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Facial movement before and after masseteric-facial nerves anastomosis: A three-dimensional optoelectronic pilot study☆

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A B S T R A C T

To quantify the effects of facial palsy reanimation, 14 patients aged 17–66 years were analysed. All patients had unilateral facial paralysis, and were candidates for surgical masseteric to facial nerve anastomosis. Two patient groups were measured: seven patients were waiting for surgery, the other seven patients had already been submitted to surgery, and had regained facial mimicry. Each patient performed three facial animations: brow raise; free smile; lip purse. These were recorded using an optoelectronic motion analyser.

The three-dimensional coordinates of facial landmarks were obtained, their movements were computed, and asymmetry indices calculated (differential movements between the two hemi-faces: healthy and paretic/rehabilitated). Before surgery, mobility was larger in the healthy than in the paretic side; after surgery, the differences were reduced (brow raise and lip purse), or even reversed (smile). Before surgery, lip purse was performed with significant labial asymmetry ($p = 0.042$; larger healthy side movement). After surgery, asymmetry indices reduced. Total labial asymmetry during smiling was significantly different from 0 before surgery ($p = 0.018$, larger healthy side movement). After surgery, all asymmetry indices became non-significant. Before surgery the lateral displacements of all labial landmarks were towards the healthy side, while they normalized after surgery.

1. Introduction

Unilateral facial paralysis is a pathological condition involving asymmetry of the face at rest, worsened by activation of facial (mimetic) musculature while smiling and during facial expression. Facial morphology is grossly distorted, while eye lubrication, nasal inspiration, labial competence, cheek and lip mobility are partially impaired. Social communication and interaction, phonation and speech articulation are also altered (Wachtman et al., 2001; Nicholls et al., 2004; Mehta et al., 2008; Popat et al., 2010). The patients have serious alterations in their quality of life, and may develop a reactive depression.

Because of this, a large number of surgical techniques have been devised to reanimate the paralytic patients early by anastomosing the facial nerve to a donor nerve (Ballance et al., 1903; Körte and Bernhardt, 1903; Smith, 1971; Scaramella and Tobias, 1973; Terzis, 1990; Biglioli et al., 2010, 2011). In 1978, Spira first reported the use of the masseteric nerve as a new axonal source for the cervico-facial branch of the impaired facial nerve, and this has been used to reanimate both recent and long-standing facial paralysis (Zuker et al., 2000; Coombs et al., 2009). A specific technique consisting of a masseteric to facial nerve anastomosis with a 4 cm great auricular interpositional nerve graft was devised by the Authors and has been used since October 2007 (Biglioli et al., 2011). A quantitative, objective assessment of results was become necessary to evaluate the effectiveness of the technique.

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Facial dysfunctions can be graded by both clinical and instrumental methods that analyse spontaneous and instructed facial movements. Clinical assessments focus on total and local facial motion, synkinesis and movement asymmetries (Coulson et al., 2005), while quantitative methods can assess both the movements of selected facial landmarks and their direction (Wachtman et al., 2001; Linstrom et al., 2002; Trotman et al., 2003; Nicholls et al., 2004; Rogers et al., 2007; Frey et al., 2008; Hontanilla and Aubá, 2008; Mehta et al., 2008; Popat et al., 2010; Sforza et al., 2010a,b).

Currently, three-dimensional motion analysers seem to be the best choice for the non-invasive assessment of soft tissue facial movements, permitting a minimally disturbing quantitative evaluation that overcome the subjective nature of the clinical scales (Coulson et al., 2005; Trotman et al., 2003; Nicholls et al., 2004; Frey et al., 2008; Hontanilla and Aubá, 2008; Mehta et al., 2008; Popat et al., 2010; Sforza et al., 2010a,b).

In our laboratory, we developed a method for the non-invasive, three-dimensional assessment of facial movements using an optoelectronic motion analyser (Sforza et al., 2010a,b). The method was found to be minimally disturbing, reliable, and to accurately detect total and local motion during the performance of standardized facial animations (Sforza et al., 2010a,b).

