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Facial reanimation with masseteric to facial nerve transfer: a three-dimensional longitudinal quantitative evaluation.

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ABSTRACT

Facial paralysis is a severe pathological condition, negatively affecting patients' quality of life. The altered tone and mobility of the mimetic musculature provoke both functional and morphological deficits. In the present study, we longitudinally measured facial movements in 14 patients (21-69 years) affected by unilateral facial paralysis not lasting longer than 23 months. The patients were analyzed before and after surgical masseteric to facial nerve neurorrhaphy. Examinations were performed at least three months after they had clinically started to regain facial mimicry. The displacement of selected facial landmarks was measured using an optoelectronic three-dimensional motion analyzer during: maximum smile without clenching (pre- and post-surgery); maximum smile by clenching on their posterior teeth (only post-surgery); spontaneous smile (recorded during the vision of a funny video in both examinations). Before facial surgery, in all smiles facial landmarks moved more in the healthy than in the paretic side; after surgery, the differences decreased for both reduction of the healthy side motion, and increment of the paretic side motion (motion ratio before 52%, after 87%, $p < 0.05$, Students' t). The ratio between the paretic and healthy side total motion (asymmetry) did not modify for maximum and spontaneous smiles, but significantly increased for the maximum smiles made with teeth clenching (asymmetry before 32%, after 11%, $p < 0.001$). Spontaneous smiles were recorded only in a subset of patients, but their execution was modified by surgery, with more symmetrical movements of the rehabilitated side landmarks (asymmetry before 33%, after 10%), and reduced motion of the healthy side ones (motion ratio before 51%, after 83%). In conclusion, the significant asymmetry in the magnitude of facial movements that characterized the analyzed patients before surgery reduced after surgery, at least in those facial areas interested by the masseteric to facial nerve reanimation.

Key words: facial nerve paresis; 3D; motion analysis; mimetics; asymmetry.

INTRODUCTION

Medical and surgical treatments of craniofacial disorders have greatly improved, with a resulting longer life expectancy after traumas, tumour removals, infective diseases, congenital malformations. In some patients, the original disorder or its treatment may provoke unilateral facial paralysis.[1-3] Facial paralysis is a severe pathological condition, negatively affecting patients' quality of life.[3, 4] The worst functional deficit is the lack of lubrication of the cornea leading to superficial lesions, ulcers and, lastly, to visual loss. On the morphological point of view, there is generally an evident asymmetry of the face at rest due to the loss of tone of the mimetic musculature. Appearance further worsen during facial expressions, particularly when smiling. Reconstructive surgery attempts to address those two main drawbacks of the paralysis.

If the paralysis is recent, lasting lesser than 24 months, and mimetic musculature is still present (fibrillations are detected at electromyographic investigation), the facial nerve may be reactivated by connecting it to a new motor source. Several nerves have being proposed in literature for this purpose, the hypoglossus being the most utilized[5]. This nerve source has the disadvantage to partially impair lingual function when anatomized end-to-end. If just a part of the hypoglossus nerve is taken, deficits are limited, but efficacy of the procedure also. A further problem is represented by the difficulty to pair facial movements to lingual ones. Lot of physiotherapy is needed and results are variable among patients.

The other motor source that has been recently highlighted is the masseteric nerve.[6] The great advantage is the low morbidity: patients generally do not feel any deficit during mastication. Additionally, it is easier to couple smiling with teeth clenching compared to pushing the tongue toward them. Surgeons among the Authors have been using a specific masseteric to facial nerve neurorrhaphy since October 2007, and some preliminary results of its effectiveness have been published.[6]

Indeed, there is not a widespread consensus about the best method for facial function assessments.[2, 3, 8] While conventional clinical methods like the House-Brackmann scale can be used everywhere and without any apparatus, they provide only qualitative assessments and are observed-dependent.[4, 9, 10] Some optical methods have been subsequently devised, providing quantitative information about the movements of selected facial landmarks and their trajectories.[3, 4, 10-15]

In our laboratory, we devised a computerized noninvasive method providing well reproducible three-dimensional dynamic measurements that permit an objective assessment of facial movements.[7, 14] The method was employed to assess both normal subjects[13] and patients with facial palsy.[7] In a preliminary report, mimicry impairment and surgical rehabilitation were analyzed cross-sectionally in two small groups of patients performing free smiles before and after facial surgery.[3,7] These cross-sectional data indicated that surgery reduced lip asymmetry during smile, but no definitive information about the total amount of labial movements was obtained.

