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Three-dimensional longitudinal evaluation of facial mimicry in orthognathic class III surgery

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Abstract. The effect of bimaxillary orthognathic surgery on facial mimicry was assessed longitudinally in 15 patients with dentoskeletal class III facial dysmorphism (seven men, eight women, mean age 28 years). The patients were analysed pre-surgery and at 6, 12, and 24 months post-surgery while performing verbal (five vowels) and non-verbal (open and closed mouth smile, lip purse) soft tissue facial movements. The three-dimensional motions of right and left nasogenian, crista philtri, cheilion, and lower lip landmarks were detected by an optoelectronic instrument, and a total mobility index was obtained. Differences between the sides were quantified by the symmetry index. Patient values were compared to those collected previously from healthy volunteers by computing *z*-scores. On average, no significant differences were found in the mobility of the buccal soft tissues at 24 months after surgery (ANOVA *P*-value, range 0.075–0.808), with positive median *z*-scores (pooled mean value close to 0.6). Symmetry indices ranged around the control reference values, showing no stage-related differences (Friedman test *P*-value, range 0.252–0.937), and exceeding 90% for all movements at 24 months after surgery. Bimaxillary osteotomy does not compromise facial mimicry in either verbal or non-verbal facial movements.

Key words: orthognathic surgery; motion capture; mimicry.

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Aesthetics and expression are the features first noticed when looking at a face. Both of these play a major role in a person's life because they can deeply influence the ability to interact socially[1–3]. Facial mimicry can completely change the appearance of a face, shaped by the contraction of many different mimic muscles[4–7]. The interaction between mimic muscles and the maxillary bones is an important aspect of communication: maxillomandibular dysmophisms can seriously compromise mimicry and aesthetics, requiring orthopaedic or surgical treatment[8]. Among other abnormalities of the jaw bones, class III malocclusions are of great interest due to their aesthetic impact, even though the prevalence in the population is not high: the incidence of Angle class III malocclusion ranges from approximately 5% in Caucasians and Iranians to 15% in Asian populations, and it is associated with skeletal class III in 58% to 70% of patients across races and sexes[9–12].

Functional and aesthetic problems of class III malocclusions involving only tooth positions can be treated orthodontically. When the dimension and/or position of the jaw bones are also altered, a combined orthodontic and surgical intervention becomes necessary[13,14]. In particular, the bimaxillary approach has become, by far, the most common and successful surgical technique in the treatment of skeletal class III[15,16]. The treatment goals are to recreate a harmonious relationship between the maxilla and mandible, correcting dimensional abnormalities and/or asymmetry, in order to achieve a functional occlusion and better aesthetics[17–19]. The procedure combines osteotomies and movements of the facial bones with soft tissue modifications: mimic muscles need to be disrupted, incised, and elevated, causing possible changes in their vector of movement and their length[20].

Although many previous studies have focused on long-term skeletal and dental stability and soft tissue or airway changes after orthognathic surgery, only a few have analysed the changes in verbal and non-verbal facial movements[16,20,21]. Johns et al.[20] evaluated the changes in muscular length after jaw bone osteotomy, showing how this can modify the amplitude of smile. They also assessed the effect on aesthetics and suggested the need for a more detailed pre-surgical analysis to predict the consequences on facial movements. More recently, Verzé et al. investigated the changes in facial non-verbal movements (smiling, frowning, grimace, and lip purse): after some post-surgical altered activity, the patients had recovered to their pre-surgery condition at the 1-year follow-up[22]. In a longitudinal study with 1 year of follow-up, Al-Hiyali et al.[23] discovered that the correction of skeletal asymmetry can improve the symmetry of facial expressions, but reported that investigations with a longer follow-up were necessary.

The evaluation of mimicry changes is therefore of increasing importance in orthognathic surgical planning, but the topic requires more detailed investigations with mid-term follow-up[24]. For instance, most investigations have assessed only non-verbal animations[22,23], and have not tested verbal movements. The latter have been reported to be more reliable and reproducible[14,25–27].

Soft tissue facial movements can be captured non-invasively and quantified by three-dimensional (3D) motion analysers[5,14,22,23,25–31]. Among others, optoelectronic motion systems offer a valuable means of obtaining objective measurements through the positioning of markers at standardized anatomical points[23,27–31].