The aim of this investigation was to quantitatively assess facial movements in a group of patients before and after masseteric to facial nerve reanimation. The patients were recorded while performing a set of standardized symmetric facial movements, and the displacement of selected facial landmarks was measured in three dimensions. Movements involving parts of the face submitted to the surgical rehabilitation (middle and lower facial thirds), and movements involving parts of the face not submitted to the surgical rehabilitation (upper facial third), were investigated.

2. Materials and methods

2.1. Patients

Fourteen patients (seven men, seven women; age range 17–66 years, mean 44 years, SD 15) were analysed. All patients were affected by unilateral facial paralysis lasting not longer than 19 months (between four and 16 months, mean 11 months, SD 4). All of them had signs of mimetic muscle fibrillations at preoperative electromyography and were candidate for surgical masseteric to facial nerve anastomosis. Those without signs of fibrillations were reanimated by free-flap surgery (Biglioli et al., 2009, 2011), and excluded from the present study.

The patients were subdivided into two groups: seven patients were waiting for surgery, while the other seven patients had already had surgery, and were analysed at least 4 months after they had clinically started to regain facial movement. All patients were instructed to call clinicians for an examination as soon as they felt and observed in a mirror, the first facial movements on the operated side.

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 and/or from the parents of the patients younger than 18 years of age. 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.

2.2. Data collection

The data collection protocol was previously described (Sforza et al., 2010a,b). In brief, facial movements were recorded using an optoelectronic three-dimensional motion analyser with a 120 Hz sampling rate (SMART System, BTS, Milano, Italy). The instrument uses nine high-resolution infrared sensitive charge-coupled device video cameras coupled with a video processor that define a working volume of 60 (width) $\times$ 60 (height) $\times$ 60 (depth) cm^3; metric calibration and correction of optical and electronic distortions are performed before each acquisition session using a 20-cm wand, with a resulting mean dynamic accuracy of 0.121 mm (SD 0.086), corresponding to 0.0158% (Sforza et al., 2010b).

The patient sat inside the working volume on a stool, and was asked to perform a series of standardized facial movements. During the execution of the movement, for any camera special software identified the two-dimensional coordinates of 16 passive markers positioned on facial landmarks (Fig. 1). Subsequently, all the coordinates were converted to metric data, and a set of three-dimensional coordinates for each landmark in each frame that constituted each movement was obtained.

For each patient, the 16 soft tissue landmarks were identified by a set of 2-mm round reflective markers (Trotman et al., 2003; Hontanilla and Aubá, 2008; Sforza et al., 2010a,b): n, nasion; prn, pronasale; f, right and left frontal; ft, right and left frontotemporale; t, right and left tragion; ng, right and left naso-genian; cph, right and

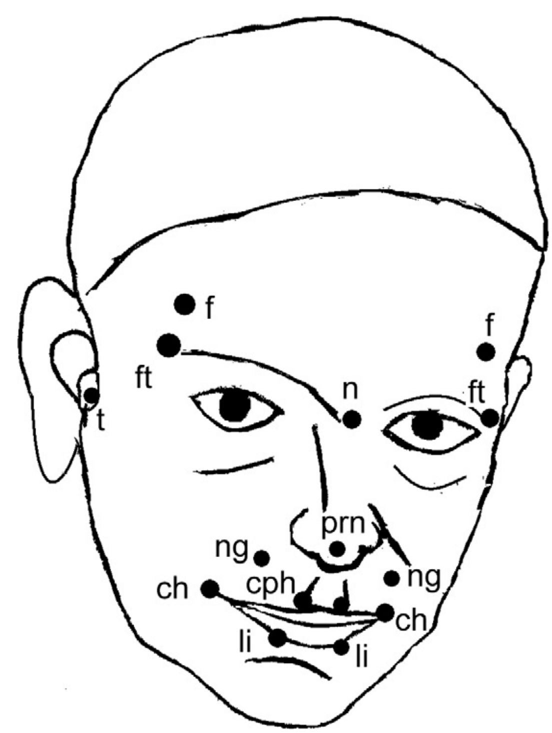

Fig. 1. Soft tissue landmarks: n, nasion; prn, pronasale; f, right and left frontal; ft, right and left frontotemporale; t, right and left tragion; ng, right and left naso-genian; cph, right and left crista philtri; ch, right and left cheilion; li, right and left lower lip midpoints.