In the present study, the same protocol was used with a longitudinal perspective; we quantitatively assessed facial movements in a group of patients before and after masseteric to facial nerve reanimation; the displacement of selected facial landmarks was measured in three dimensions during standardized animations (free smile, smile with teeth clenching and spontaneous smile).

MATERIALS AND METHODS

Patients

Fourteen patients (five men, nine women; age range 21 to 69 years, mean 47 years, SD 16) were analyzed. All patients were affected by unilateral facial paralysis not lasting longer than 23 months (between one and 23 months, mean 13 months, SD 5). Patients came from a consecutive series. All of them had signs of mimetic muscle fibrillations at preoperative electromyography and were candidate for surgical masseteric to facial nerve neurorrhaphy. Preoperatively, all patients had normal electromyographic masseteric nerve findings.

The patients were analyzed twice, at first just before surgery, and then after surgery and rehabilitation (between 11 and 25 months, mean 18 months, SD 4). In all but two patients who did not recover facial movements, examinations were performed at least three months after they had clinically started to regain facial mimicry (on average, 6 months, SD 3; maximum interval 12 months).

Data were also evaluated according to a modified House Brackman clinical classification specifically devised for patients with a facial paralysis or who had recovered from it.[16] By this way, a 6 grades subjective scale (Table 1) was coupled to data objectively acquired by optoelectronic instruments.

All patients were operated on at San Paolo Hospital and Galeazzi Hospital (Milano, Italy) by one of the authors (FB). After the nature and possible risks of the study had been completely described, written informed consent was obtained from each patient. The protocol used in the current study was approved by the Ethics Committee of the Department of Human Morphology, and it did not involve dangerous or painful activities, in accord with the Helsinki Declaration.

Data collection

The data collection protocol was previously described.[2, 7, 14] In brief, in each patient facial movements were recorded using an optoelectronic three-dimensional motion analyzer with a 60 Hz sampling rate (SMART System, BTS, Milano, Italy). Nine high-resolution infrared sensitive charge-coupled device video cameras coupled with a video processor were positioned at the corners of a working volume of 44 (width) × 44 (height) × 44 (depth) cm^3. Before each acquisition session, metric calibration and correction of distortions were performed using a 20-cm wand; the resulting mean dynamic accuracy was 0.121 mm (SD 0.086), corresponding to 0.0158% of the diagonal of the working volume.[13] Overall, this means that the movement of 2-mm markers could be detected with a sub-millimetric accuracy, in line with previous studies.[4, 9, 14, 17]

The patient sat inside the working volume on a stool, and was asked to perform some standardized facial animations. During the execution of the movement, the three-dimensional coordinates of 11 passive markers positioned on facial landmarks were obtained (Figure 1).

The 11 soft tissue landmarks were identified by a set of 2-mm round reflective markers:[2, 8, 15] n, nasion; ft, right and left frontotemporale; ng, right and left naso-genian; cph, right and left crista philtri; ch, right and left cheilion; li, right and left lower lip midpoints (Figure 1). The positions of the markers did not interfere with facial movements.

In particular, in the current investigation we asked the patients to perform: maximum smile without clenching (in both pre- and post-surgery examinations); maximum smile by clenching on their posterior teeth (only in the second examination); spontaneous smile (recorded during the vision of a funny video in both examinations). The two maximum smile animations were explained and shown to the patients, who practiced before actual data acquisition; in contrast, no specific instructions were given for the spontaneous smile. For each patient, five repetitions of each voluntary expression were recorded without modifications of the marker positions.

Within- and between-session repeatability of the protocol was previously assessed in healthy subjects; within session, single landmarks technical error of the measurement was, on average, 0.5-3.38 mm, showing a sufficient reproducibility. Between sessions, all facial movements had standard deviations lower than 1 mm.[14]

Data analysis

The method has been previously described.[2, 7, 14] In short, nasion and frontotemporale landmarks defined a head reference plane that was used to mathematically eliminate head movements during the animation, and to standardize the coordinate reference system within and between subjects. Therefore, only movements occurring in the face (activity of mimetic muscles) were further analyzed.

During each facial animation, the three-dimensional displacements of each labial marker (naso-genian, crista philtri, cheilion, lower lip) were computed, and the modulus (intensity) of the three-dimensional vector of maximum displacement from rest was calculated. For each side (paretic and healthy), a total labial mobility was obtained from the sum of the displacements of the four landmarks. To assess the side differences, two indices were used: the ratio of paretic to healthy side mobility,[4, 9] and the asymmetry index (percentage ratio between the difference and the sum of the healthy/ paretic displacements, where –100% indicates a complete paretic side prevalence during the movement, and +100% indicates a complete healthy side prevalence.[7, 14] The latero-lateral (frontal plane, right-left direction) component of the maximum displacement of the crista philtri, cheilion and lower lip landmarks was also computed as suggested by Frey et al.[12].

