of direct neurotization and static procedures (mini-tendon ($n = 3$), eye spring ($n = 3$), gold weight ($n = 1$)) was used in 7 cases (Table 5). Eye closure was graded as good and excellent in 62.50% of the patients ($n = 10$) ($p < 0.0001$) (Table 6).

Smile

Levator neurotization was performed in 5 cases. Levator substitution was performed in 11 cases with one free muscle transfer ($n = 8$) (gracilis ($n = 6$), pectoralis ($n = 2$)) or combination ($n = 3$) (free gracilis/pectoralis + minitemporalis) (Table 5). Good and excellent results were observed in 68.75% ($n = 11$) of the patients ($p < 0.0001$) (Table 6).

Depressor

Depressor neurotization was performed in 12 cases. Depressor complex substitution was performed in 4 cases with digastric ($n = 3$) and platysma ($n = 1$) muscles (Table 5). Good and excellent results were observed in 68.75% ($n = 11$) of the patients ($p < 0.0001$) (Table 6).

EMG

Mean preoperative and postoperative results of the EMG study for eye sphincter, levator and depressor are summarized in Table 7. The difference between preoperative and postoperative EMG results was statistically significant ($p < 0.0001$ for each target).

Prognostic factors

According to this study, sex ($p = 0.93$), tumor location ($p = 0.30$) and chemotherapy/radiation administration ($p = 0.30$) were not correlated with the functional outcome. On the other hand, age of the patients ($p = 0.014$) and denervation time ($p = 0.033$) affected the outcome of facial reanimation (Table 8). Thus, patients aged $\leq$10 years and

Table 4 Mean reviewers' scores for overall functional and esthetic results according to the type of nerve transfer.

Nerve transfer	Mean reviewers' scores					Patients
	Poor	Fair	Moderate	Good	Excellent	
CFNGs	–	3 (18.75%)	1 (6.25%)	6 (37.50%)	2 (12.50%)	**12**
'Baby-sitter' procedure	–	–	1 (6.25%)	1 (6.25%)	1 (6.25%)	**3**
Masseteric nerve transfer + CFNGs	–	1 (6.25%)	–	–	–	**1**
Patients	–	**4 (25.00%)**	**2 (12.50%)**	**7 (43.75%)**	**3 (18.75%)**	**16 (100%)**

The number of patients and type of procedure are in bold.

Table 5 Procedures performed for eye closure reanimation, smile and lower lip depressor.

	Patients
Procedures for eye closure	
Neurotizations	**9**
Neurotizations + static procedures (mini-tendon, eye spring, gold weight)	7
- Eye spring	3
- Mini-tendon graft	3
- Gold weight	1
Procedures for smile	
Levator substitution	**11**
- with free gracilis	6
- with free pectoralis minor	2
- with free gracilis + free pectoralis minor + mini-temporalis[a]	1
- with free pectoralis minor + mini-temporalis	2
Levator neurotization	5
Procedures for depressor	
Depressor substitution + neurotization	**4**
- with digastric	3
- with platysma	1
Depressor neurotization	**12**
Myectomy of the unaffected depressor	**1**

[a] : In this patient the first free flap (pectoralis minor) suffered late necrosis secondary to trauma and so the patient underwent a new free Gracilis muscle transfer for smile reanimation. Further augmentation of smile was achieved with a mini-temporalis muscle transfer.

with denervation time ≤2 years achieved better functional recovery and this was statistically significant.

Exemplary cases of pediatric patients with FP following tumor extirpation and subsequent facial reanimation surgery are depicted in Figures 1–4.

Discussion

Unlike FP in adults, in children it is more frequently associated with tumor (2–12%).[14] Moreover, the FP might be the first manifestation of a systemic disease, such as acute lymphoblastic leukemia.[15] A number of clinical features should alert the clinician to the possibility of a neoplastic etiology such as slow progression beyond three weeks, no return of function after six months, bilateral or recurrent unilateral FP, other cranial nerve involvement, facial hyperkinesia or spasm, single branch paralysis and pain.[16,17]

May et al.[18] reported that the incidence of FP due to tumor in children was 2%, which included neurinoma and glioma. Evans et al.[19] reported an incidence of 2.86% in a series of 35 pediatric patients with FP. On the other hand, Shih et al.[14] reported an incidence of 7.1% of FP due to tumor in a series of 56 children.

