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Smile Reanimation with Masseteric-to-Facial Nerve Transfer plus Cross-Face Nerve Grafting in Patients with Segmental Midface Paresis: 3D Retrospective Quantitative Evaluation

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Abstract: Facial paresis involves functional and aesthetic problems with altered and asymmetric movement patterns. Surgical procedures and physical therapy can effectively reanimate the muscles. From our database, 10 patients (18–50 years) suffering from unilateral segmental midface paresis and rehabilitated by a masseteric-to-facial nerve transfer combined with a cross-face facial nerve graft, followed by physical therapy, were retrospectively analyzed. Standardized labial movements were measured using an optoelectronic motion capture system. Maximum teeth clenching, spontaneous smiles, and lip protrusion (kiss movement) were detected before and after surgery (21 ± 13 months). Preoperatively, during the maximum smile, the paretic side moved less than the healthy one (23.2 vs. 28.7 mm; activation ratio 69%, asymmetry index 18%). Postoperatively, no differences in total mobility were found. The activity ratio and the asymmetry index differed significantly (without/with teeth clenching: ratio 65% vs. 92%, $p = 0.016$; asymmetry index 21% vs. 5%, $p = 0.016$). Postoperatively, the mobility of the spontaneous smiles significantly reduced (healthy side, 25.1 vs. 17.2 mm, $p = 0.043$; paretic side 16.8 vs. 12.2 mm, $p = 0.043$), without modifications of the activity ratio and asymmetry index. Postoperatively, the paretic side kiss movement was significantly reduced (27 vs. 19.9 mm, $p = 0.028$). Overall, the treatment contributed to balancing the displacements between the two sides of the face with more symmetric movements.

Keywords: facial paresis; reanimation; masseter-to-facial transfer; motion capture; symmetry

1. Introduction

Facial paresis involves aesthetic and functional problems that can compromise life from a personal, familial, and social point of view. Depending on the etiology of the paresis, different percentages of patients spontaneously recover totally or partially: recovery rates of 70–94% for idiopathic Bell's palsy have been reported [1,2]. Indeed, after partial healing, a small percentage of patients affected by Bell's palsy manifest an incomplete function of the mimetic musculature: facial paresis results from an aberrant and successive partial recovery of the facial nerve fibers. At 6–9 months follow-up, about 4% of the patients have a severe residual paresis and 7% show synkinesis [1]. Physical alterations combine with psychological impairments, thus significantly reducing the patients' quality of life [3,4]. Indeed, soft tissues asymmetry and reduced facial movements can limit facial expressiveness and impair communication. Additionally, patients with long-standing facial paresis can suffer from muscle hypertonicity and facial synkinesis, which can further worsen the performance of the voluntary movements of the paretic side of the face [1,5,6].

Movements of the orolabial region can be voluntary or spontaneous, contributing in different ways to our verbal and non-verbal expressions [7–9]. In the middle and lower parts of the face, lips opening may result from different neural pathways [10]. Voluntary movements (also called instructed or posed smiles) start with precentral gyrus pyramidal cells activation, stimulating the lower part of the contralateral facial nerve nucleus in the pons, while spontaneous movements start from subcortical structures (basal ganglia, limbic system nuclei) and produce a wider set of movements, also involving eye closure [11]. On both occasions, the zygomaticus major muscles contract to elevate the labial commissure and smile, even if the movement is less forceful for spontaneous smiles than for posed ones. The final result and the emotional content are different [7,9]. Moreover, both facial animations are associated with activity in the cingulate cortex [10].

Considering the reduced quality of life of these patients, it is not surprising to find that treatments for facial nerve palsy had been described by medical literature since the 11th Century BC [12], showing that patients had always been seeking medical and/or surgical treatments to improve their muscular function and regain the lost facial expressiveness [13,14].

Notwithstanding the similar signs and symptoms, the etiology of idiopathic facial palsy may be varied; moreover, there are various treatment options for which different clinicians may have differing levels of expertise. The choice may thus depend more on the experience of the neurologist, surgeon, or ENT specialist than on internationally recognized guidelines obtained from randomized trials or well-organized meta-analyses [1,15]. Furthermore, while the acute and short-term impairments seem to be beneficially treated by corticosteroids independently from the etiology [2,15], the subsequent mid- and long-term management of the palsy also depends on its origin, and the treatment should be tailored to the single patient.

Different procedures can be used to support the paretic muscles and partially hide the deficits, from a minimally invasive technique, such as injection of neurotoxin for the treatment of muscle hypertonicity and facial synkinesis [16], to the use of more invasive surgical procedures. Among the latter, the masseteric-to-facial nerve transfer has been proposed by Biglioli and colleagues [17,18], evolving Spira's intuition presented in 1978 to treat segmental paralysis [19]. A recent systematic review summarized data including 13 studies and a total of 183 patients, and it reported a successful procedure outcome, with improvements in facial mobility and mouth symmetry during voluntary smiles [3]. The surgical procedure can be combined with a cross-face facial nerve graft to recover spontaneous smiles using the contralateral healthy side's stimulus [3,18]. Moreover, a facial therapy approach, conducted by a specialized physical therapist after the surgical treatment, has been demonstrated to positively enhance the functional outcomes in patients with facial palsy [20,21].