Table 1
Analysed patients in the pre- and post-surgical groups.

	Before surgery ($n = 7$)			After surgery ($n = 7$)		
	Mean	SD	Range	Mean	SD	Range
M:F	2:5	–	–	5:2	–	–
Age (years)	45	14	17–59	42	17	18–66
Paresis duration before surgery (mo)	13	3	9–16	9	4	4–15
Mobility recovery after surgery (mo)	–	–	–	6	2	4–11
Recovery follow-up (mo)	–	–	–	14	6	4–21

left crista philtri; ch, right and left cheilion; li, right and left lower lip midpoints (Fig. 1). The positions of the markers were carefully controlled to avoid any interference with facial movements.

Each patient performed three standardized, maximum facial animations from rest (Wachtman et al., 2001; Rogers et al., 2007; Hontanilla and Aubá, 2008; Mehta et al., 2008; Sforza et al., 2010a,b): brow raise (upper facial third); free (natural) smile (middle and lower facial thirds); lip purse (middle and lower facial thirds). Each animation was explained and shown to the patients, which they practiced before data acquisition. For each patient, five repetitions of each expression were recorded without modifications of the marker positions.

For brow raise, pronasale and tragi landmarks defined a head reference plane that was used to mathematically eliminate head movements during the animation, and to standardize head position within and between subjects. The origin of axes was set in the left tragus. For free smile and lip purse, the head reference plane was defined by nasion and frontotemporale landmarks (origin of axes: left frontotemporale).

2.3. Data analysis

The method has been described in detail by Sforza et al. (2010a,b). At first, head and neck motion was subtracted from the raw facial movements using the three cranial (reference) markers, so only movements occurring in the face (activity of mimetic muscles) were further considered. Subsequently, for each facial marker, the three-dimensional movements during each facial animation were computed, the modulus (intensity) of the three-dimensional vector of maximum displacement from rest was calculated. For free smile, the latero-lateral (right-left direction) component of the maximum displacement of the analysed landmarks was computed.

Considering the unilateral kind of facial palsy, in patients with a right-side paresis all paired landmarks were mirrored on the other side of the face, and all movements were further considered relative to the healthy or paretic side.

For each animation, the total movement of the relevant facial part was obtained as the sum of the movement of selected facial markers: the larger the value, the larger the facial movement. For the smile and lip purse movements, markers ng, cph, ch and li were considered; for brow raise, markers f were considered.

To assess differential movements between the two hemi-faces, percentage indices of asymmetry were computed as: (healthy side displacement − paretic side displacement)/(healthy side displacement + paretic side displacement) × 100. The indices were computed for the total movement, as well as for the single landmarks. The indices range between −100 (complete paresis during the movement) and +100 (complete movement on the health side) (Linstrom et al., 2002; Sforza et al., 2010b).

2.4. Method error

Within- and between-session repeatability was previously assessed in healthy subjects. Within session, the technical error of the measurement for single landmarks (random error) was, on average, 0.5–3.38 mm, showing good reproducibility. Between sessions, all facial movements had standard deviations lower than 1 mm (Sforza et al., 2010a,b).