The MRI scan is of less diagnostic value than the CT scan for FN tumors in the temporal bone, but the MRI scan may help to distinguish FN tumors from congenital cholesteatoma. MRI scan is of great diagnostic value for FN tumor in the pontocerebellar angle, brainstem and cerebellum.

Once the FN tumor has been identified, surgical resection should be adopted as soon as possible. Most authors agree that postoperative radiation therapy does not have a detrimental effect on outcome.[20] Because postoperative FP is almost inevitable after tumor removal, the earliest possible repair (at best, at the time of the tumor extirpation surgery) will result in the best functional outcome of all surgical rehabilitation strategies.[21] Dynamic panfacial reanimation proves superior to any combination of static procedures[9] and aims to physiological coordinated reanimation of all three main targets (eye-smile-depressor).

Nerve transfers

The key factor that determines success with nerve transfers is the duration of muscle denervation and residual motor activity. Denervated muscles undergo a characteristic pattern of changes as the denervation evolves from an acute phase through a subacute and then chronic phase.[22,23] Acute changes occur within a month following denervation, subacute changes are those that follow from 12 to 20 months, and chronic changes occur after 12–20 months. Acute denervation is characterized by an increase in muscle volume, and no fatty infiltration. Subacute denervation is characterized by fatty replacement of the denervated muscles without increase in muscle volume. Early or mild chronic denervation is characterized by mild fatty change of the affected musculature without evidence of appreciable volume loss. Long-standing chronic denervation is characterized by extensive fatty infiltration and volume loss of the denervated musculature.

Following reinnervation, regenerating axon terminals will produce new neuromuscular junctions either on or near the regions of the old neuromuscular junctions.[24] Watanabe et al.[25] demonstrated a gradual decrease of muscle thickness and cross-sectional area in gracilis transfers until

Table 6 Preoperative and postoperative functional grading for eye sphincter, levator and lower lip depressor.

Target	Functional grading scores		G & E results	Patients	*p*-value
	Preop	Postop			
Eye sphincter	1.30 (range 1–3)	3.90 (range 2–5)	**10 (62.50%)**	**16**	**<0.0001***
Levator	1.44 (range 1–3)	3.75 (range 3–5)	**11 (68.75%)**	**16**	**<0.0001***
Depressor	1.12 (range 1–2)	3.94 (range 2–5)	**11 (68.75%)**	**16**	**<0.0001***

Abbreviations: G & E results: good and excellent results, Preop: preoperative, Postop: postoperative, *: statistical significant.
The number of patients with good and excellent results, the total number of patients and the *p*-values are in bold.

Table 7 Mean preoperative and postoperative EMG results for eye sphincter, levator and lower lip depressor.

Target	EMG mean scores		Patients	*p*-value
	Preop	Postop		
Eye sphincter	0.56 (range 0–1)	2.31 (range 1–3)	**16**	**< 0.0001***
Levator	0.43 (range 0–1)	2.56 (range 2–3)	**16**	**< 0.0001***
Depressor	0.44 (range 0–1)	2.19 (range 1–3)	**16**	**< 0.0001***

Abbreviations: EMG: electromyography, Preop: preoperative, Postop: postoperative, *: statistical significant.
The total number of patients and the *p*-values are in bold.