Our experience with patients affected by segmental midface paresis reported a successful outcome for the paretic-side labial commissure displacement during voluntary smiling (masseteric nerve function), as well as a more pleasant, even if less powerful, emotional smiling (contralateral facial nerve function) [18]. Together with clinical observations, the rehabilitation outcomes were analyzed using the e-face system [22], which allows a quantitative assessment of photographic records limited to the two-dimensional coronal plane. Current technology instead allows tracking facial movements in all three spatial dimensions, thus providing a contactless, non-invasive, and complete picture of the analyzed animations [23–28].

From our database, a group of patients suffering from unilateral segmental midface paresis and rehabilitated by a masseteric-to-facial nerve transfer combined with a cross-face facial nerve graft, followed by physical therapy, were retrieved. Their facial movements were retrospectively analyzed. The purpose of the current investigation is to quantify the effectiveness of this facial reanimation technique and rehabilitative recovery using standardized animations such as lip protrusion (kiss), voluntary smile with and without teeth clenching, and spontaneous smile [29].

2. Materials and Methods

2.1. Patients

In this single-center, retrospective study, our database was screened to retrieve all patients recruited in the last 5 years at the Department of Maxillofacial Surgery, San Paolo Hospital in Milan, who fulfilled the inclusion criteria: (i) clinical characteristics: unilateral segmental midface paresis, evaluated III and IV grade according to modified House–Brackmann grading scale (M.H.B.) before operation; (ii) treatment: surgery and physical therapy: masseteric-to-facial nerve transfer combined with a cross-face facial nerve graft, followed by physical therapy; and (iii) measurements: pre- and post-treatment three-dimensional computerized analysis of facial movements. All patients were in good general health and did not report complications or adverse events during the treatment. The research protocol was performed following the Declaration of Helsinki standards. All patients were informed about the procedures and possible risks for surgical and physiotherapy treatments according to hospital guidelines and gave their written consent. Informed consent was also signed before participating in the motion capture protocol: all procedures were without risks and did not include painful or fastidious activities. The patients also approved the possible reuse of their pseudo-anonymized personal data as done in the current retrospective study.

An a priori power analysis was performed based on previously published data recorded with a similar protocol [30]. Power calculations were achieved using General Linear Mixed Model Power and Sample Size (GLIMMPSE) 3.0 for repeated measures design with the Hotelling–Lawley trace test and the null hypothesis that all mean differences were zero ($\alpha = 0.05$). The healthy and paretic-side three-dimensional labial mobility during smile were set as dependent variables, and the analysis yielded a minimum sample size of 9 to reach the statistical power of 80%, selected as the target.

The search in the database retrieved 10 patients with unilateral facial paresis lasting more than two years who underwent direct neurorrhaphy between the masseter nerve and a branch of the facial nerve directed to the great zygomatic muscle. A total of 7 of the 10 patients also received a cross-face sural nerve graft between a central branch of the contralateral facial nerve and the same branch of the injured facial nerve connected with the masseteric nerve. Three patients did not receive cross-face nerve grafts because their paresis was minimal: in these cases, the surgeon performed only a neurorrhaphy between the masseteric nerve and a branch of the injured facial nerve directed to the great zygomatic muscle. All patients were evaluated before and after the surgical treatment using the modified House–Brackman grading scale (M.H.B.) [31]. In addition, needle electromyography was performed in all the patients before surgery to reveal mimetic muscle fibrillations. At surgery, the patients were aged 18 to 51 years (mean, 32 years, standard deviation (SD) 8 years; Table 1). Facial paresis was due to incomplete recovery from Bell's palsy ($n = 4$), facial trauma ($n = 1$), incomplete recovery from Ramsay Hunt Syndrome ($n = 1$), iatrogenic injury to the facial nerve after parotid surgery ($n = 1$), injury to the facial nerve during neurinoma removal ($n = 2$), and congenital palsy ($n = 1$). On average, the patients were operated 11 years (SD 8 years) after the beginning of the facial paresis. Each patient underwent one-step (three patients; F2, F4, M2) or two-step (seven patients) surgery performed by the same senior author (F.Bi.).

Table 1. Analyzed patients.

Patient (M/F)	Age (yrs)	Side (R/L)	Etiology	Surgery	Time between Lesion and Operation (Year)	Time between Operation and 3D Analysis (Months)	M.H.B. Scale (Grade)		First Mimic Muscle Contraction After Surgery-Beginning of Physiotherapy (Months)
							Preop	Postop	
M1	31	R	Acoustic neurinoma	M-F neurorrhaphy + cross-face sural nerve graft	10	15	III	II	3
M2	36	R	Facial trauma	M-F neurorrhaphy + cross-face sural nerve graft (two-step surgery)	2	8	IV	III	6
M3	18	L	Congenital palsy	M-F nerve neurorrhaphy	18	27	III	II	6
M4	51	L	Facial neurinoma	M-F neurorrhaphy + cross-face sural nerve graft	2	12	III	II	4
M5	32	R	Bell's palsy	M-F neurorrhaphy	5	48	III	II	3
F1	25	L	Bell's palsy	M-F neurorrhaphy	16	16	III	II	3
F2	35	L	Ramsay Hunt Syndrome	M-F neurorrhaphy + cross-face sural nerve graft (two-step surgery)	12	39	IV	III	4
F3	27	R	Bell's palsy	M-F neurorrhaphy + cross-face sural nerve graft	12	8	III	II	4
F4	33	R	Parotid surgery	M-F nerve neurorrhaphy + cross-face sural nerve graft (two-step surgery)	30	20	IV	III	4
F5	37	L	Bell's palsy	M-F neurorrhaphy + cross-face sural nerve graft	3	25	III	II	4