2.5. Statistical calculations

For each patient, the five series of facial animations were averaged. Descriptive statistics were obtained for the total movement for each facial area, the lateral displacement and the asymmetry indices separately for the patients analysed before and after surgical facial reanimation. The total movements for each facial area obtained in the two groups were compared by two-way analyses of variance (between subjects factor: group, before and after surgery; within subject factor: facial side, healthy and paretic; the group × side interaction was also computed); post hoc tests were made by Wilcoxon signed rank tests. To assess if the asymmetry indices significantly deviated from the expected value of 0, Wilcoxon signed rank tests were made. Fisher's exact test and Mann–Whitney U test were used to compare the sex, age and paresis duration of the two patient groups.

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

3. Results

The sex, age and paresis duration distributions in the two analysed groups were not significantly different (sex, Fisher's exact test, $p = 0.286$; age, Mann–Whitney U test, $p = 0.654$; paresis duration, U test, $p = 0.054$) (Table 1).

Fig. 2 shows the static and dynamic facial characteristics of an 18-year-old patient before and 5 months after the functional recovery of the anastomosis.

Before facial surgery, mobility was larger in all animations in the healthy compared to the paretic side; after surgery, the differences reduced (brow raise and lip purse), or even reversed (smile) (Table 2). In no occasion, the between-group differences were significant, but for all animations a significant ($p < 0.05$) or nearly significant (lip purse, $p = 0.056$) between-sides difference was found. In the smile movement, a significant group × side interaction was found; post hoc tests demonstrated that the side difference was significant only in the pre-surgery patients (Wilcoxon test, $p = 0.02$).

Before surgery, the patients performed the lip purse animation with significant asymmetry of the cheilion landmark (Wilcoxon test, $p = 0.042$; larger healthy side movement), and a nearly significant total labial asymmetry ($p = 0.063$). After surgery, all asymmetry indices but that of the lower lip midpoints reduced (Fig. 3).

Total labial asymmetry during the smile animation was significantly different from 0 before surgery (Wilcoxon test, $p = 0.018$ for both total asymmetry, and landmarks ch, cph, li), with a larger movement of the healthy side (Fig. 4). After surgery, all asymmetry indices became not significantly different from 0 (Wilcoxon test, $p > 0.05$). In particular, before surgery the lateral displacements of all labial landmarks (cph, ch and li) were all in the healthy side direction, while they normalized after surgery (Fig. 5).

4. Discussion

Data were collected in two groups of patients with unilateral facial palsy, assessed before and after masseteric to facial nerve reanimation according to Biglioli et al. (2011). This is a new reanimation technique for early facial nerve repair, to be performed when the facial paralysis has not been present for more than 24 months. The presence of fibrillation potentials at the preoperative electromyographic examination is essential, as it guarantees a chance for the reinnervation. Fibrillations document that mimetic muscle fibres still exist and may regain function with appropriate reinnervation. Masseteric to facial nerve anastomosis allows a quick functional recovery of movement (about 5 months). This timing is comparable to the results of the traditional hypoglossus to facial nerve anastomosis (Körte and Bernhardt, 1903), while the much lower morbidity represents a great advantage for the patients (Yetiser and Karapinar, 2007).

At the end of clinical follow-up, final results were assessed by an objective method, allowing quantification and comparison to those obtained with other procedures.