15–20 weeks postoperatively, and thereafter these values increased proportional to reinnervation and amplitude and density of the reinnervation potentials on needle electromyography. Harii[26] stated that the first twitches of the transplanted muscle are noticed between the fifth and eighth postoperative months; thereafter, the strength of the contractions increases, reaching a plateau at approximately 18 months post-operatively. Moreover, in pediatric FP patients, the first twitches of the free muscle are between the 3rd and 5th month postoperatively.[27]

The use of preoperative needle EMGs and nerve conduction studies is critical in order to precisely assess the degree of denervation of the affected facial musculature. Moreover, needle EMG studies offer an objective assessment of the function and integrity of other neighboring nerves which can be used as motor donors for nerve transfer procedures.

CFNGs procedure allows the possibility of synchronous, coordinated movements as well as emotional expression. The procedure involves placement of a CFNG dedicated for eye reanimation, a second CFNG for smile restoration, and a third CFNG for depressor complex. The choice of the donor branches of the contralateral FN relates to the regions in the paralyzed face that need to be reanimated. In the current series, the CFNGs procedure was used in 12 patients with good and excellent results in 8 patients (66.67%). In 9 out of 12 cases, the CFNGs procedure was combined with muscle transfers and in 3 cases it was used as a sole procedure without further muscle augmentation.

The 'Baby-sitter' procedure was introduced in 1984 by the senior author (JKT)[7,28–30] and combines the preservation of the bulk of the facial muscles (accomplished by the minihypoglossal transfer to the ipsilateral FN) and the coordinated animation (from the CFNGs). This technique is aimed at preventing irreversible atrophy of the paralyzed mimetic muscles during the long regeneration period of elongating axons through CFNG's. In the current series, the 'Baby-sitter' procedure was used in three with good and excellent results in two patients (66.67%).

Table 8 Effect of demographic variables on the facial reanimation outcome.

Variable	Groups	Patients	*p*-value
Age	0–10 year	7 (43.75%)	**0.014***
	>10 years	9 (56.25%)	
Sex	Male	5 (31.25%)	**0.93**
	Female	11 (69.25%)	
Denervation time	0–24 months	5 (31.25%)	**0.033***
	>24 months	11 (69.75%)	
Tumor location	Intracranial	11 (69.75%)	**0.30**
	Extracranial	5 (31.25%)	
Chemotherapy/radiation	Yes	5 (31.25%)	**0.30**
	No	11 (69.75%)	

Abbreviations: *: statistical significant.
The *p*-values are in bold.

Although the best timing for using the 'Baby-sitter' procedure is between 6 months and 2 years of denervation, satisfactory results were produced in cases with longer denervation time, provided that the facial nerve was in-continuity. Various authors[31,32] have reported satisfactory results with hypoglossal to facial nerve transfer even after 4 years after injury, if the facial nerve was in-continuity.

The masseteric nerve transfer was popularized by Zuker and Manktelow[33] who utilized it in an end-to-end-fashion for the treatment of patients with Mobius syndrome. In contrast, the senior author (JKT) has successfully utilized the masseteric nerve in an end-to-side fashion,[34] in order to prevent further downgrading of masseteric function, for neurotization of the free muscle transfer in Mobius patients. Thus, complete paralysis of the masseter muscle is avoided. In the current series the masseteric nerve transfer was used for eye sphincter neurotization in combination with the CFNGing procedure.

Direct neurotizations

Direct muscle neurotization (DMN) concerns three types of muscle: native facial muscles, local pedicled muscles that are transferred to augment a specific function, and free transplanted muscles. The procedure, which involves the implantation of a nerve (either directly or via an interposition nerve graft) into the selected muscle, aims to strengthen a weak target without sacrificing its native innervation.[35]

For DMN to be effective, preoperative needle EMG studies must disclose evidence of remaining muscle function for eye sphincter, levator, or depressor neurotization. In long denervation time (over 2 years) with silent preoperative EMGs, a CFNG is used for neurotization of a free muscle for substitution of the denervated target.