The aim of this longitudinal study was to analyse the pre-surgery versus post-surgery differences in verbal and non-verbal soft tissue facial movements in a group of patients with a dentoskeletal class III relationship who were candidates for bimaxillary orthognathic surgery. It was sought to determine whether functional symmetry and movement balance of the lower two-thirds of the face change after surgery by comparing the results to reference values obtained from healthy individuals[25,29]. The null hypothesis was that bimaxillary orthognathic surgery does not change facial mimicry.

Materials and methods

Patients

Fifteen patients (seven men and eight women, mean age 28 years, standard deviation (SD) 4 years), natural speakers of the Italian language, with a diagnosis of dentoskeletal class III facial dysmorphosis, were recruited. These patients were candidates for bimaxillary osteotomy in the Maxillofacial Surgery Unit of Fondazione IRCCS Cà Granda Ospedale Maggiore Policlinico of Milan (University of Milan). The patients were evaluated longitudinally during the period October 2013 to September 2016. All patients underwent an Obwegeser/Dal Pont bilateral sagittal split osteotomy and a Le Fort I osteotomy. The direction and extent of the movements performed on each patient, together with the anti-inflammatory and analgesic therapies and postoperative physiotherapy provided, are detailed in Table 1. Intraoperative or postoperative complications were reported in six patients.

All patients were analysed before and after surgery at 6, 12, and 24 months of follow-up with a mimicry evaluation of the whole buccal area following a previously published protocol[25,28,29].

Buccal mimicry evaluation: recording protocol

Mimicry movements in verbal and non-verbal activities were recorded using an optoelectronic 3D motion analyser (SMART-E; BTS, Garbagnate Milanese, Italy). To record lip movements[17,32–34], nine infrared sensitive CCD video cameras were deployed around a stool and calibrated to create a 60 (width) cm × 60 (height) cm × 60 (depth) cm working volume. Metric calibration and correction of optical and electronic distortion were performed before each acquisition session using a 20-cm wand, with a resulting mean dynamic accuracy of 0.121 mm (SD 0.086 mm), corresponding to 0.0158%[33]. A 60 Hz sampling ratio was used for all acquisitions.

The patients were sat on the stool inside the working volume and asked to perform a series of standardized lip movements and speech pronunciations. During the execution of movements, the cameras detected the positions of lightweight, 2-mm round, passive retro-reflective markers with a spatial accuracy of up to 0.1 mm. Eleven facial landmarks were identified: *n*, nasion; *ft*, right and left frontotemporale; *ng*, right and left nasogenian; *cph*, right and 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 lip and speech movements[32–36]. Subsequently, all coordinates were converted to metric data, and a set of 3D coordinates was obtained for each landmark in each frame that constituted each movement.

The patients performed three standardized non-verbal animations (open mouth smile, closed mouth smile, and lip purse) and five verbal movements (natural sequence of the five Italian vowels /a/, /e/, /i/, /o/, /u/). Each animation was explained and shown to the patients, who practiced before data acquisition. For each animation, 10 standardized maximum facial expressions from rest were made, without modifications of the marker positions[25,32,33,36–38].

The recordings took approximately 30 minutes for each patient (including the time needed to prepare the patient). The protocol did not involve dangerous or painful procedures, and it was preventively approved by the Ethics Committee of the Fondazione IRCCS Ca' Granda Ospedale Maggiore Policlinico (Milan, Italy). After the methods and aims of the investigation had been described in detail, written informed consent was obtained from each participant.

Data analysis

All buccal landmark coordinates were referred to a cranial reference system, defined by the nasion and frontotemporale landmarks, thus mathematically eliminating head and neck movements. The 3D motion of the eight buccal landmarks was computed for both verbal and non-verbal animations, and the magnitude of each 3D vector of maximum displacement from rest was calculated. The sum of these maximum displacements was calculated to provide a 'total mobility index'. Differ-

Table 1. Surgical interventions and clinical information for the 15 class III patients analysed.

