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Three-dimensional superimposition for patients with facial palsy: an innovative method for assessing the success of facial reanimation procedures

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Abstract

Facial palsy is a severe condition that may be ameliorated by facial reanimation, but there is no consensus about how to judge its success. In this study we aimed to test a new method for assessing facial movements based on 3-dimensional analysis of the facial surfaces. Eleven patients aged between 42 and 77 years who had recently been affected by facial palsy (onset between 6 and 18 months) were treated by an operation based on triple innervation: the masseteric to temporofacial nerve branch, 30% of the hypoglossal fibres to the cervicofacial nerve branch, and the contralateral facial nerve through two cross-face sural nerve grafts. Each patient had five stereophotogrammetric scans: at rest, smiling on the healthy side (facial stimulus), biting (masseteric stimulus), moving the tongue (hypoglossal stimulus), and corner-of-the-mouth smile (Mona Lisa). Each scan was superimposed onto the facial model of the "rest" position, and the point-to-point root mean square (RMS) value was automatically calculated on both the paralysed and the healthy side, together with an index of asymmetry. One-way and two-way ANOVA tests, respectively, were applied to verify the significance of possible differences in the RMS and asymmetry index according to the type of stimulus ($p = 0.0329$) and side ($p < 0.0001$). RMS differed significantly according to side between the facial stimulus and the masseteric one on the paralysed side ($p = 0.0316$). Facial stimulus evoked the most asymmetrical movement, whereas the masseteric produced the most symmetrical expression. The method can be used for assessing facial movements after facial reanimation.

Keywords: facial palsy; facial reanimation; stereophotogrammetry; 3D-3D superimposition

Introduction

Facial palsy is a severe condition that has several causes and may be a complication or expected outcome of specific operations on the cranial base and brain.[1]

Facial paralysis greatly affects the quality of life of affected patients, both clinically and socially.[2,3] At present, surgical facial reanimation is based on providing a new neural stimulus, and the hypoglossal and masseteric nerves are the most commonly used.[4,5] The masseteric nerve, and less so the hypoglossus, partially change their function (smiling without clenching the teeth) – so called cerebral adaptation[6] – though their original function still provides the maximal

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stimulus: smiling plus clenching the teeth or pushing with the tongue against lower incisors leads to a wider movement.

This type of smile is seldom spontaneous, however, as only the facial nerve can be activated by emotions.[1] Often one or more branches of the contralateral healthy facial nerve can therefore be used to evoke a "qualitative" improvement of facial expression through the "cross-face" nerve grafts.[7]

Surprisingly at present there is no method that is the "gold standard" for assessing the restored facial functions.[2] Traditional methods for verifying the improvement of facial activity are clinical classifications such as the House-Brackmann scale,[8] which is easy to use but provides only qualitative evaluations and is observer-dependent.[9,10] An attempt to introduce a world-wide assessment method is the e-FACE evaluation proposed by the Harvard facial paralysis team.[11] It is being adopted by many other teams, and has the great merit of permitting comparisons between units – the draw-back is still the lack of objectivity because it is based on observers' evaluations.

With time and the introduction of modern 3-dimensional acquisition of images and elaboration systems, procedures in the sensitive field of facial palsy have been reported, through the 3-dimensional analysis of patients' faces.[2,12,13] However, existing studies have so far analysed the facial movements almost only through the dislocation of landmarks, which has limited the evaluation to selected points. However, now the 3-dimensional analysis of faces allows research workers to make more detailed analyses (for example, through the recording and superimposition of 3-dimensional facial models and calculation of point-to-point distances between all the facial surfaces). This approach has already been reported in different types of research.[14,15]

In this study we report a new method for assessing the success of facial reanimation surgery through 3-dimensional recording and superimposition; the results may enable clinicians to develop new objective and quantitative methods useful in maxillofacial surgical practice.

Patients and methods

Data were collected for 11 subjects (mean (range) age 58 (42–77) years) who had unilateral facial palsy, in most of cases following excision of an acoustic neurinoma (Table 1). The mean (SD) time between the facial nerve being affected and the operation was 11 (3) months, while between operation and 3-dimensional analysis it was 24 months (10) months. All patients were treated between 2013 and 2016 by a single operation based on triple innervation: end-to-end masseteric to temporofacial branch neurorrhaphy, side-to-end hypoglossus to cervicofacial branch neurorrhaphy, and two cross-face sural nerve grafts (end-to-end at the proximal coaptation and end-to-side at the distal one).