The major indication for DMN procedure is the augmentation of partially denervated muscles. If the muscle presents adequate motor unit potentials ($\leq 2+$) during needle EMG, it is wise not to disrupt the current innervation and to proceed with DMN of that muscle. This results in

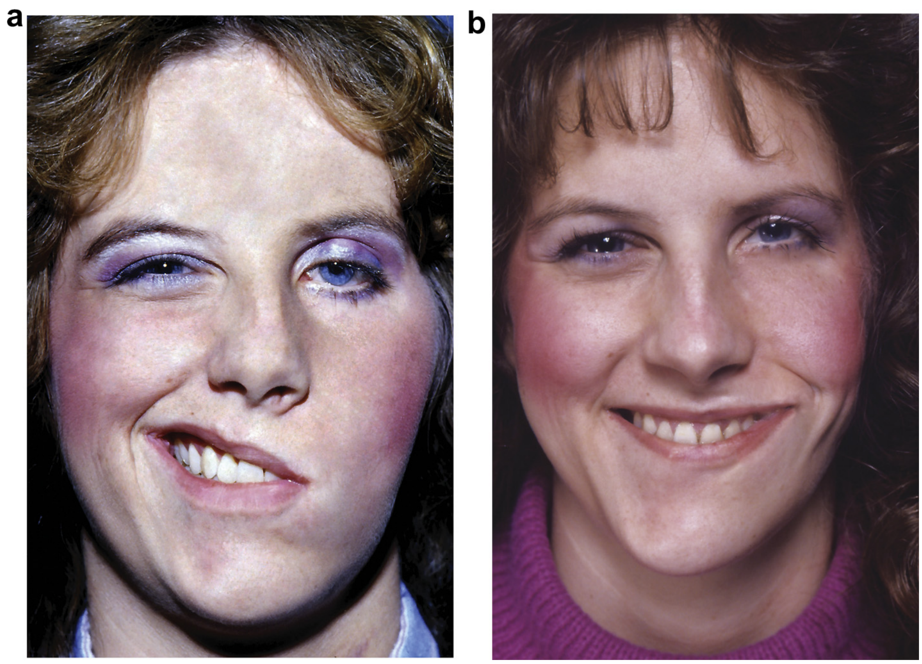


Figure 1 A 17-year-old female patient presented with complete left-sided facial palsy resulting from excision of a left acoustic neuroma. The denervation time was 2 years at the time of the first surgery in our center. She had first stage reconstruction with CFNGs x3. Twenty-two months later she had free pectoralis transfer for smile reanimation and left eye sphincter neurotization. Seventeen months later, the patient had her third stage of reconstruction with eye spring insertion to the left upper eyelid. Preoperative smile and overall appearance. Smile was graded as poor (**1a**). The final postoperative result smiling (**1b**). Smile was graded as excellent.