Patient	Age[a] (years)	Surgical	techniques	Maxillary movements	Mandibular movements	Anti-inflammatory and analgesic therapy	Corticosteroid therapy	Intra-/postoperative complications
			Postoperative physiotherapy					
F1	34	BSSO + LFI	Advancement: 3.0 mm Impaction: 2.6 mm	Impaction: 4.9 mm Rotation: 1.0 mm left	P three times a day for 2 days, then once for 2 days K twice a day for 1 day, then once for 2 days	Dex 4 mg twice a day for 1 day, then once for 1 day	Temporary (2 months) left IAN hypoesthesia	–
F2	24	BSSO + LFI	Advancement: 5.1 mm Rotation: 1.7 mm left	Impaction: 0.8 mm Rotation: 5.0 mm left Setback: 2.8 mm	P twice a day for 4 days, then once for 2 days K twice a day for 2 days, then once for 2 days	Dex 4 mg twice a day for 1 day, then once for 1 day	Right TMJ disorder	10 physiotherapy sessions in the first 6 postoperative weeks
F3	28	BSSO + LFI	Advancement: 4.0 mm Impaction: 2.9 mm Rotation: 1.2 mm left	Impaction: 6.4 mm Rotation: 1.6 mm left Setback: 2.6 mm	P three times a day for 1 day, then once for 3 days K once for 1 day	Dex 4 mg twice a day for 1 day, then once for 1 day	–	–
F4	26	BSSO + LFI	Advancement: 4.3 mm Impaction: 0.2 mm	Advancement: 3.4 mm Impaction: 0.7 mm Rotation: 0.6 mm right	P twice a day for 2 days, then once for 2 days K once for 3 days	Dex 4 mg twice a day for 1 day, then once for 1 day	–	–
M1	28	BSSO + LFI	Advancement: 4.1 mm Impaction: 1.9 mm	Advancement: 0.5 mm Impaction: 3.1 mm Rotation: 3.0 mm left	P three times a day for 3 days, then once for 2 days K twice a day for 2 days, then once for 2 days	Dex 8 mg twice a day for 1 day, then 4 mg twice for 1 day, then once for 1 day	–	–
F5	29	BSSO + LFI	+ genioplasty	Advancement: 1.2 mm Impaction: 1.3 mm Rotation: 1.2 mm right	Advancement: 1.1 mm Impaction: 1.7 mm Rotation: 2.4 mm right	P three times a day for 2 days, then once for 2 days K twice a day for 1 day, then once for 2 days	Dex 4 mg twice a day for 1 day, then once for 1 day	Temporary (8 months) bilateral IAN hypoesthesia
4			physiotherapy sessions in the first 4 postoperative weeks					
F6	21	BSSO + LFI	+ genioplasty	Advancement: 2.0 mm Impaction: 2.0 mm	Impaction: 3.5 mm Rotation: 0.5 mm left Setback: 1.6 mm	P twice a day for 3 days, then once for 1 day K once a day for 3 days	Dex 4 mg twice a day for 1 day, then once for 1 day	–
–								

Table 1 (*Continued*)