M: male, F: female, R: right, L: left, M-F: Masseteric–facial nerve neurorrhaphy M.H.B. Scale: modified House–Brackman grading scale [31].

2.2. Surgical Procedures

Under general anesthesia, infiltration with a vasoconstrictor was performed in the interested area and facial movements were tested during surgery using electrostimulation. The correct branches of the facial nerve were identified. A facelift-type incision was made on the paretic side of the face, then a subcutaneous pocket extending 2 cm medial to the anterior margin of the parotid gland was prepared. The deficient branch of the facial nerve supplying the zygomatic muscles was isolated and sectioned using a neurostimulator. Next, the branches of the facial nerve innervating the orbicular muscle of the eye were identified and partially sectioned. A similar procedure was performed in the healthy side of the face, but only one middle-size branch of the facial nerve (around 1 mm in caliber) providing the zygomatic muscles was isolated and partially sectioned.

The masseter nerve was found about 2 cm deeper than the surface of the masseter muscle on the paralyzed side of the face. The sural nerve graft was placed from the healthy side crossing the mid-facial level to the paretic side (cross-face). Through a surgical microscope, on the paralyzed side of the face, an end-to-end neurorrhaphy was packaged between the masseter nerve and the previously isolated facial nerve branch for the zygomatic muscle distal to the previous neurorrhaphy, an end-to-side neurorrhaphy was made between the cross-face sural nerve and the same facial nerve branch. On the healthy side of the face, an end-to-end neurorrhaphy was performed between the distal head of the cross-face graft of the sural nerve and the previously selected centrofacial branch of the facial nerve. Lastly, all neurorrhaphies were stabilized with fibrin glue to fix nerve courses in the desired position. Two steps were planned for cross-face nerve grafting in patients with severe paresis (M.H.B. scale: IV): the first operation placed the cross-face sural nerve graft and performed the neurorrhaphy between the distal head of the cross-face graft and the previously selected centrofacial branch of the contralateral facial nerve. Finally, after about 8–12 months, when Tenel's sign was positive, a second operation completed the remaining neurorrhaphies described on the paretic side of the face [17,32].

2.3. Physical Therapy

After the surgical treatment, the rehabilitative training started when the patient reported the first mimic muscle contraction, and it was performed several times a day. All patients received postoperative physiotherapy working directly with an expert physiotherapist explaining the exercises to be performed. Indeed, each patient received a plan of clinical rehabilitation exercises to be carried out at home independently and met the therapist once a week for 1 month, then twice a week for 3 months. After this time the frequency of treatment decreased to once a month up to 18–24 months (Table 2) [20,33]. The protocol was tailored for each patient according to the treatment needs.

Table 2. Facial exercise therapy after the first mimic muscle contraction.

Treatment Timing	Specific Rehabilitative Training
1–3 months	- Clench the teeth to stimulate the contraction of the mimic muscles of the paretic side - Recognize the amount and direction of movements - Observe the movement of the healthy side in the mirror, then try to do it by clenching the teeth and perceiving the quality of movement obtained from the operated side - Modulate the amount of force delivered by clenching the teeth to obtain a small, a medium, and a large movement of the paretic side - Perform the movement with the new motor pattern at different amplitudes, and coordinate it with the healthy side to obtain the correct symmetry of the smile
3–12 months	- Clench the teeth recalling recent or past emotional life situations - Associating the smile with tactile stimuli with pleasant surfaces, or by imitating emotional expressions from other people - Repeat the smile comparing it to the healthy side to improve the symmetry - Perception of the position of the lips during the speech - Start using the smile in emotional contexts
12–24 months	- Repeat different complex emotional expressions: joy, anger, sadness, and disgust - Intensify the work on the use of speech by reading and interpreting what you read - Modulate the quality of the movement to symmetrize a spontaneous smile - Perform the smile movement with spontaneity and symmetry without or with minimal teeth clenching

2.4. Facial Animation: Data Collection

The three-dimensional motion analysis and the clinical evaluation were performed before and after an average period of 21 months (SD 13 months) from surgical operation (Table 1). All patients were analyzed using a previously reported protocol [24]. An opto-electronic 3D motion capture system (SMART System, BTS, Milan, Italy) recorded the facial motion at a sampling rate of 60 Hz. The patients were instructed to sit inside an acquisition working volume given by nine high-resolution video cameras. After metric calibration and optic/electronic distortion correction, the patients were asked to perform four standardized facial expressions: lip protrusion (kissing), maximum smile without clenching, and spontaneous smile while looking at a funny video (see Supplementary Material, the participants being unaware of the purpose of that acquisition phase) [30]. The first three animations were performed before and after surgery, while the last one was done only after surgery. Each animation was repeated five to six times. The patients were instructed and allowed to practice the voluntary facial expressions before data collection; however, no instructions were given regarding the spontaneous smile task.