Statistical calculations

For each patient and smile, the five repetitions of facial animations were averaged. Descriptive statistics were obtained for the total displacement of the healthy and paretic sides (modulus), the lateral displacement (frontal plane component), the ratios and the asymmetry indices, separately for the three analyzed smiles, before and after surgical facial reanimation. Maximum smile with and without teeth clenching data were normally distributed (Kolmogorov-Smirnov test, not significant) and variables obtained before and after surgery were compared by paired Student's t tests. Data obtained during spontaneous smile were not compared by statistical tests, due to the reduced sample size.

The level of significance was set at 5% ($p < 0.05$).

RESULTS

Some patients did not perform all requested animations correctly, and were excluded from the analysis of specific smiles: in the second assessment, one patient could not smile without clenching, another one did not smile but only clenched on her teeth, and spontaneous smiles were recorded in five patients only (four women and one man).

Before facial surgery, in all smiles total three-dimensional landmark displacement was larger in the healthy than in the paretic side; after surgery, the differences decreased for two combined factors: reduction of the healthy side motion (significant for both maximum smile and maximum smile with teeth clenching), and increment of the paretic side motion (significant for maximum smile, Table 2). The ratio between the paretic and healthy side total landmark displacements did not modify for the maximum and spontaneous smiles, but significantly increased for the maximum smiles made with teeth clenching (on average, from 52% to 87%). The asymmetry index significantly reduced from 32% to 11% during the performance of the maximum smile with teeth clenching (paired Student's t test, $p < 0.001$).

Before surgery, during the maximum smile animation all labial landmarks moved toward the healthy side (frontal plane, right-left direction, Figure 2); after surgery, the movement was more symmetrical, with significant differences for all landmarks of the paretic side (paired Student's t test; ch, $p = 0.008$; cph, $p = 0.01$; li, $p = 0.004$), and for two landmarks of the healthy side (cph, $p = 0.024$; li, $p = 0.006$).

The effect was larger for the smile with teeth clenching animation: after surgery the cheilion and crista philtri landmarks of the rehabilitated (paretic) side moved in the correct direction, and the lower lip landmark greatly reduced its asymmetric motion (before vs after, $p < 0.001$ for all landmarks; Figure 3). A reduced displacement was found also for the healthy side landmarks ($p < 0.001$ for cph and li, $p = 0.017$ for ch).

Notwithstanding the reduced number of patients, also the execution of the spontaneous smiles was modified by surgery, with more symmetrical displacements of the rehabilitated side landmarks (on average, from 33% to 10%), and reduced motion of the healthy side ones, with an average motion ratio from 51% to 83% (Figure 4).

Figures 5 to 10 show the pre- and post-surgical images of a 34-year-old patient with right side facial paralysis lasting 12 months. Before surgical rehabilitation, soft-tissue asymmetry and lagophtalmus were evident at rest (Figure 5); there was a clear worsening of asymmetry while smiling (Figure 6). The incomplete eyelid closure was reduced by a gold lid applied in another Center (Figure 7). Twelve months after surgery, a great improvement in facial soft tissues symmetry was evident at rest (Figure 8), during smiling (Figure 9), and during eyelid closure (Figure 10). Voluntary smiling (with teeth clenching) was performed without accessory facial movements.

After surgery, the patients were analyzed according to the 6 grades clinical scale devised by Henstrom et al.[16]. Three patients were classified grade I (21.43%), 8 patients were grade II (57.15%), and one patient was classified in each of the III, V, and VI grades (7.14% for each grade). In general, a good correspondence between the clinical scale and the landmark displacements measured by the optoelectronic instruments was observed.

DISCUSSION

The current study presents a set of longitudinal data collected in a group of patients with unilateral facial palsy, that were assessed before and after masseteric to facial nerve reanimation according to Biglioli et al.[6]

All medical interventions should be performed to better the quality of life of the patients: the rehabilitation of facial muscles activity allows a better visceral function (eye lubrication, nasal inspiration, labial competence, cheek and lip mobility during chewing and swallowing), and a better social interaction, both at rest (facial asymmetry and morphology) and during communication (verbal and not verbal expressions).

Alongside with clinical evaluation and patient's opinion, the final results of the surgical rehabilitation must be assessed by an objective method. To the scope, the computerized method previously developed in our laboratory[2, 7, 14] was used for the automatic recording and analysis of facial motion, with minimal disturbance to the patient and without dangerous or painful procedures.