Patient	Age[a] (years)	Surgical	techniques	Maxillary movements	Mandibular movements	Anti-inflammatory and analgesic therapy	Corticosteroid therapy	Intra-/postoperative complications
			Postoperative physiotherapy					
F7	23	BSSO + LFI	Impaction: 0.8 mm Rotation: 3.2 mm left	Impaction: 3.0 mm Rotation: 3.1 mm left Setback: 2.7 mm	P twice a day for 3 days, then once for 2 days	Dex 4 mg twice a day for 1 day, then once for 1 day	–	–
M2	30	BSSO + LFI	Advancement: 3.4 mm Rotation: 1.6 mm left	Rotation: 2.3 mm right Setback: 7.0 mm	P three times a day for 1 day, then twice for 2 days K twice a day for 1 day, then once for 2 days	Dex 8 mg twice a day for 1 day, then 4 mg twice for 1 day, then once for 1 day	Temporary (6 months) left IAN hypoesthesia	–
M3	25	BSSO + LFI	Advancement: 4.1 mm	Impaction: 1.8 mm Rotation: 2.0 mm left Setback: 0.8 mm	P three times a day for 2 days, then once for 2 days K once a day for 2 days	Dex 8 mg twice a day for 1 day, then 4 mg twice for 1 day, then once for 1 day	–	–
F8	26	BSSO + LFI	+ genioplasty	Advancement: 2.7 mm Impaction: 0.6 mm	Rotation: 0.6 mm right Setback: 1.5 mm	P twice a day for 3 days, then once for 3 days K twice a day for 3 days, then once for 2 days	Dex 4 mg twice a day for 1 day, then once for 1 day	Left bad split in SSO
–								
M4	34	BSSO + LFI	Advancement: 2.1 mm Rotation: 1.3 mm left	Impaction: 0.5 mm Rotation: 1.4 mm right Setback: 5.8 mm	P three times a day for 3 days, then once for 2 days K twice a day for 2 days, then once for 2 days	Dex 8 mg twice a day for 1 day, then 4 mg twice for 1 day, then once for 1 day	–	5 physiotherapy sessions in the first 4 postoperative weeks
M5	33	BSSO + LFI	Advancement: 4.3 mm Impaction: 2.0 mm	Impaction: 2.6 mm Rotation: 2.4 mm right Setback: 1.4 mm	P three times a day for 1 day, then twice for 2 days K once a day for 1 day	Dex 8 mg twice a day for 1 day, then 4 mg twice for 1 day, then once for 1 day	–	–
M6	30	BSSO + LFI	Advancement: 3.1 mm Rotation: 1.4 mm left	Impaction: 1.9 mm Rotation: 4.3 mm right Setback: 3.4 mm	P three times a day for 1 day, then once for 2 days	Dex 8 mg twice a day for 1 day, then 4 mg twice for 1 day, then once for 1 day	LFI osteotomy severe bleeding	–
M7	23	BSSO + LFI	Advancement: 3.0 mm Impaction: 0.2 mm Rotation: 1.7 mm left	Impaction: 1.6 mm Setback: 2.8 mm	P twice a day for 2 days, then once for 2 days K once a day for 2 days	Dex 8 mg twice a day for 1 day, then 4 mg twice for 1 day, then once for 1 day	–	–

BSSO + LFI: Obwegeser/Dal Pont bilateral sagittal split osteotomy and Le Fort I osteotomy; Dex, dexamethasone (intravenous); IAN, inferior alveolar nerve; K, ketorolac tromethamine (30 mg, intravenous); P, paracetamol (1000 mg, intravenous); SSO, sagittal split osteotomy; TMJ, temporomandibular joint.

[a] Age at surgery.

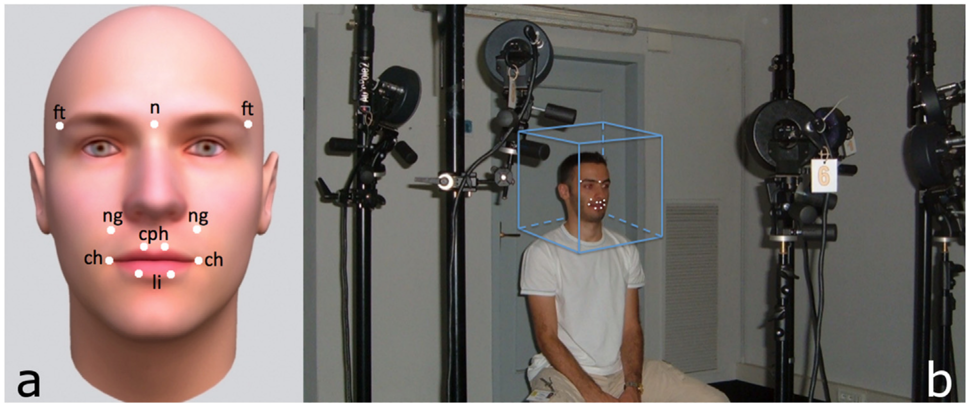

Fig. 1. The experimental setup and position of the facial landmarks. Cameras surround the patient's head. The working volume is shown.

ences between the sides were quantified by the 'symmetry index', calculated as the ratio between the smaller and the larger unilateral mobility, with values ranging from 0% (complete asymmetry) to 100% (perfect symmetry)[25].

Using the same experimental setup on healthy volunteers, the intra-session technical error of single landmarks was smaller than 3.4 mm, while the inter-session reproducibility of facial movements showed standard deviations of less than 1 mm[26].

Statistical analysis

For all patients, the 10 repetitions of verbal (vowels) and non-verbal (open and closed mouth smile, lip purse) animations were averaged, and the mean maximum displacement value of each landmark was used to compute the individual 3D total mobility and symmetry index for all pre- and post-surgery assessments.