Before data were collected, all patients were given a detailed description of the procedure and signed an informed consent form that had previously been approved by the ethics committee of the University of Milan Medical School in accordance with the standards of the 1964 Declaration of Helsinki. No procedure was invasive, dangerous or painful, and involved minimal discomfort.

A series of 50 reference points were marked on each face according to a set of landmarks already described elsewhere.[16,17] Each patients face was scanned five times by stereophotogrammetry (VECTRA-3D®: Canfield Scientific, Inc., Fairfield, NJ). The first scan was taken in the "rest" position, and then scans were taken during a posed "smile" that was evoked by the three functional manoeuvres recognised as stimuli for the corresponding nervous connections (smiling on the healthy side for the cross-face procedure, biting for masseteric neurorrhaphy, and pushing with the tongue against the lower incisors for hypoglossal neurorrhaphy). Finally, they were requested to produce the most natural corner-of-the-mouth smile (Mona Lisa) using all the strategies that they had learned.

The 3-dimensional reconstructions of the smiling face obtained through the four different smiling manoeuvres were recorded on the corresponding neutral one for a total of four superimpositions for each subject. To construct a proper superimposition, a facial area of interest was segmented in

Table 1
Clinical data of the 11 patients selected for the study. The preoperative House–Brackmann score was six for all patients.

Sex	Age (years)	Diagnosis	Time between lesion and operation (months)	Time between operation and 3D analysis (months)	Postoperative House–Brackmann score
Female	60	Acoustic neurinoma	14	15	2
Male	49	Acoustic neurinoma	10	14	3
Male	69	Acoustic neurinoma	13	43	3
Female	52	Acoustic neurinoma	13	29	2
Male	59	Acoustic neurinoma	6	22	2
Male	77	Acoustic neurinoma	8	23	2
Female	53	Car accident	18	13	3
Female	43	Acoustic neurinoma	10	19	2
Female	68	Acoustic neurinoma	10	14	2
Female	42	Acoustic neurinoma	13	32	2
Female	68	Neoformation of the petrous portion of temporal bone	10	35	3