The method has been developed and applied in a previous cross-sectional pilot study, where we analyzed two different small groups of patients, one before surgery, and one after masseteric to facial nerve neurorrhaphy.[7] Overall, for free smiles the results of the previous cross-sectional investigation are in good accord with the present longitudinal ones, while new information came from the other smile animations (smiles without teeth clenching and spontaneous smiles).

Additionally, the use of a longitudinal design permitted to assess the actual differences in labial motion induced by the surgical rehabilitation as we could compare the displacements performed by the same patients in the two occasions.

Three kinds of smiles were assessed; as expected, the best results were obtained when the patients elicited the contraction of their mimetic muscles by clenching on their posterior teeth. Indeed, the surgical technique used part of the ipsilateral masseteric nerve to provide new motor fibers to the paretic facial nerve, [5] and they were instructed to clench insofar they wanted to contract their labial elevator muscles.[9, 17] For reference, we also assessed voluntary maximum smiles performed without teeth clenching: the results clearly show that the patients learned to restrict the displacement of their healthy side landmarks during smiling (mean reductions: ch, 0.8 mm; cph: 3 mm, $p = 0.001$; li, 3.3 mm, $p = 0.004$), thus increasing their symmetry and activity ratio,[8] and reducing the pulling effect on the paretic side.

During maximum smile with teeth clenching, the average three-dimensional displacements of the labial commissura were 9.4 mm (healthy side) and 8.5 mm (rehabilitated side), in good accord with literature reports from similar patients.[5]

The spontaneous smile was assessed because of its different neural pathways. According to classical descriptions, the emotional contraction of the mimetic muscles is centrally controlled with excitatory stimuli on the facial nerve nucleus in the brainstem.[9, 17] In the present patients, this should be impossible for the paretic side. Indeed, we could record post-surgery spontaneous smiles only in five patients; when these data were compared to those collected before surgery, we observed not only a reduction in the total healthy side movements, but also an increase in the paretic side movements. Of course, the patients possibly “provoked” the smile by teeth clenching, even if great care was taken to avoid this voluntary action. Other investigations reported that training and motivation may induce some cortical plasticity, thus achieving a new pathway for the control of movement.[9, 17] In particular, a recent report found that women were more likely than men to become able to smile spontaneously and independently from teeth clenching after a masseteric to facial nerve neurorrhaphy for facial rehabilitation.[17] This seems in good line with the current results, where four women out of nine but only one men out of five could smile spontaneously.

Nonetheless, the reduced number of patients, and the lack of a control of the masseter muscle contraction (by surface electromyography), impose great caution in the interpretation of these findings. Functional magnetic resonance imaging has also been suggested for a better understanding of the results.[17]

As suggested by Frey et al.,[11] we analyzed in detail the frontal plane displacement of the labial landmarks. Before surgery, all six analyzed labial landmarks (paretic and healthy side cph, ch, li) moved in the healthy side direction during smile (Figures 2-4). After surgery, both spontaneous and teeth clenching smiles were performed with more correct lateral displacements. The best pre-post surgery difference was obtained by the labial commissura (Figure 11). The healthy side reduced its lateral mobility of 2.7 mm on average, while the paretic (rehabilitated) side regained 5.3 mm in the correct direction. The other two labial landmarks (cph and li) had less satisfactory results. In the orolabial area, landmark displacements measured by the motion analysis system substantially agreed with the modified House-Brackmann facial grading clinical scale.[2]

The method developed in our laboratory allows the not invasive and minimally disturbing analysis of movements in all parts of the face.[2, 14] In the present study, we restricted our analysis to the perioral region and to smile animations, that are those most commonly used to assess surgical results.[1, 8, 9]

CONCLUSION

The method used in the current investigation allowed a longitudinal study of the quantitative alterations in facial movements in patients with unilateral facial palsy, and their rehabilitation after surgical reanimation. The significant asymmetry in the magnitude of facial movements that characterized the patients analyzed before surgery reduced after surgery, at least in those facial areas interested by the masseteric to facial nerve reanimation.

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no conflicts of interest.

Funding Sources: none declared

Ethical Approval: After the nature and possible risks of the study had been completely described, written informed consent was obtained from each patient. The protocol used in the current study was approved by the Ethics Committee of the Department of Human Morphology, and it did not involve dangerous or painful activities, in accord with the Helsinki Declaration.