Since no gender difference has been observed previously in healthy volunteers[25,33], data from male and female patients were pooled. The normality of the data distribution was checked using the Kolmogorov–Smirnov test, and it was found that several symmetry index values deviated significantly from normality. Therefore, the mean and SD were computed for total mobility, and the median and interquartile range (IQR) for the symmetry index. The four acquisitions were compared by repeated measures one-way analysis of variance (ANOVA) for total mobility and by Friedman test for the symmetry index. The significance level was set at 5% for all analyses ($P < 0.05$).

Patient indices were also compared to those collected previously from healthy volunteers[25,29] by computing *z*-scores: patient value minus reference mean value divided by the relevant standard deviation. Inter-patient median *z*-scores were obtained for each animation and follow-up examination. Negative scores indicated that the patient values were overall smaller than the healthy reference mean values, while positive values indicated the opposite.

Results

On average, for all verbal and non-verbal animations, the mobility of the buccal soft tissues was similar before surgery and at 24 months after surgery (Tables 2 and 3). With the exception of lip purse, the median *z*-scores (difference relative to control subjects) were positive at 24 months after surgery, with a median value close to 0.6 when all animations were pooled (Fig. 2). On average, for all verbal and non-verbal animations, the mobility of the buccal soft tissues was similar before surgery and at 24 months after surgery (ANOVA *P*-value, range 0.075–0.808) (Tables 2 and 3). A large inter-individual variability was found, although without any significant differences.

For closed mouth smile, performance was on average increased at 2 years after surgery. The mean increase was around 1 cm, with 12 of 15 patients able to improve their performance; only patient F8 had a decrease larger than 25%. The mean relative increase in mobility was 19.7% (SD 23%), with six patients (F2, F3, F7, M1, M4, M5) showing increases larger than 30% (highest increase, 62%).

>For open mouth smile at 2 years after surgery, patient M4 showed a relative increase in mobility of greater than 30%. Before surgery, mobility during the performance of lip purse was superimposable in patients and reference subjects; however, it decreased during post-surgical follow-up, with a final median *z*-score of −0.21.

For verbal animations, patients progressively increased their performance during the observation period, with final median *z*-scores ranging from 0.53 (/a/) to 1.22 (/i/). On average, the largest percentage increase was found for vowel /o/, with six out of 15 patients recording an increase greater than 30% (F3, F4, F7, M2, M4, M7); the lowest percentage improvement was found for vowel /a/.

Patients had symmetry indices ranging around the control reference values, showing no stage-related differences (Friedman test *P*-value, range 0.252–0.937) and exceeding 90% of symmetry for all verbal and non-verbal animations at 2 years after surgery (Tables 4 and 5).

Table 2. 3D total mobility of the buccal soft tissues before surgery and during postoperative follow-up in non-verbal animations[a].

Total mobility	Open mouth, smile				Closed mouth, smile				Lip purse			
	Pre	P6	P12	P24	Pre	P6	P12	P24	Pre	P6	P12	P24
Mean (mm)	92.1	97.1	96.0	93.9	60.1	62.7	71.2	70.5	68.2	71.5	63.0	67.0
SD (mm)	17.5	22.3	21.4	17.6	14.6	18.3	22.1	16.9	16.4	14.8	13.8	15.9
p-Value (ANOVA)	0.808				0.189				0.356			
Median *z*-score[b]	0.50	0.79	0.43	0.57	−0.11	0.17	0.29	0.24	−0.06	−0.43	−0.41	−0.21

3D, three-dimensional; ANOVA, analysis of variance; SD, standard deviation.
[a] P6, P12, and P24 indicate 6, 12, and 24 months after surgery; Pre indicates pre-surgery.
[b] The *z*-scores were computed using reference data[25,29] as patient value minus reference mean value divided by the relevant standard deviation.