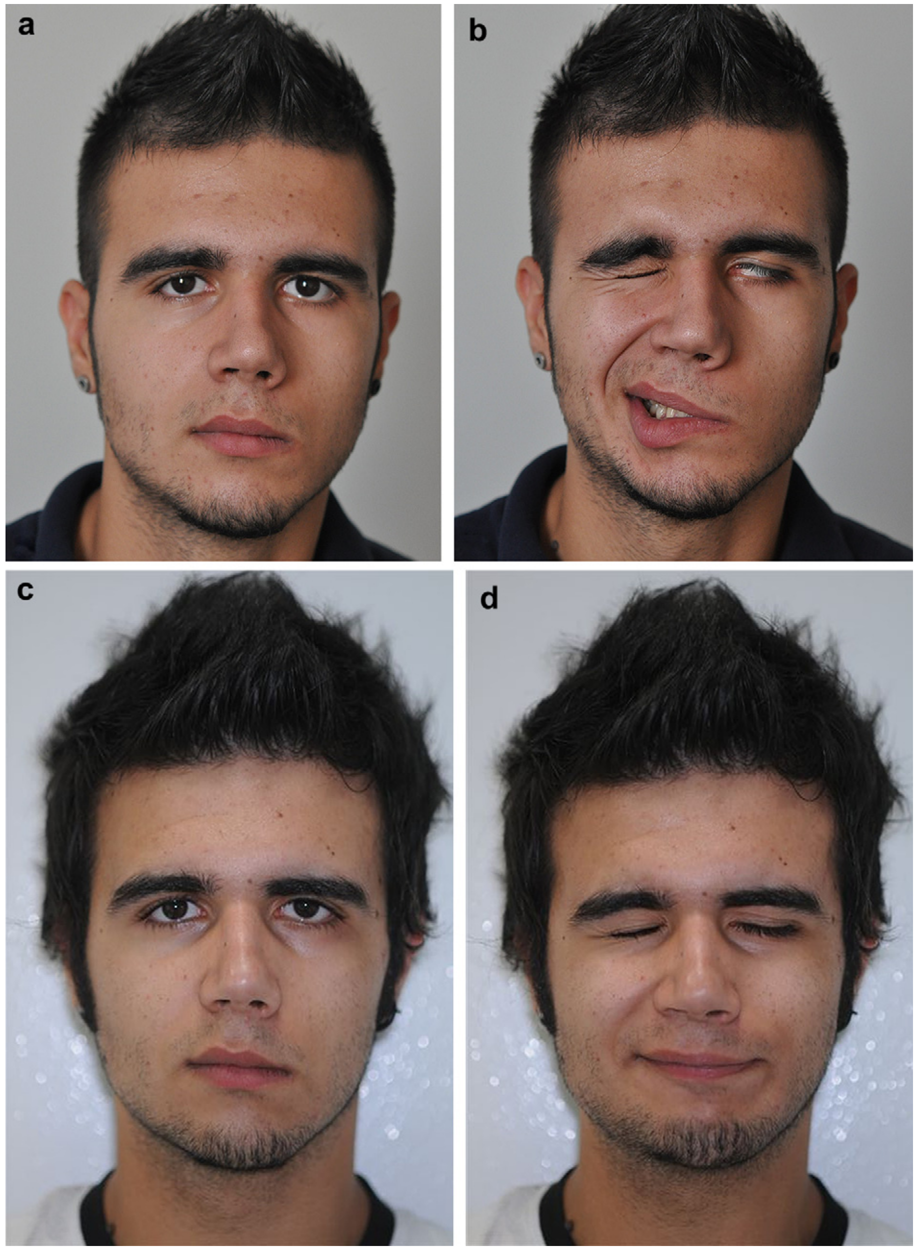

Fig. 2. Static images of the face (a, c) and dynamic ones (b, d) of an 18 years old patient before (a, b) and 9 months after (c, d) the surgical masseteric to facial nerve anastomosis. The patient clinically started to regain facial mimicry 4 months after surgery.

Table 2
Total facial mobility during standardized movements before and after surgery.

Side	Before surgery ($n = 7$)				After surgery ($n = 7$)				Comparisons		
	Healthy		Paretic		Healthy		Paretic				
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Group	Side	G × S
Brow raise	7.1	2.7	2.1	0.8	5.9	0.8	2.0	0.6	0.321	<0.001	0.348
Lip purse	35.3	11.0	26.6	12.0	35.8	12.3	32.6	9.6	0.554	0.056	0.348
Smile	37.4	19.8	19.4	8.8	24.9	9.1	26.6	7.6	0.664	0.014	0.005

All values are mm. Comparisons were made by analyses of variance; 1;12 degrees of freedom for both factors and interactions.