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FIGURE LEGENDS

Figure 1. Soft tissue landmarks: n, nasion; ft, right and left frontotemporale; ng, right and left naso-genian; cph, right and left crista philtri; ch, right and left cheilion; li, right and left lower lip midpoints.

Figure 2. Maximum smile animation: lateral displacement (right-left direction, mm) of labial landmarks before and after surgery (mean ± 1 SD). Positive displacements: healthy side direction; negative displacements: paretic side direction. Before vs after comparisons: paired Student's t tests: all significant ($p < 0.05$) except cheilion (ch) landmark of the healthy side. cph: crista philtri; li: lower lip midpoint.

Figure 3. Smile with teeth clenching animation: lateral displacement (right-left direction, mm) of labial landmarks before and after surgery (mean ± 1 SD). Positive displacements: healthy side direction; negative displacements: paretic side direction. Before vs after comparisons: paired Student's t tests: all significant ($p < 0.05$). ch: cheilion; cph: crista philtri; li: lower lip midpoint.

Figure 4. Spontaneous smile animation: lateral displacement (right-left direction, mm) of labial landmarks before and after surgery (mean ± 1 SD). Positive displacements: healthy side direction; negative displacements: paretic side direction. ch: cheilion; cph: crista philtri; li: lower lip midpoint.

Figure 5. Face at rest of a 34-year-old patient with right side facial paralysis lasting 12 months.

Figure 6. Pre-operative worsening of asymmetry while smiling.

Figure 7. Incomplete eyelid closure reduced by a gold lid applied in another Center.

Figure 8. Twelve months after surgery: great improvement in facial soft tissues symmetry.

Figure 9. Well balanced smiling 12 months postoperatively.

Figure 10. Complete eyelid closure 12-months postoperatively.

Figure 11. Smile with teeth clenching animation: schematic illustration of mean lateral displacements (right-left direction, mm) of cheilion landmarks before and after surgery.

Table 1. Modified House-Brackmann facial grading reference card.

Movement/ Synkinesis						
Movement Brow/ Eye/ Nasolabial fold/ Oral	Normal	>75%	>50%	<50%	Trace	None
Points M- B/E/N/O	*1*	*2*	*3*	*4*	*5*	*6*
Synkinesis Brow/ Eye/ Nasolabial fold/ Oral	None	Slight	Obvious	Disfiguring	--	--
Points S- B/E/N/O	*0*	*1*	*2*	*4*	--	--
Total points (M+S)	*4*	*5-9*	*10-14*	*15-19*	*20-23*	*24*
Grade (HB modified)	I	II	III	IV	V	VI

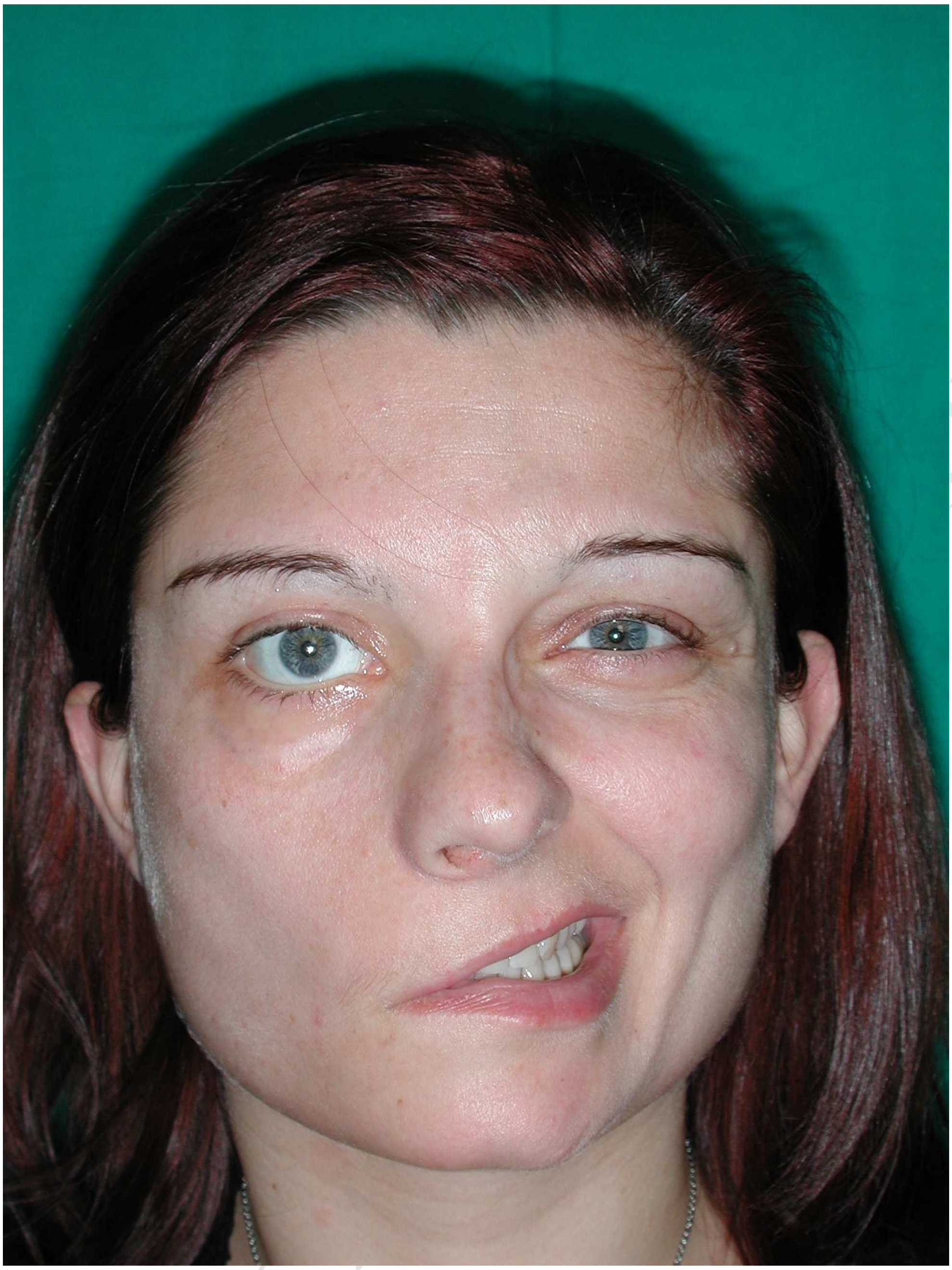
Modified and adapted from [16]. Movement assessment and synkinesis evaluation are performed separately for the four facial parts (brow, eye region, nasolabial fold, oral region), and summed up. The larger the score, the worse the clinical picture.