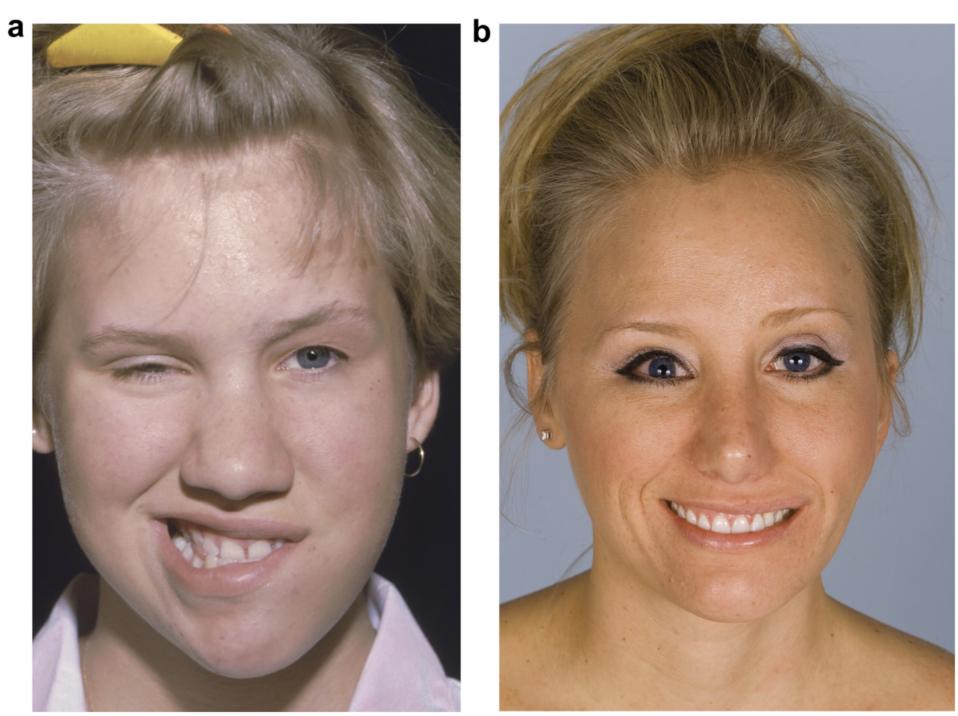


Figure 2 A 11-year-old female patient presented with complete left-sided facial palsy resulting from excision of a left cheek hemangioma. The denervation time was 11 years at the time of the first surgery in our center. Her first stage reconstruction involved CFNGs x3. Thirteen months later she had a free pectoralis minor transfer for smile reanimation. Fifteen months later, the patient had her third stage of reconstruction with digastric transfer for depressor substitution and transposition of the left superficial temporal fascia to left cheek. Preoperative smile and overall appearance. Smile was graded as poor (**2a**). Late final postoperative follow-up smiling (**2b**). Smile was graded as excellent.

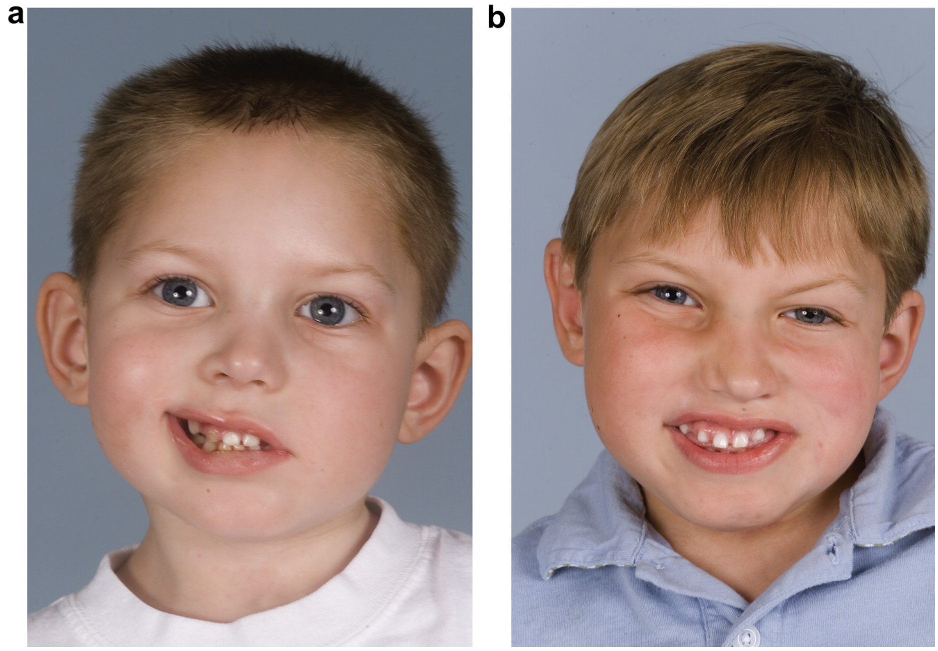


Figure 3 A 3-year-old male patient presented with complete left-sided facial palsy resulting from excision of a posterior fossa ependymoma. The denervation time was 1 year at the time of the first surgery in our center. He had first stage reconstruction with 'Babysitter' procedure: mini-hypoglossal transfer via two nerve grafts, one for eye sphincter neurotization and the other was banked for smile, and placement of two CFNGs. Fifteen months later he had a free gracilis transfer for smile reanimation which was neurotized by one CFNG and the previously banked graft from the ipsilateral hypoglossal. Preoperative smile and overall appearance (**3a**). Smile was graded as poor. The final postoperative result (**3b**). Smile was graded as good.