During the execution of each facial animation, the system identified the planar position of 9 passive reflective markers taped on specific facial landmarks (Figure 1) by gaining the 2D coordinates from each camera. Subsequently, the software converted all coordinates into metric data, gathering a set of 3D coordinates for each marker in each frame of every performed movement [24].

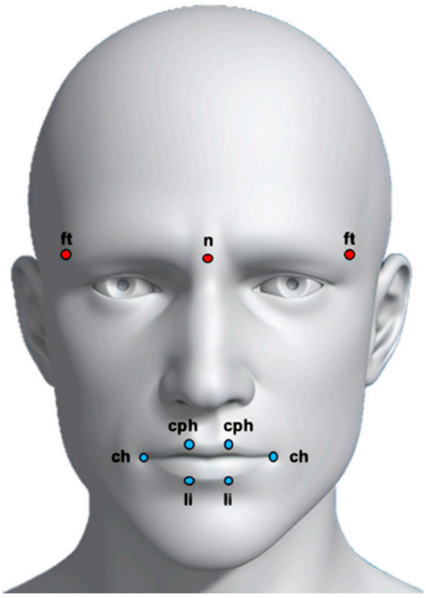

Figure 1. Position of the nine passive reflective markers: n, nasion; right and left side of ft, frontotemporal; cph, crista philtri; ch, cheilion; and li, lower lip midpoints. Red: reference markers; blue: tracked markers.

The 2 mm round reflective markers were glued to the skin, avoiding interferences with facial movements: n, nasion; right and left side of ft, frontotemporal; cph, crista philtri; ch, cheilion; and li, lower lip midpoints. Within- and between-session repeatability of the protocol was assessed in healthy and paretic subjects in a previous study [30].

2.5. Facial Animations: Data Analysis

To eliminate head and neck movements during the facial animations, a head reference system was mathematically defined using nasion and frontotemporal landmarks [24]. Therefore, the analysis took only the face movements produced by the mimetic muscles into consideration without limitations or restrictions to the head movements [24,30].

The three-dimensional coordinates of the six labial markers (right and left crista philtri, cheilion, and lower lip) were computed during each facial animation, and their 3D maximum displacement from rest was calculated. For each side (paretic and healthy), the total labial mobility was obtained from the sum of the landmarks displacements. Two indices were computed to quantify the side differences: the ratio of the paretic to healthy side [24] and the asymmetry index (percentage ratio between the difference and the sum of the healthy/paretic movements, ranging from −100%, paretic-side prevalence during the movement to +100%, healthy-side prevalence) [30].

2.6. Facial Animations: Statistical Analysis

Two thresholds were defined to reduce noise due to incomplete or poorly recorded movements and ensure a good signal-to-noise ratio. First, the total 3D mobility of the healthy side should be larger than 1 cm, and then the lateral displacement of its commissure should be larger than 1 mm [18].

For each patient, the relevant repetitions of facial movements were averaged. Calculations were performed separately for kisses and each kind of smile before and after surgical facial reanimation.

A Shapiro–Wilk test was performed to test the normality of the data. Since data were found to have a non-normal distribution, the results for the total displacements of the healthy and paretic side, the ratios, and the asymmetry indices were described as the median and interquartile range (IQR). Nonparametric statistical tests were applied. The Friedman test compared maximum smiles performed before and after surgery either without (facial nerve stimulus) or with teeth clenching (masseter nerve stimulus). Effect sizes were expressed as Kendall's W test value. When appropriate, post hoc tests were carried out using the paired Wilcoxon rank test.

Wilcoxon rank tests were used to compare spontaneous smiles (before vs. after surgery) and kisses (before vs. after surgery). Effect sizes were calculated as the coefficient of correlation (r). For all the analyses, the alpha level was set at 5% ($p < 0.05$), with a Bonferroni correction for post hoc tests ($p < 0.017$).

3. Results

Before surgery, three patients showed a grade IV M.H.B. scale value that improved to a grade III value at the post-surgery analysis (Table 1). For the other patients, the pretreatment grade III improved to grade II at the end of the physical therapy. In all patients, the first sign of muscular recovery was detected around 4 months after surgery (range 3–6 months).

The recording of facial movements was adequate on almost all occasions, and only two files were dismissed because they did not fulfill the previously defined thresholds. In the maximum smiles recorded during the preoperative data collection session, the average total 3D mobility of the paretic side was lower than that of the healthy side (23.2 mm vs. 28.7 mm), with a 69% activation ratio and an 18% asymmetry index (Table 3, Figure 2). In the post-surgical data acquisition session, Friedman tests revealed no significant differences concerning the total 3D mobility, with a small effect size. On the contrary, the activity ratio and the asymmetry index differed significantly ($p = 0.006$). In particular, post hoc tests identified a difference between the two postoperative smile movements (without and with teeth clenching; ratio 65% vs. 92%, $p = 0.016$) and asymmetry index (21% vs. 5%, $p = 0.016$, respectively; strong effect size).