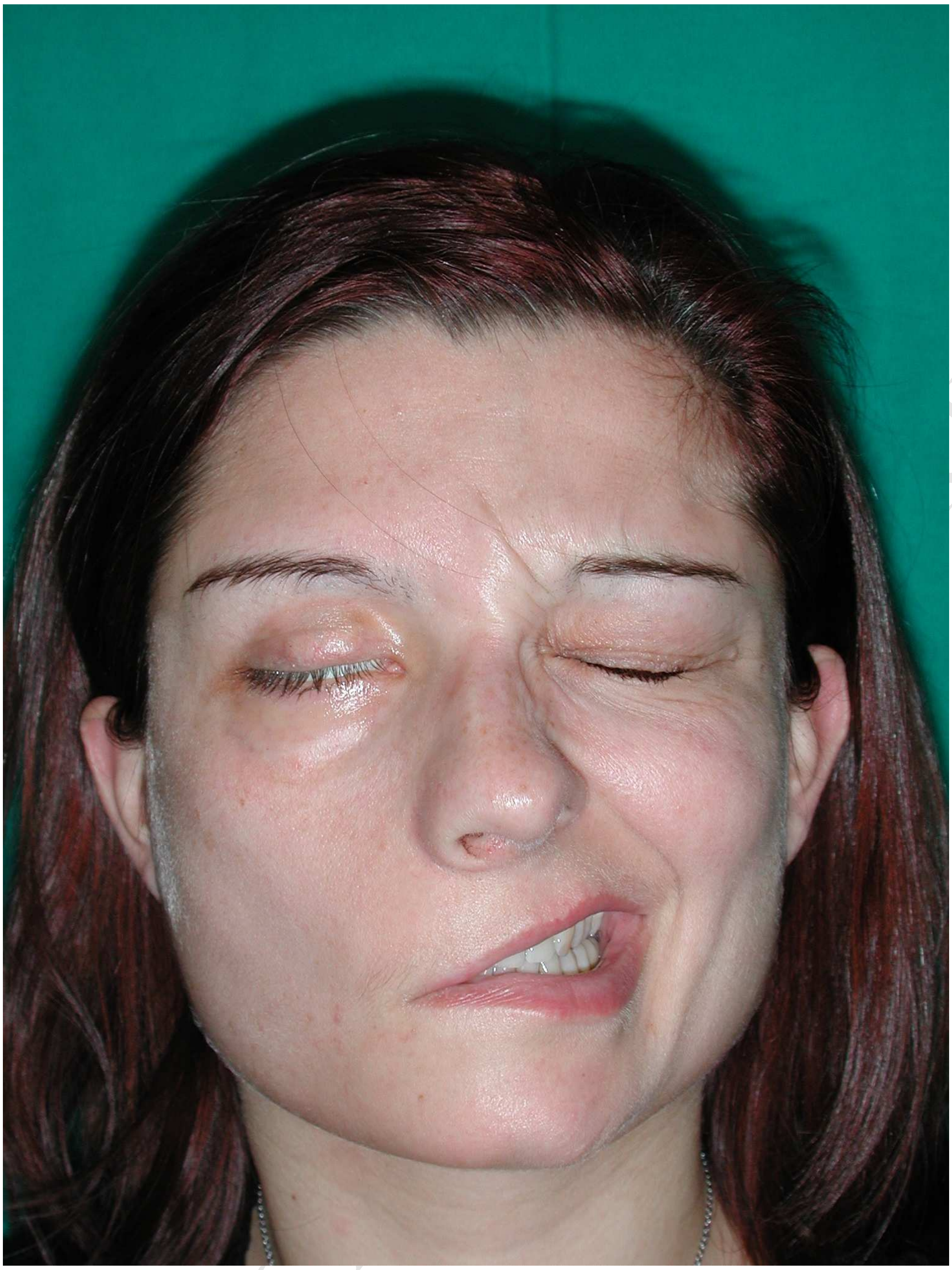
Table 2. Total three-dimensional labial mobility during smile movements before and after surgery.