Figure 4 A 12-year-old female patient presented with left-sided facial palsy resulting from excision of a pilocytic astrocytoma. The denervation time was 10 years at the time of the first surgery in our center. The patient had residual function in the ipsilateral facial nerve. She had first stage reconstruction with 'Babysitter' procedure: mini-hypoglossal transfer to cervicofacial branch of left facial nerve and CFNGs x3. Seven months later she had free gracilis transfer for smile reanimation neurotized by a CFNG, carrying 'smile' fibers, and direct neurotization of eye sphincter by a CFNG, carrying 'eye' fibers. Nineteen months later, she had her third stage of reconstruction with mini-temporalis transfer for smile augmentation. Preoperative smile and overall appearance (**4a**). Smile was graded as poor. The final postoperative result smiling (**4b**). Smile was graded as good.

augmentation of function without downgrading of the existing function.

In the current series, direct neurotization of the eye sphincter was performed in all cases. The motor donor was the contralateral FN ($n = 12$), the hypoglossal nerve ($n = 3$) or the masseteric nerve ($n = 1$). Good and excellent results were observed in eight cases (50.00%). Direct neurotization for smile augmentation was performed in all cases by a CFNG with good and excellent results in nine cases (56.25%). For depressor neurotization the motor donor was the contralateral FN ($n = 13$) and the hypoglossal nerve ($n = 3$). Good and excellent results were obtained in twelve cases (75.00%).

Muscle transfers

Regional and free muscle transfers have been utilized for eye sphincter substitution. In particular, segmental temporalis muscle and its fascia have been used for eye closure.[36] Disadvantages of this technique include the bulge over the lateral orbital area, the slit-like appearance of the eye upon closure and the movement of the eyelid upon chewing. Lee and Terzis[37] have studied extensively the microanatomy of several muscles, namely, the platysma and the frontalis, for eye sphincter substitution. Pedicle or free muscle transfer innervated by a CFNG carrying 'eye' fibers from the contralateral FN has successfully restored coordinated eye closure and blink. This combination should be considered as the treatment of choice in pediatric FP cases with severe ocular involvement.

The gracilis muscle transfer is the workhorse for smile reanimation. The senior author (JKT)[38] favors the use of pectoralis minor transfer in young children due to its short triangular shape and dual innervation which offers greater possibilities for facial expression. In the current series, levator substitution was performed in 11 cases (gracilis ($n = 7$), pectoralis minor ($n = 5$)). Good and excellent results were obtained in eight cases (72.73%).

In cases of weak depressor muscle, the platysma muscle, if uninvolved, or the digastric transfer, are viable options.[11] In the current series, depressor substitution was performed in four cases with platysma ($n = 1$) and digastric ($n = 3$). Good and excellent results were obtained in 10 patients (83.34%).

Ancillary techniques

Patients with inadequate outcomes of eye reanimation are complemented with ancillary procedures. A gold weight or eye spring is selected for the upper lid[39] and the mini-tendon graft, using a strip of palmaris longus tendon, for the lower eyelid.[40] The decision of whether to place a gold weight or a palpebral eye spring is based on the compliance of the patient, the contour and preexisting eyelid anatomy, the site and depth of the upper eyelid fold, and whether some blink and/or some eye closure exists or not.[12] In the current series, combined dynamic and static procedures were used in 6 cases with good and excellent results in four (66.67%).

In cases of inadequate results from a free-muscle transfer for smile reanimation, the senior author (JKT) supplements the levator complex with mini-temporalis transposition to the upper lip and oral commissure.[41] This technique has effectively augmented functional and esthetic results in our center.[42] A mini-temporalis transfer not only improves the symmetry of the smile but also increases cheek tone, which improves speech[43] and helps emptying of the buccal sulcus, facilitating better oral hygiene.[44] Intensive mirror training and motor reeducation are necessary for satisfactory outcomes. In the current series, free muscle transfer was combined with mini-temporalis transposition in 3 cases with good and excellent results in two cases (66.67%).