The computerized method previously developed in our laboratory (Sforza et al., 2010a,b) was used for the automatic recording and analysis of facial motion: an optoelectronic motion analyser detected the three-dimensional position of small, weightless, passive markers glued on the face in correspondence of selected anatomical landmarks. Marker displacements were used to investigate facial motion without interfering with the movement, and custom algorithms allowed compensation for head motion, without the need for head holding (Mehta et al., 2008).

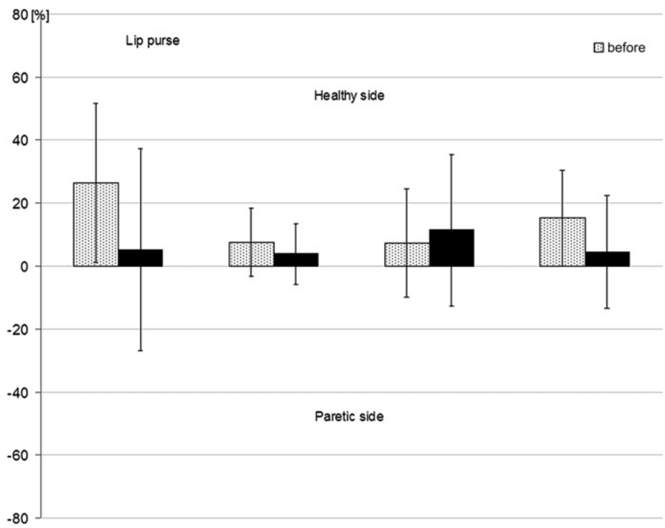

Fig. 3. Lip purse animation: total labial asymmetry and asymmetry of selected landmarks before and after surgery (mean ± 1 SD).

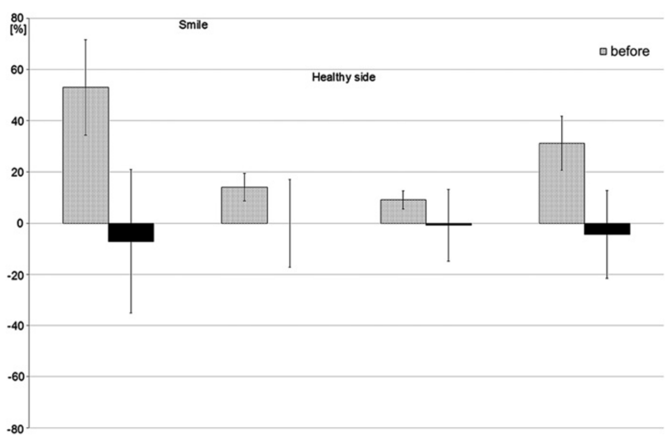

Fig. 4. Smile animation: total labial asymmetry and asymmetry of selected landmarks before and after surgery (mean ± 1 SD).

As discussed in previous investigations (Sforza et al., 2010a,b), when assessing facial motion the use of passive markers glued on the face is common (Trotman et al., 1998, 2003; Linstrom et al., 2002; Hontanilla and Aubá, 2008). Alternatively, the landmarks can be drawn directly on the face using an eyeliner pencil (Frey et al., 2008). Both protocols need the semi-automatic tracking of the markers to obtain their three-dimensional reconstruction. A distinct method is the automatic individualization of the facial features of interest without previous marking (Wachtman et al., 2001; Rogers et al., 2007). This last method is likely to be less disturbing and invasive for the patient, and faster for the investigator than the use of physical markers. Nonetheless, current applications are only two-dimensional (Wachtman et al., 2001; Rogers et al., 2007). The method may be difficult to apply in patients with facial scars or hairs. Stereophotogrammetry and laser scanning have also been used to assess facial motion in three dimensions, but both methods require a sufficiently large non-moveable part of the face (typically the forehead), thus restricting the kind of movements analysable and necessitating carefully controlled experimental conditions (Mehta et al., 2008; Sawyer et al., 2009; Popat et al., 2010). Additionally, facial hairs prevent correct detection of the facial features of interest (de Menezes et al., 2010).