Table 3. 3D total mobility of the buccal soft tissues before surgery and during postoperative follow-up in verbal animations.[a]

Total mobility	/a/				/e/				/i/				/o/				/u/			
	Pre	P6	P12	P24	Pre	P6	P12	P24	Pre	P6	P12	P24	Pre	P6	P12	P24	Pre	P6	P12	P24
Mean (mm)	71.5	75.2	73.9	81.3	48.7	56.4	61.4	59.0	41.2	39.1	38.6	47.2	47.7	42.2	55.7	56.3	43.4	43.6	48.9	48.4
SD (mm)	21.4	33.5	19.3	27.5	16.0	30.2	27.2	22.2	12.5	25.0	12.8	17.7	22.7	22.3	20.0	20.0	18.1	10.7	14.6	18.0
p-Value (ANOVA)	0.642				0.463				0.428				0.075				0.605			
Median *z*-score[b]	0.15	0.10	0.04	0.53	0.32	0.65	0.83	1.08	0.78	0.18	0.66	1.22	0.15	−0.68	0.51	0.48	−0.35	−0.20	0.58	0.72

3D, three-dimensional; ANOVA, analysis of variance; SD, standard deviation.
[a] P6, P12, and P24 indicate 6, 12, and 24 months after surgery; Pre indicates pre-surgery.
[b] The *z*-scores were computed using reference data[25,29] as patient value minus reference mean value divided by the relevant standard deviation.

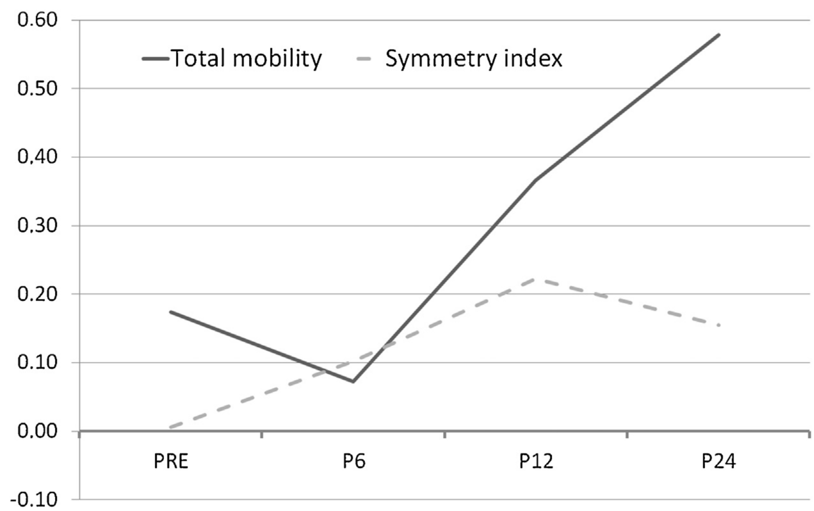

Fig. 2. Median z-scores pooled for all facial animations before surgery (PRE) and during postoperative follow-up (P6, P12, and P24, indicating 6, 12, and 24 months after surgery). The *z*-scores were computed using reference data[25,29] as patient value minus reference mean value divided by the relevant standard deviation.

Discussion

Mimicry is a critical factor that can influence both aesthetics and the function of a face[1]. Maxillofacial surgery techniques may need to disrupt mimic muscles, changing their lengths and vectors, possibly entailing modifications in mimicry. Previous studies have already analysed the changes in mimicry after maxillofacial surgery, such as conservative parotidectomy or open technique rhinoplasty, but little is known about orthognathic surgery[2–4].

The fate of mimic function after orthognathic surgery might be a concern for patients, who seek not only to recover compromised function, but mostly to improve their appearance. As mimicry can modify facial aesthetics, post-surgical modifications in mimicry become a factor of primary interest in treatment planning. The literature underlines the need to study both verbal (vocal) and non-verbal (smile, lip purse) facial movements: there should be major reproducibility in verbal movements, being more natural and easy to perform; non-verbal movements provide more realistic results for the evaluated performances [5–7,25,27,30–31].

In this study, both global aesthetics and motor function of the mimic muscles were evaluated using the symmetry index and average mobility, respectively. Open mouth smile and vowel /a/ were associated with the largest total mobility values at 24 months postoperative, in accordance with previous studies reporting greater lip excursions in expressions that involve mouth opening[32,33], as these animations are generated by both mimic muscles and movements produced around the temporomandibular joint by the masticatory muscles.