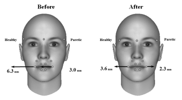
Side			Healthy (mm)			Paretic (mm)			Ratio (%)			Asymmetry index (%)		
Examination		N	Before	After	Comparison	Before	After	Comparison	Before	After	Comparison	Before	After	Comparison
Max smile	Mean	13	42.8	30.8	0.041 *	22.0	16.5	0.026 *	51.73	56.67	0.577	32.33	30.88	0.781
	SD		18.7	9.7		9.3	6.7		9.38	30.92		7.94	18.59	
Max smile (clenching)	Mean	13	42.7#	25.8	0.014 *	22.0#	21.1	0.722	51.97#	87.42	0.005*	32.15#	10.84	0.001 *
	SD		19.5	6.0		9.7	6.5		9.75	36.91		8.27	18.67	
Spontaneous smile	Mean	5	34.8	33.0	--	17.8	26.9	--	50.73	88.13	--	33.26	10.15	--
	SD		10.0	9.66		5.5	10.9		3.99	43.07		3.52	24.34	

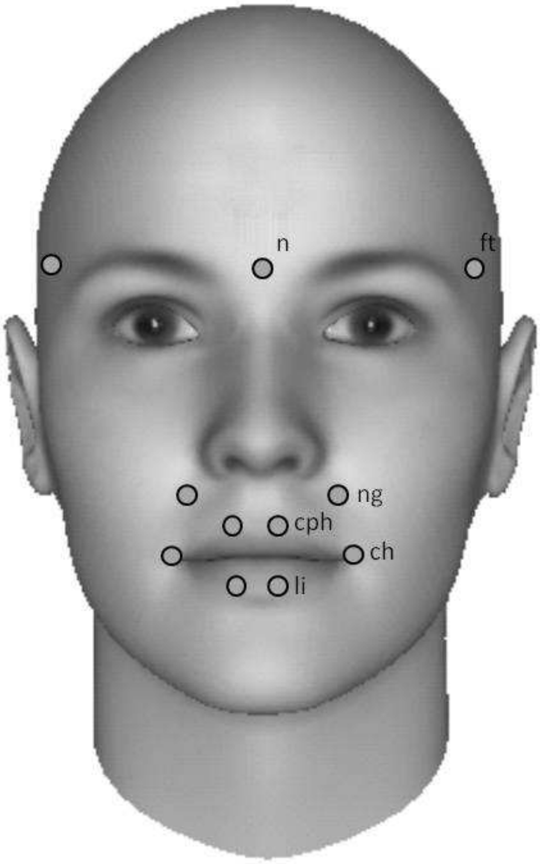
#Before values obtained without teeth clenching

Comparisons are obtained by paired Student's t tests; * significant values ($p < 0.05$). Spontaneous smiles were not statistically compared.