Table 3. Total three-dimensional labial mobility during smile movements before (A) and after surgery (B: without teeth clenching; C: with teeth clenching).

Variable		**Maximum Smile Before Surgery (A)**	**Maximum Smile after Surgery (B)**	**Maximum Clenching Smile after Surgery (C)**	**Friedman Test**	**Effect Size**
					***p*-Value**	**Kendall's *W***
Healthy side (mm)	Median	28.7	28.1	24	NS (0.104)	0.323
	IQR	15.4	11.2	5.2		
Paretic side (mm)	Median	23.2	18.7	22.4	NS (0.156)	0.265
	IQR	11.9	12.1	8.8		
Ratio (%)	Median	69	65	92	0.006 B vs. C, $p = 0.017$	0.735
	IQR	31	29	57		
Asymmetry index (%)	Median	18	21	5	0.006 B vs. C, $p = 0.017$	0.735
	IQR	20	22	30		

Comparisons are made by Friedman Test; a post hoc test was conducted using paired Wilcoxon test; significant values for Friedman Test; $p < 0.05$; NS: not significant; significant values for post hoc test, $p < 0.017$. Effect size is expressed as Kendall's W test value. IQR: interquartile range. Ratio: paretic/healthy side percentage. Asymmetry index: percentage ratio between the difference and the sum of the healthy/paretic displacement.

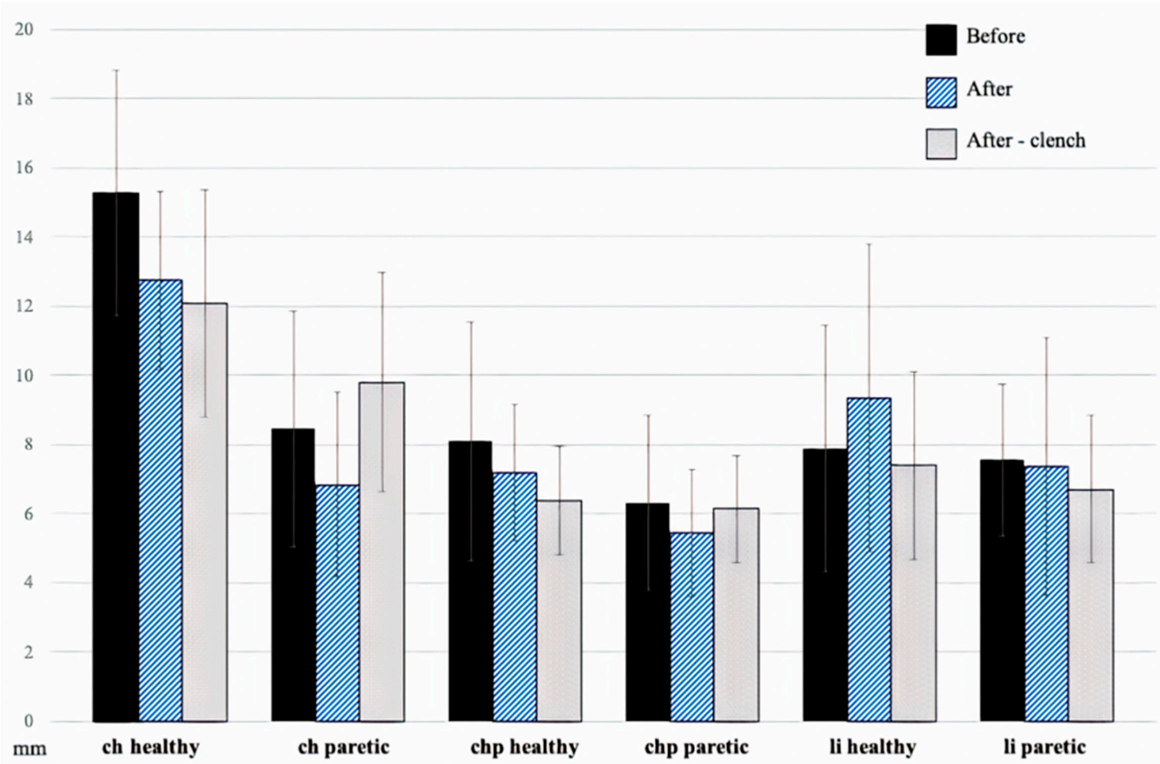

Figure 2. 3D maximum displacement from the rest position of the six labial markers (crista philtri, cheilion, and lower lip) during the smile animation before and after surgery, without and with teeth clenching (mean ± 1 SD).

Different trends of modifications were appreciated for the performance of spontaneous smiles (Table 4), with a significant reduction in the 3D total mobility of both the healthy and paretic sides in the post-operation assessment (25.1 vs. 17.2 mm, p = 0.043 and 16.8 vs. 12.2 mm, p = 0.043, respectively, medium effect size), while the activity ratio and asymmetry index revealed non-substantial variations (small effect size; Figure 3).