Inadequate results with depressor complex reanimation are supplemented with static procedures. In such cases, the senior author favors myectomy of the normal side in order to restore symmetry in the lower lip.[9] Contralateral selective neurectomy has the disadvantage of further weakening the lower lip. Moreover, botulin toxin can be used as an alternative to surgical neurectomy.[45] The temporary effect of Botox on the normal depressor (3–6 months) is a distinct disadvantage of this technique.

Demographic variables

There are some limitations to this study that should be discussed. Our study population consisted of patients referred to a microsurgery practice for FP post-tumor extirpation, sometimes following multiple ineffective treatments. This is likely reflected in the severe and therapy resistant nature of our patients' complaints and, therefore, combinations of procedures were utilized compared to studies from other medical centers. Moreover, the number of patients included is small, but given the reasonably low incidence of pediatric FN palsy post-tumor extirpation, our study was based on a relatively large number of patients.

Age seems to influence the speed of nerve regeneration. In a clinical study of Tinel signs over CFNGs, Braam and Nicolai[46] reported an inverse relationship between the age of the patient and the rate of regeneration. Trojaborg et al.[47] computed a decrease of 0.9 m/s per 10 years of age in the sural nerve. In our study, the younger the patient at the time of the surgical intervention, the better the postoperative result ($p = 0.014$).

Prolonged denervation time necessitates new muscle supplementation. In our series, patients with denervation time $\leq$2 years achieved better results when compared with longer denervation ($p = 0.033$). Thus, the timing of surgical intervention is critical. Early intervention stops the denervation clock to the affected facial musculature and allows the possibility of reinnervation of the native facial musculature which leads to improved outcomes.

On the other hand, there was no correlation between location of the tumor and clinical outcomes ($p = 0.30$, Table 8). This is most likely related to the fact that the majority of the patients were late cases (denervation time $>$2years) and multistage surgery was equally utilized for overcoming the facial asymmetry.

However, we do not consider that there is an end-point in treating facial palsy patients and especially complicated ones like those of post-tumor extirpation. All patients with FP, and especially the parents of pediatric patients, demand 'physiological reanimation' when the various options are presented to them, even if such surgical management will involve several stages of reconstruction and longer operations. Thus, if such patients are 'cleared' medically and upon patient consensus, then the three-stage reanimation strategy can be implemented.

Female patients tended to report the first contraction of the free muscle graft earlier than male. This could be related to enhanced nerve regeneration probably due to the ability of gonadal steroids to augment the reparative response of nerves to injury.[10] In the current series, patients' sex did not adversely affect the outcome ($p = 0.93$).

Furthermore, there was no correlation between previous chemotherapy/radiation administration and clinical outcomes ($p = 0.30$). Bascom et al.[20] also suggested that previous chemotherapy/radiation therapy does not have a detrimental effect on outcome.

Other series

Although there are several studies concerning the etiology, diagnosis and conservative treatment of pediatric FP, there is paucity in the literature for dynamic facial reanimation in children following tumor extirpation. This to date is the largest series of patients with FP post-tumor extirpation operated by a single surgeon (JKT).

The existing sporadic reports are mainly focused on smile restoration. Moreover, in these series FP was due to various (either congenital or acquired) causes. Thus, the results of the current series can not be compared with those studies.

Conclusions

The surgical goal in pediatric patients with post-tumor FP is to augment the function of the paretic facial musculature with multi-staged facial reanimation surgery. A detailed objective and quantitative assessment should guide the reconstructive surgeon to the optimal reconstruction strategy. Furthermore, it is critical for the surgeon to aim toward panfacial restoration of function without neglecting the paretic eye sphincter nor the affected depressor complex. Young age and early appropriate treatment are associated with improved outcomes.

Conflict of interest statement

The authors have no conflict of interest.

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