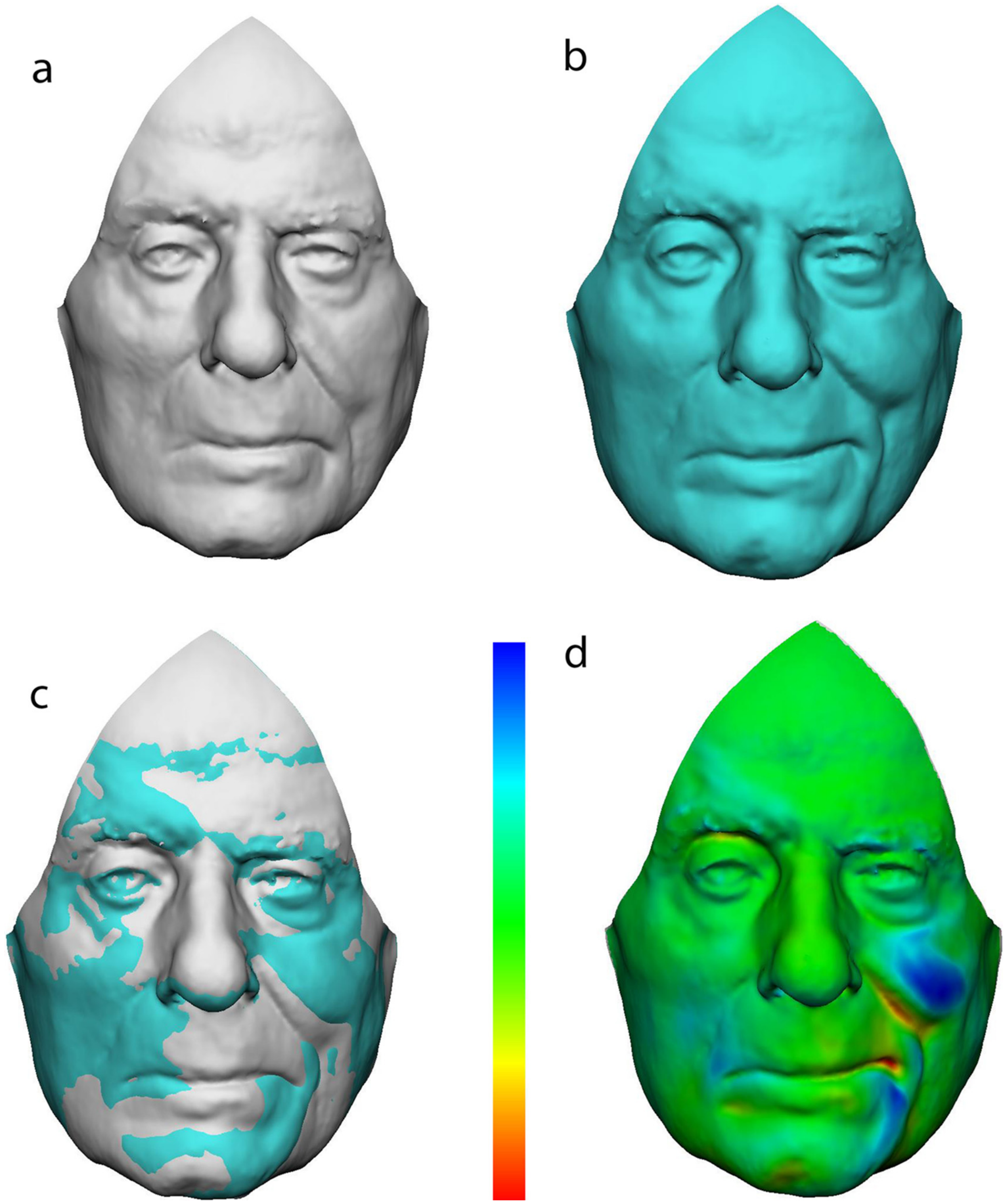

Fig. 1. Steps of 3-dimensional superimposition: A) 3-dimensional facial model of the patient at rest. B) 3-dimensional model of the patient (with Mona Lisa or "corner-of-the-mouth" smile). C) Superimposition according to the least point-to-point distance between the two models. D) Chromatic map of distances between the two models: green areas are unchanged, blue areas are more prominent in the smiling model than in the rest position, and vice versa for the red and yellow areas. In this case the right side is the paralysed one and shows most green colouration.

each model.[18] The area of interest was automatically superimposed by the software to reach the least distance between points of the entire surfaces (Fig. 1).

After the recording between the two surfaces had been reached, the facial models were further segmented to divide the right from the left side according to seven midline landmarks: (trichion, sellion, pronasale, subnasale, sublabiale, pogonion, menton).

We then used the Mirror® Vectra software (Canfield Scientific, Inc., Fairfield, NJ) to calculate the point-to-point root mean square (RMS) value between the neutral expression model and the different types of smile on the paralysed and healthy sides, separately. In addition, we extracted an asymmetry index from the RMS values, as the absolute value of the following formula: (RMS healthy side – RMS paralysed side)*100/RMS healthy side.

The entire procedure from segmentation of the areas of interest to the calculation of the RMS values was repeated for 24 superimpositions by the same operator and by another observer to verify intraoperator and interoperator error, respectively, using the Bland–Altman test.

The Jarque–Bera test and Bartlett test were used to verify the normal distribution and homoscedasticity of RMS values and of the asymmetry index, respectively. Both tests were done using Matlab® software. When RMS data did not pass the Jarque–Bera or Bartlett test, the natural logarithm of the RMS value and asymmetry index was used for the analyses, after having verified the normal distribution and homoscedasticity of the transformed data.

Results were then analysed using a two-way ANOVA to verify significant differences between RMS values according to the side, type of stimulus, and their interaction. Probabilities of less than 0.05 were accepted as significant. For both tests, post-hoc comparisons were made separately for the paralysed and healthy side using a one-way ANOVA.

Symmetry indices were analysed through one-way ANOVA to assess the significance of differences according to the type of stimulus, and post-hoc tests were done when appropriate.

Results

The extraction of RMS values showed intraobserver and interobserver repeatability of 97%.

Results are shown in Table 2. On the healthy side of the face, cross-face stimulus (smiling on the healthy side) and masseteric stimulus (biting) reached the highest RMS values. The same variables were lower on the paralysed side than on the healthy one: the masseteric stimulus reached the highest RMS distance relative to the rest position, followed by the hypoglossal one. The Mona Lisa smile reached intermediate scores for both the healthy and paralysed sides.