Table 4. Total three-dimensional labial mobility during spontaneous smile and kiss movements before and after surgery.

		Healthy Side (mm)	Paretic Side (mm)	Ratio (%)	Asymmetry Index (%)
Spontaneous smile before	Median	25.1	16.8	76	12
	IQR	18.7	9.6	26	15
Spontaneous smile after	Median	17.2	12.2	75	16
	IQR	11.3	9.1	52	13
Wilcoxon test	p-value	0.043	0.043	NS (0.465)	NS (0.686)
Effect Size	r	0.561	0.561	0.211	0.112
Kiss before	Median	34.9	27	75	18
	IQR	19.1	25.9	52	28
Kiss after	Median	32.2	19.9	69	18
	IQR	8.1	20	44	33
Wilcoxon test	p-value	NS (0.091)	0.028	NS (0.092)	NS (0.063)
Effect Size	r	0.410	0.533	0.436	0.452

Comparisons are made using the Wilcoxon test; IQR: interquartile range, NS: not significant, $p > 0.05$. Effect Size is expressed as the correlation coefficient (r). Ratio: paretic/healthy side percentage. Asymmetry index: percentage ratio between the difference and the sum of the healthy/paretic displacement.

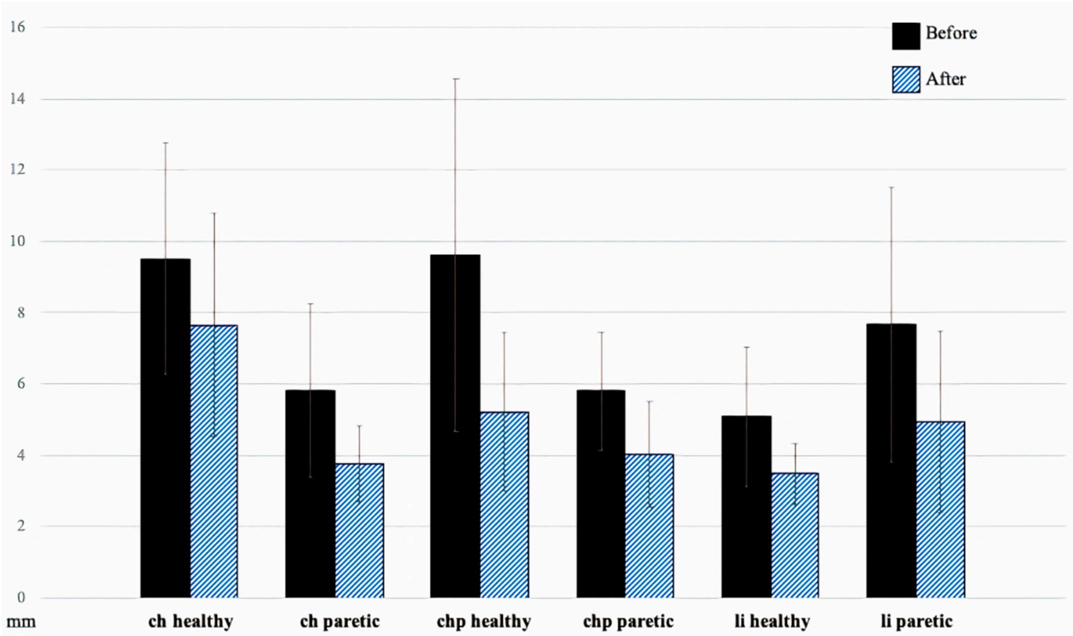

Figure 3. 3D maximum displacement from the rest position of the six labial markers (crista philtri, cheilion, and lower lip) during the spontaneous smile animation before and after surgery, without and with teeth clenching (mean ± 1 SD).

During the kiss/labial protrusion movement (Table 4), only the 3D total mobility of the paretic side showed a significant decrease between the pre- and post-operation evaluation (27 mm vs. 19.9 mm, p = 0.028). In contrast, the 3D total mobility of the healthy side and the indexes showed no significant changes (Figure 4). Overall, the effect size was small to medium.