Before
After
Healthy
Paretic
Healthy
Paretic
6.3 mm
3.0 mm
3.6 mm
2.3 mm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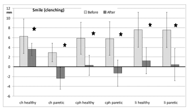
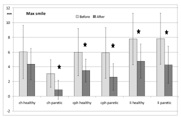


Smile (clenching)
mm
Before
After
12
10
8
6
4
2
0
-2
-4
-6
ch healthy
ch paretic
cph healthy
cph paretic
li healthy
li paretic


Max smile
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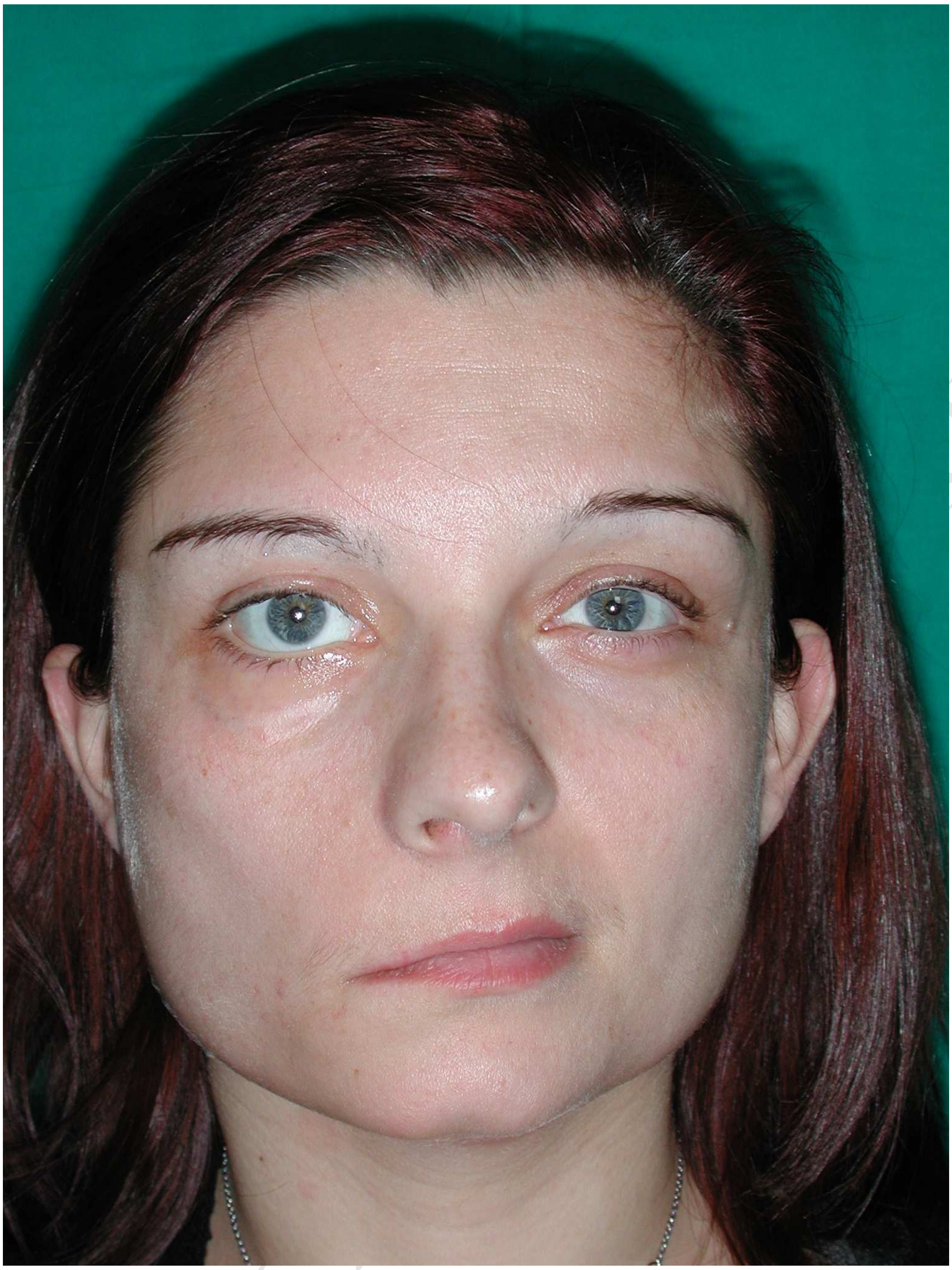
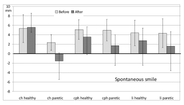
-2
ch healthy
ch paretic
cph healthy
cph paretic
li healthy
li paretic




10
mm
8
6
4
2
0
-2
-4
-6
-8
Before
After
Spontaneous smile
ch healthy
ch paretic
cph healthy
cph paretic
li healthy
li paretic