To detect actual variations between and within individuals, the signal-to-noise ratio of each measuring system should be known. The optoelectronic instrument used in this study was calibrated with an accuracy lower than 0.02%. This means that the movement of each 2-mm marker could be detected within 0.12 mm, a value similar (Hontanilla and Aubá, 2008), or even better (Trotman et al., 1998, 2003) than those reported in previous studies.

Overall, the error of the current method was limited, and in good accord with data reported by other investigators. According to Trotman et al. (1998), reproducibility in non-verbal facial movements can be met when variations are lower than 4 mm. If this criterion is valid, all our expressions can be considered reproducible (mean TEMs all lower than 3.3 mm). For the inter-session variations, all the movements analysed had standard deviations lower than 1 mm. The current intra- and inter-session variability in single landmark movements was comparable (or even better) to previous reports (Trotman et al., 1998, 2003; Mehta et al., 2008).

Recently, better reproducibility has been reported for verbal animations (speech) than for non-verbal ones (Popat et al., 2010), but in the current study we limited our analysis to conventional clinical movements (Coulson et al., 2005; Frey et al., 2008).

In this preliminary study two different groups of patients were analysed, and the current results can be considered only indicative of the possibilities of the surgical rehabilitation technique. Nonetheless, the two groups of patients had similar pre-surgical clinical characteristics, as well as similar ages and duration of facial palsy. Together with this study limitation, there is the reduced number of facial animations, where not all movements previously proposed in the literature (for instance, eye closure, grimacing, cheek puff, and even verbal expressions) were used (Wachtman et al., 2001; Popat et al., 2010; Sforza et al., 2010a,b). The number of facial movements should be a compromise between the detailed examination of the patients, and the time necessary for the test, considering both recording and semi-automatic tracking. In the current study we limited our analysis to the maximum displacement of the landmarks, neglecting their directions (Wachtman et al., 2001; Trotman et al., 2003; Frey et al., 2008).

Previous studies have underlined the need to select facial animations that could detect regional mobility in the various parts of the face, according to the anatomical branches of the facial nerve (Coulson et al., 2005; Frey et al., 2008; Mehta et al., 2008; Sforza et al., 2010a,b).

In this study, both movements involving parts of the face submitted to the surgical rehabilitation (smile and lip purse, performed in the middle and lower facial thirds), and movements involving parts of the face not submitted to the surgical rehabilitation (brow raise, made in the upper facial third), were investigated. Brow raise was not expected to be different because the temporal branch is a very thin one, without significant anastomoses among adjacent ones that could partially accomplish its function. Indeed, the highly significant asymmetry between the movements of frontal landmarks was similar in the two patient groups: the paretic side movement was on average only 30–34% of the healthy side movement. This similar behaviour in the two groups further confirms the homogeneous facial conditions of the patients, except the surgical intervention.

In contrast, both smile and lip purse were influenced by the surgical treatment, with significant reductions of labial asymmetry during the movement: on average, before surgery the paretic side movement during the lip purse was only 75% of the healthy side movement, and became more than 90% after surgery. During the free smile, the modification was even larger: from 52% (before) to 101% (after). After surgery, asymmetry indices became similar to those found in healthy control subjects (Sforza et al., 2010a,b).