During the early postoperative period, patients treated for an Angle class III malocclusion have been found to present reduced vertical movements of the upper lip, together with reduced lateral cheek movements. The frontal projection of the lower lip is reduced (perhaps a direct consequence of surgical movements), while the frontal projections of the cheeks, labial commissures, and soft tissues of the chin are increased[39]. In pre-surgery assessments, the same patients had greater vertical translation during lip protrusion and a greater lateral movement of the cheeks, with values higher than those in the control group. For these movements, the present study found comparable results, with similar variations in the median *z*-score for vowel /i/ (Table 3).

As regards facial mobility, no significant variations were found during the 24 months of follow-up for any of the facial animations studied. Nonetheless, in most verbal animations (except vowel /u/) and in the smile ones, total mobility between 6 and 12 months after surgery showed a sharp increase and then return to values similar to the pre-surgical ones at the 24-month evaluation. The literature reports considerable increases in bilateral mimic mobility 6 months after a bimaxillary osteotomy for class III malocclusion: surgical repositioning of the maxilla ante-

Table 4. 3D symmetry index before surgery and during postoperative follow-up in non-verbal animations[a].

Symmetry index	Open mouth, smile				Closed mouth, smile				Lip purse			
	Pre	P6	P12	P24	Pre	P6	P12	P24	Pre	P6	P12	P24
Median (%)	93.3	92.7	94.2	94.9	88.3	88.0	89.6	91.0	91.1	92.3	91.6	93.0
IQR (%)	7.8	8.4	5.8	4.5	10.5	9.5	15.4	10.7	11.1	5.1	6.3	7.0
p-Value (Friedman)	0.915				0.534				0.252			
Median *z*-score[b]	0.33	0.25	0.44	0.54	−0.29	−0.33	−0.11	0.08	−0.92	−0.30	−0.22	−0.50

3D, three-dimensional; IQR, interquartile range.
[a] P6, P12, and P24 indicate 6, 12, and 24 months after surgery; Pre indicates pre-surgery.
[b] The *z*-scores were computed using reference data[25,29] as patient value minus reference mean value divided by the relevant standard deviation.

Table 5. 3D symmetry index before surgery and during postoperative follow-up in verbal animations[a].

Symmetry index	/a/				/e/				/i/				/o/				/u/			
	Pre	P6	P12	P24	Pre	P6	P12	P24	Pre	P6	P12	P24	Pre	P6	P12	P24	Pre	P6	P12	P24
Median (%)	95.9	95.7	94.4	94.7	92.3	92.7	92.8	92.2	89.4	93.6	93.8	94.6	92.1	95.5	96.4	94.3	96.0	88.0	92.8	90.7
IQR (%)	8.1	5.0	5.9	6.3	4.3	13.0	8.4	9.3	11.5	10.7	9.3	11.2	8.6	9.2	3.8	6.2	15.2	17.2	7.7	7.6
p-Value (Friedman)	0.553				0.937				0.492				0.661				0.661			
Median *z*-score[b]	0.22	0.17	−0.14	−0.08	−0.04	0.04	0.07	−0.08	−0.38	0.26	0.29	0.41	0.15	0.68	0.83	0.50	1.00	0.05	0.62	0.37

3D, three-dimensional; IQR, interquartile range.

[a] P6, P12, and P24 indicate 6, 12, and 24 months after surgery; Pre indicates pre-surgery.

[b] The *z*-scores were computed using reference data[25,29] as patient value minus reference mean value divided by the relevant standard deviation.

riorly and inferiorly stretches the mimic musculature, leading to larger facial movements, particularly evident during smile[20]. Similar findings were reported by Verzé et al.[22] at 12 months after surgery. Additional elements that could affect facial mobility are the mechanical forces acting on the soft tissues during surgery, where traction, divarication, and tissue manipulation lead to an increase in laxity and a greater degree of freedom of mimic muscle movements. This situation seems to last for the whole period in which the intervention area remains oedematous and locally traumatized, which is up to 12 months according to Proffit et al.[40].

Considering individual results, after large surgical bone repositioning, the best improvements at 24 months were observed in patient F3, who showed increases in facial mobility for all animations of up to 220% (/e/). Six patients had intraoperative or postoperative complications (Table 1). Patient F2 suffered a temporomandibular joint disorder and was treated with physiotherapy. She also underwent the largest maxillary advancement and mandibular rotation of the group. Nonetheless, at the final examination she showed increases in all three non-verbal animations (up to 42%).