RMS values in the eight groups followed a normal distribution but did not have similar variances; on the other side, the natural logarithm of RMS values showed that they were normally distributed and had similar variances, so we applied the statistical analyses using the ANOVA to the natural logarithm of RMS value ($\log_e$RMS).

Significant differences were found according to side (F: 20.91; p = <0.0001; df: 1;80) and type of stimulus (F: 3.06; p = 0.0329; df: 3;80). Side x stimulus interaction did not reach significance (F: 2.2; p = 0.0945; df: 3;80). On the healthy side, post-hoc testing failed to verify significant differences according to type of stimulus (F: 2.2; p = 0.1030; df: 3;40). On the other side, significant differences were found between the facial and masseteric stimulus on the paralysed side (F: 3.25; p = 0.0316; df: 3;40).

The highest asymmetry index was shown by the facial cross-face stimulus, whereas the masseteric stimulus proved to evoke the most symmetrical movements of the face. The asymmetry index was normally distributed and homogenous according to variance. Significant differences were found according to the type of stimulus (F: 3.64; P: 0.0237; df: 3;30), although on post hoc testing there were differences only between the facial and masseteric stimuli.

Discussion

Facial palsy has obvious physical consequences in the form of oral incompetence and corneal lesions, and the asymmetry and distortion of face often lead to social isolation.[1,3,4] Facial reanimation has proved to be an option to minimise the effects of the facial palsy, but we still do not have a universally agreed quantitative method for the assessment of facial movements. Existing clinical scales are qualitative, subjective, and do not quantify the facial modifications evoked by different stimuli, although they can promote comparisons between centres (e-FACE).[12]

The introduction of modern 3-dimensional acquisition and elaboration systems has enabled research workers to improve analyses of facial movement, as shown by Popat et al who used a stereophotogrammetric motion analyser.[19,20] The main limitation of this method is that it restricts the kind of movements that can be analysed.[19,20] A similar method was also used by Okada through laser scanning.[21]

We have developed a method for the quantitative assessment of facial mimicry based on the 3-dimensional displacement of landmarks detected by an instrument that captures motion,[2,22] and the protocol has proved to be repeatable.[23] Unfortunately, the instrument is not widely used, and it is unlikely that its use will become widespread.[24] Indeed, we have also recently devised a 2-dimensional photographic method to quantify the success of facial rehabilitation procedures,[25] and this paper is a further step in that direction.

To our knowledge this is the first study that has applied the modern procedures of 3-dimensional facial recording

Table 2
Root mean square values for the healthy and paralysed sides, and asymmetry index for all the four elicited stimuli. Values are mean (SD).

	Facial cross-face stimulus	Hypoglossal stimulus	Masseteric stimulus	Corner-of-the-mouth smile
Healthy side (mm)	1.38 (0.63)	0.82 (0.44)	1.31 (0.46)	1.13 (0.53)
Paralysed side (mm)	0.54 (0.24)	0.67 (0.31)	0.95 (0.49)	0.59 (0.14)
Asymmetry index (%)	62 (28)	42 (25)	30 (22)	41 (20)

and superimposition to patients affected by facial palsy: the proposed protocol is easily repeatable, contactless, and non-invasive with clear advantages in comparison with electromyography, which is usually used to assess facial movements.

Interestingly, our results confirm the common opinion about the three different reported surgical techniques: cross-face intervention is unable to produce important facial movements, being a "qualitative" nervous connection, whereas the masseteric one provides the widest facial modifications.[1]

The highest facial asymmetry is reached by the facial cross-face stimulus, as it evokes the movement of the healthy side, whereas the paralysed one is minimally stimulated. On the other side, the masseteric one creates the most symmetrical expression. The Mona Lisa smile reached intermediate levels of both facial movement and asymmetry. After the operation, patients soon learn that the most "natural" smile can be reached through a limited activation of muscles on the healthy side (reducing the pulling effect on the paretic side), which increases the symmetry of the expression.[1,2]

In conclusion, this study describes a new, highly repeatable method for assessing facial movements in patients treated by facial reanimation. It may be useful not only for assessing the success of surgical treatment, but also as a test for the progressive training of patients during the follow-up phase.

Ethics statement/confirmation of patients' permission

Before data were collected, we gave a detailed description of the procedure to all patients, who signed an informed consent form previously approved by the ethics committee of the University of Milan in accordance with the standards of the Declaration of Helsinki. No procedure was invasive, dangerous, or painful, and involved minimal discomfort.

Conflict of interest

We have no conflicts of interest.

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