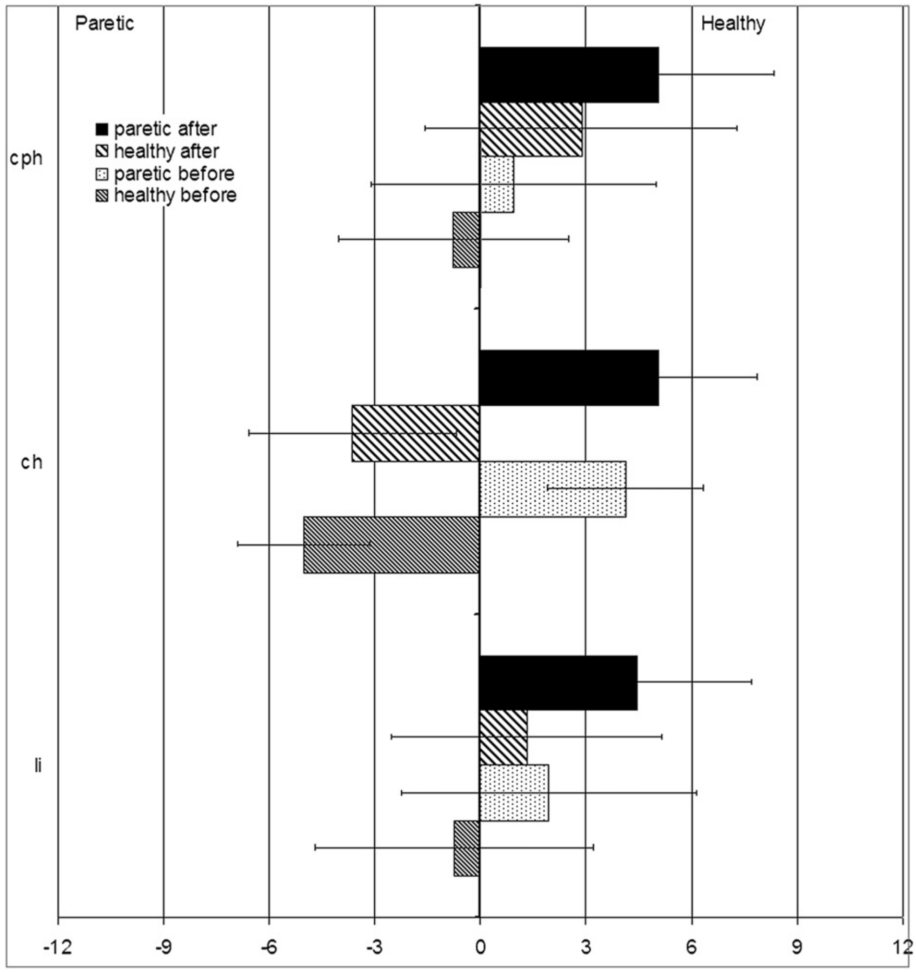

Fig. 5. Smile animation: lateral displacement (right–left direction, mm) of labial landmarks before and after surgery (mean ± 1 SD). Positive displacements: healthy side prevalence; negative displacements: paretic side prevalence.

The successful effect of surgery can be appreciated better by analysing the lateral displacement of the labial landmarks, as suggested by Frey et al. (2008). Before surgery, all six labial landmarks analysed (paretic and healthy side cph, ch, li) had considerable lateral movements, all in the healthy side direction (Figs. 2b, 5). After surgery, only the ch landmark maintained a lateral displacement, while both the other two landmarks remained nearer to the symmetry plane, as expected in healthy persons (Sforza et al., 2010a,b).

It has been reported that the assessment of synkineses and of the actual components of a movement may be difficult for a clinical observer because they require switching from a global, broad-external view to a local, narrow-internal focus on the animation being performed (Coulson et al., 2005). Computerized motion analysis can easily overcome this problem (Rogers et al., 2007).

On going investigations in our laboratory are following up the same patients before and after surgical reanimation, to document the actual individual modifications in facial movements and asymmetry (Frey et al., 2008).

5. Conclusion

The method used in this investigation allowed us to quantitatively detect both the alterations in facial movements in patients with unilateral palsy, and their rehabilitation after surgical reanimation. The significant asymmetry in the amount of facial movements that characterized the patients analysed before surgery reduced after surgery in those facial areas involved in the masseteric to facial nerve anastomosis.

Conflict of interest

The authors have no conflicts of interest in relation to the current investigation.

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