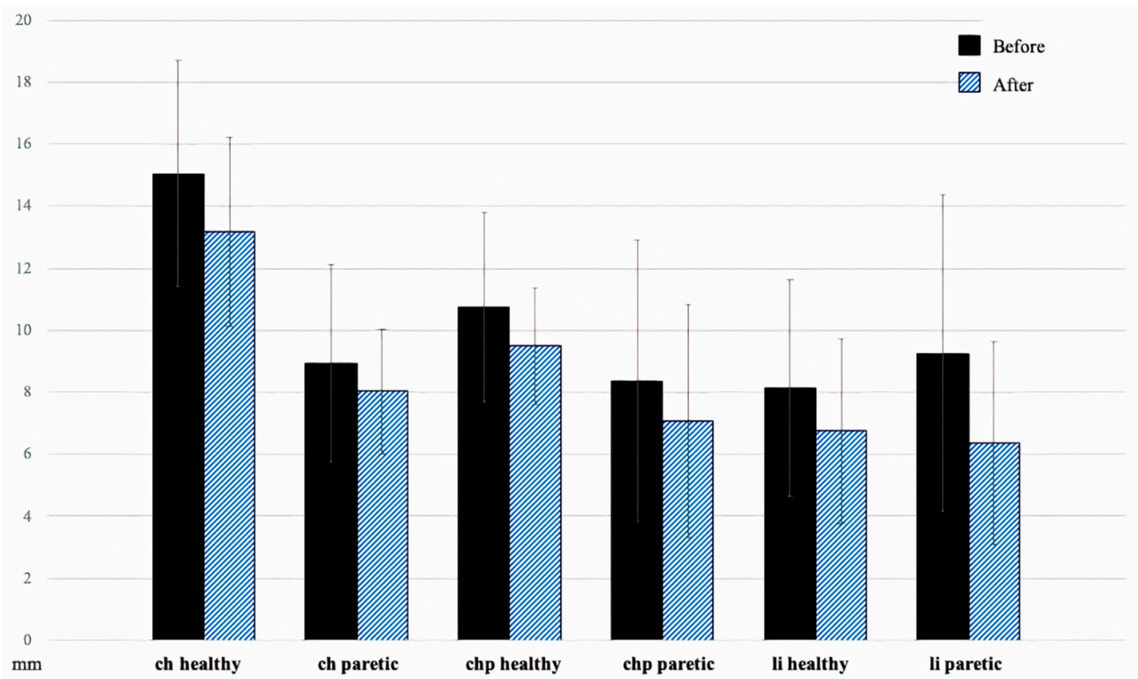

Figure 4. 3D maximum displacement from the rest position of the six labial markers (crista philtri, cheilion, and lower lip) during the kiss animation before and after surgery (mean ± 1 SD).

4. Discussion

Nowadays, the treatment of facial paresis remains a still debated topic. The variety of etiologies, the low number of cases, and the extensive use of non-invasive treatments have led to limited knowledge and diffusion of surgical techniques. Indeed, the reduced and altered contraction of part of the facial musculature, together with its hypertonia at rest, can be treated with a combination of non-surgical treatments: physical rehabilitation, chemical neurectomy, and injection of neurotoxin [34]. These interventions have the advantage of minimal invasiveness, but their limited time duration results in periodic re-treatments. Moreover, their efficacy is restricted to mild facial palsy, with a reduction in unpleasant movements and muscle tightness; no additional muscular strength may be added. In order to treat severe cases and obtain long-lasting results, patients must resort to surgical options to improve the insufficient spontaneous growing of axons and even the aberrant neural regeneration [35].

The aim of microsurgical facial reanimations is to restore the functionality of the facial nerve without losing the partially obtained spontaneous recovery. In the case of patients suffering from segmental midface paresis and with still functioning muscles, we propose a facial reanimation with the masseteric nerve as a donor nerve in order to obtain long-lasting results. Through this type of intervention, we increase the innervation of the zygomatic muscles and separate the neuronal stimulus of the orbicularis oculi from the zygomatic muscular complex reducing smiling synkinesis with the absence of functional sequelae at the donor site. At the same time, we perform an end-to-side neurorrhaphy of a cross-facial nerve graft to achieve a spontaneous smile [17].

An alternative frequently used nerve source is represented by the hypoglossal nerve, which has been used since 1903 for facial nerve rehabilitation [12]. Unfortunately, an interpositional nerve graft is often necessary, thus entailing a further neurorrhaphy with a consequent reduction in axon growth [15,35]. Moreover, for most patients it is almost impossible to reach the cerebral adaptation necessary to perform smiling by lingual movements naturally; therefore, we prefer to use only a part of the fibers of the hypoglossal nerve to restore the correct muscle tone at rest while treating the lower third of the face in recent facial paralysis [36,37]. Additionally, hypoglossal nerve use can lead to a worsening of synkinesis [38].

We think that other surgical techniques, such as free muscle transfer (latissimus dorsi, gracilis muscle transplantation), are much more invasive with higher morbidity and can potentially damage the remaining facial innervation [1]. In addition, for both gracilis transplantation and temporalis lengthening myoplasty, there is a big concern regarding the possibility of coordination of these muscles with the mimetic activity already present in the face [39–42].

The current study results show that the masseteric stimulus significantly increased labial symmetry during smiling with teeth clenching (asymmetry index 21% vs. 5%, $p = 0.016$). This significant result is due to two reasons: first, an increment of the paretic-side motion due to the masseteric motor source with also a synkinesis reduction; second, the role of rehabilitative recovery that allows learning how to modulate the movements of the healthy side of the face. This result confirms our previous studies, which showed a restricted activity of the non-paralyzed face and improved symmetry [5,36]. Indeed, in normal subjects, asymmetry increases as a function of the labial displacement for both spontaneous and posed smiles [43,44].