Patient F8 had decreases in both closed mouth smile and lip purse (−25%) and vowel /u/ (approximately −45%). Her surgical treatment did not require large mandibular and maxillary movements, but included a genioplasty, and unfortunately she had a complication in her left side sagittal split osteotomy. Both of these latter factors may have influenced the final mimicry result, which was successful for the other verbal animations.

Patient F5 also underwent a genioplasty, and this patient suffered temporary inferior alveolar nerve hypoesthesia and cervical pain after surgery. Physiotherapy sessions were included in her treatment. Overall, her mimicry at 24 months postoperative was lower than before treatment, especially for vowel /o/ (−44%).

Inferior alveolar nerve hypoesthesia was reported by both F1 and M2, but while F1 had some reduction in vowel pronunciations, M2 had a very successful outcome, with increases in all animations (up to +100%, vowel /u/), except open mouth smile (no variation). This patient underwent the largest mandibular setback of the group.

Patient M6 had severe bleeding after his Le Fort I osteotomy. This patient's facial mobility during vowel pronunciations was impaired even after 24 months, with reductions of up to 69% (vowels /e/, /u/). After undergoing the second largest mandibular setback of the group, patient M4 attended physiotherapy sessions, but mostly for professional reasons (he was a professional water polo player); he regained his full facial mobility with improvements larger than 60% (closed smile, vowel /e/).

Patient M3 had no surgical complications. His maxillary and mandibular surgical movements were similar to those of the group, but his final facial movements for open smile, lip purse, vowels /e/ and /u/ were smaller than those recorded before surgery (up to −38%). Also patient F6 showed no improvements in her mimicry after 24 months except for vowel /u/(+44%). Her treatment included genioplasty.

The main innovative feature of the present study was the performance of a global quantitative analysis of the impact of orthognathic surgery on facial mimicry. A final post-surgical observation period of 24 months appears to be adequate, and represents a good compromise between the time needed for soft tissue stabilization in the new skeletal balance and patient compliance with the study. On average, the mobility of the buccal soft tissues at 24 months after surgery was similar to that before surgery, with positive median *z*-scores. The only movement that had a reduced performance at the final follow-up examination was lip purse. In the different facial animations examined, the symmetry index indicated a common and shared well-balanced motion of the facial muscles at 24 months after surgery. Both the increased asymmetry in the intermediate follow-up examinations and final average symmetry values appear to fit perfectly within the normal range obtained in previous studies[22,23,29].

Nonetheless, inter-patient variability was high, and the present observations were not associated with any statistically significant differences; therefore, the null hypothesis could not be rejected. In general, the worst mimicry performances at 24 months post-surgery were found in patients who had intraoperative or postoperative complications (F1, F2, F5, F8, M6), and who underwent genioplasty (F5, F6, F8), but did not seem to be related to the direction or amplitude of the maxillary and mandibular surgical movements. Physiotherapy had a beneficial effect in two patients out of three (F2, M4), and it should be included in the rehabilitation protocol.

Certain limitations of this study should be noted. The small number of patients examined may in part explain the lack of significant differences, and even though similar sample sizes have been reported for other investigations[20,22,23], additional patients should be recruited and investigated using the protocol of the present study. This may allow a better understanding of the relationships between clinical findings and mimicry assessments. Furthermore, the analysis focused on landmark movements, while the entire facial surface moves during mimic animations. Future studies may include surface assessments of the entire facial surface[5,22,23].

In conclusion, bimaxillary osteotomy does not compromise facial mimicry, in either verbal or non-verbal facial movements. Optoelectronic motion capture systems can support the surgeon during the diagnosis and treatment planning, helping to provide a more customized therapy to improve the quality of life of patients with dysfunctional problems.

Patient consent

Not required.

Funding

None.

Ethical approval

This investigation complied with the principles stated in the Declaration of Helsinki ''Ethical Principles for Medical Research Involving 'Human Subjects'', adopted by the 18th World Medical Assembly, Helsinki, Finland, June 1964, and as amended most recently at the 64th World Medical Assembly, Fortaleza, Brazil, October 2013. Ethical approval was obtained from the Fondazione IRCCS Ca' Granda Ospedale Maggiore Policlinico di Milano, Milan, Italy (#843 03 April 2012).

Competing interests

None.

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