The surgical procedure can be combined with a cross-face facial nerve graft to recover spontaneous smiles using the contralateral stimulus (7 out of 10 patients). For those cases with a little smiling deficit and without an evident eyelid closure/smiling synkinesis, the masseteric nerve alone may be used (without cross-face nerve grafting): a middle size branch of the facial nerve for zygomatic muscles innervation is coopted. Thus, a powerful neural source is added, with the spontaneity of smiling guaranteed by neighboring functioning branches. The selection of the correct branches of the facial nerve is performed during surgery using electrostimulation in order to check if the correct movements are performed. Avoiding the use of local anesthetic drugs is therefore recommended. Overall, the movements recorded in these patients were comparable with those of the entire group, with a significant reduction in the 3D total mobility of both the healthy and paretic sides in the post-operation assessment, without substantial asymmetry variation. In addition, we recorded a significant decrease in the 3D mobility of the paretic side during lip protrusion. This analysis confirms that the nerve stimulus for the zygomatic complex is increased. At the same time, the aberrant neural regeneration, which is responsible for muscular hypertonicity and facial synkinesis, is highly resolved. The results obtained with surgery provide the patient with greater control over facial muscles. These improvements are increased with clinical physiotherapy, which is completed with an exercise plan independently performed at home from the first contraction up to two years.

In a recent systematic review, Murphey et al. [3] compared the time of nerve recovery after treatment: the first contraction of the paretic side of the face was detected clinically or instrumentally about 5 months (range 2–7 months) after surgery. This outcome also depends on the location of the coaptation: a neurorrhaphy to the zygomatic branch recovers much faster than one to the main trunk. In the current investigation, this value is confirmed, and the first sign of recovery was around 4 months (range 3–6 months); we performed all coaptations between the masseter nerve and the previously isolated facial nerve branch for the zygomatic muscles. The first tasks focused on those voluntary masseter muscle movements that should provoke facial mimicry animations (Table 2). A similar protocol is used for hypoglossal–facial nerve anastomosis [35].

Recovery time also varies according to age [1]. According to Wang et al. [45], it is longer in patients older than 40 years, thus underlying the importance of the young age of patients for fast nerve recovery. Indeed, 9 out of 10 patients in the current analysis were less than 40 years old at the time of surgery. Other investigations devised different protocols for patients older than 20 years [46].

5. Limitations

Among the limitations of our study is the sample size and some heterogeneity in patient characteristics that possibly influenced the effect size of most of the non-significant statistical comparisons. Even if the sample size estimation yielded a value lower than the actual number of patients analyzed in our motion capture laboratory, this number is reduced, and larger samples are necessary to better understand the actual effects of surgery and tailored physiotherapy for a successful outcome [3]. Although these patients were managed in a referral center for the treatment of facial palsy, where an average of four facial reanimations are performed every week, the surgical treatment is usually built specifically on each patient, and some variability is expected. The evaluation of the treatment outcomes requires clustering the patients, and only a select group of patients had the same preoperative features and performed the same surgical and physical therapy procedures.

As expected from a retrospective investigation, some heterogeneity was observed in several patient characteristics: age and etiology, the time between the lesion and surgical treatment, and follow-up interval, ranging from 8 to 48 months. One reason for this last variable may be that the second assessment (post-treatment) was performed after a good smile quality had been obtained, and not at a fixed interval.

The young age of most patients limits our results generalization: according to our inclusion criteria, only patients that received all the selected treatments were included in the sample. Younger patients seemed more involved in their physical therapy schedule, thus fulfilling the criteria better. As age is likely to influence neuromuscular recovery, with younger people healing faster than older ones [1,45], the current results should be analyzed with caution.

Moreover, we did not assess patient-oriented outcomes, and the analysis of clinical data cannot fully assess the actual impairments in the various aspects of the patient life [4]. For instance, the adherence to the physical therapy sessions and the constant performance of the home training selected only very motivated patients. During data collection and analysis, it was not possible to blind the operators, as the performed movements typically depicted facial palsy [4,12,22,25,26].

Data collection was performed in a research laboratory outside the hospital, another characteristic that may have contributed to patient selection. From this point of view, patients have to move to a dedicated motion analysis laboratory with a specific set of instruments that can detect and reproduce movements in three dimensions [28]. Currently, most analyses are performed in two dimensions [22], but some ongoing investigations aim to use simplified, portable, low-cost instruments such as smartphones to record three-dimensional data [47]. This new technology may improve the quantitative analysis of patients with facial palsy.

6. Conclusions

The surgical technique used for facial reanimation in the current group of patients affected by segmental midface paresis was successful, as quantitatively assessed by the 3D motion analysis of instructed smiles and kiss movements. Owing also to physical therapy, the new neural stimulus to the zygomatic muscle significantly increased the symmetry of labial commissure displacement during voluntary smiling and contributed to a pleasant emotional smiling together with the contralateral facial nerve graft. Considering the reduced number of analyzed patients and their heterogeneity, further assessments are necessary to improve treatment planning and monitoring.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/sym14122570/s1, Web address of the funny videos shown to all patients.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki. All patients were informed about the procedures and possible risks for surgical and physiotherapy treatments according to hospital guidelines and gave their written consent. Informed consent was also signed before participating in the motion capture protocol, and the possible reuse of their pseudo-anonymized personal data was approved. Additional ethical review and approval were waived for this study due to the retrospective study design where no new data were collected.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

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