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Title: 3D LONGITUDINAL EVALUATION OF FACIAL MIMICRY IN ORTHOGNATHIC CLASS III SURGERY.

Article Type: Research Paper

Keywords: Orthognathic surgery; motion capture; mimicry

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Manuscript Region of Origin: ITALY

Abstract: The effect of bimaxillary orthognathic surgery on facial mimicry was longitudinally assessed in 15 patients with dentoskeletal Class III facial dysmorphosis (7 men, 8 women, mean age 28 years). The patients were analyzed pre-surgery and 6, 12 and 24 months post-surgery while performing verbal (five vowels) and nonverbal (open and closed mouth smile, lip purse) soft-tissue facial movements. The 3D motions of right and left naso-genian, crista philtri, cheilion and lower lip landmarks were detected by an optoelectronic instrument, and a total mobility index was obtained. Side differences were quantified by an index of symmetry. Patients values were compared to those previously collected in healthy volunteers by computing z-scores. On average, 24 months after surgery no significant differences were found in the mobility of the buccal soft tissues (ANOVA p values 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 values range 0.252-0.937), and exceeding 90% for all movements 24 months after surgery. Bimaxillary osteotomy does not compromize facial mimicry, in both verbal and nonverbal facial movements.

Cover letter

Dr. Nabil Samman, Hong Kong, China
International Journal of Oral and Maxillofacial Surgery

Milano, 18 febbraio 2018

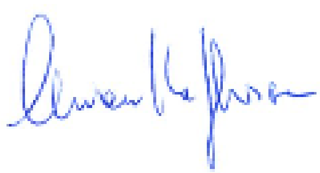
Dear dr. Samman,

Please find enclosed the manuscript "DENTOFACIAL DEFORMITIES WITH CLASS III MALOCCLUSION: A 3D LONGITUDINAL STUDY OF FACIAL MIMICRY IN ORTHOGNATHIC SURGERY PATIENTS" by Federico Cullati, Francesca M.E. Rusconi, Andrea Mapelli, Matteo Zago, Giada A. Beltramini, Aldo Bruno Giannì, and Chiarella Sforza, which I would like to submit as Research Paper for the publication in the International Journal of Oral and Maxillofacial Surgery.

In the paper, we investigated the modifications in facial mimicry after orthognathic surgery using a motion capture instrument. The method of data collection had already been published by the Journal (Facial mimicry after conservative parotidectomy: A three-dimensional optoelectronic study. Int J Oral Maxillofac Surg. 2012;41:986–93; The effect of age and sex on facial mimicry: a three-dimensional study in healthy adults. Int J Oral Maxillofac Surg. 2010;39:990-9).

All authors made substantial contributions to the conception and design of the study, or acquisition of data, or analysis and interpretation of data; they either prepared a draft version of the article or revised it critically for important intellectual content. The final manuscript has been seen and approved by all the authors; they have taken due care to ensure the integrity of the work.

Thank you for your kind attention.



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INTERNATIONAL JOURNAL OF ORAL & MAXILLOFACIAL SURGERY

CONFIRMATION OF AUTHORSHIP FORM

Title of Submission: **DENTOFACIAL DEFORMITIES WITH CLASS III MALOCCLUSION: A 3D LONGITUDINAL STUDY OF FACIAL MIMICRY IN ORTHOGNATHIC SURGERY PATIENTS.**

Contributing Authors :-

Author: (surname and initials)	**Signature (Mandatory)**
1. Federico Cullati	…………………………
2. Francesca M.E. Rusconi	…………………………
3. Andrea Mapelli	…………………………
4. Matteo Zago	…………………………
5. Giada A. Beltramini	…………………………
6. Aldo Bruno Giannì	…………………………
7. Chiarella Sforza	…………………………

"I warrant that all the authors listed above have made a significant contribution to this manuscript and have agreed to its submission to the IJOMS".

Signed (corresponding author) ……………………………………………………………

Name and Title of Corresponding Author: Chiarella Sforza, MD

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***Declaration Form**

Journal: INTERNATIONAL JOURNAL OF ORAL & MAXILLOFACIAL SURGERY

Title of Paper: **DENTOFACIAL DEFORMITIES WITH CLASS III MALOCCLUSION: A 3D LONGITUDINAL STUDY OF FACIAL MIMICRY IN ORTHOGNATHIC SURGERY PATIENTS.**

Declarations

The following additional information is required for submission. Please note that failure to respond to these questions/statements will mean your submission will be returned to you. If you have nothing to declare in any of these categories then this should be stated.

Please state any conflict of interests. A conflict of interest exists when an author or the author's institution has financial or personal relationships with other people or organisations that inappropriately influence (bias) his or her actions. Financial relationships are easily identifiable, but conflicts can also occur because of personal relationships, academic competition, or intellectual passion. A conflict can be actual or potential, and full disclosure to The Editor is the safest course.

Competing Interests

NONE

Please state any sources of funding for your research

NONE

DOES YOUR STUDY INVOLVE HUMAN OR ANIMAL SUBJECTS? Please cross out whichever is not applicable

YES

If your study involves human or animal subjects or records of human patients you MUST have obtained ethical approval. Ethics approval or exemption are required for retrospective studies on patients' records

Please state whether Ethical Approval was given, by whom and the relevant Judgement's reference number. A COPY OF THE ETHICAL APPROVAL OR EXEMPTION LETTER MUST BE UPLOADED WITH YOUR SUBMISSION

Ethical approval by Fondazione IRCCS Ca' Granda Ospedale Maggiore Policlinico di Milano, Milan, Italy #843 03 April 2012

Patient Consent – please state that written patient consent has been obtained to publish clinical photographs. If you have no clinical photographs, please state "not required".
The Journal may request a copy of this consent prior to acceptance

Not required

Please add a statement to confirm that all authors have viewed and agreed to the submission

All authors have viewed and agreed to the submission

This information must also be inserted into your manuscript under the acknowledgements section prior to the References.

FONDAZIONE IRCCS CA' GRANDA
OSPEDALE MAGGIORE POLICLINICO

DETERMINAZIONE N. 843 del 03 APR. 2012 Atti n. 1127/11

STUDIO OSSERVAZIONALE SPONTANEO FINANZIATO: "LA VALUTAZIONE DELLA MORFOLOGIA FACCIALE PRIMA E DOPO CHIRUGIA ORTOGNATICA"-PRESSO L'UOC CHIRURGIA MAXILLO FACCIALE

IL DIRETTORE GENERALE,

VISTO il D. lgs. del 24.2.2003, n. 211, con il quale è stata recepita la direttiva comunitaria n. 2001/20/cee, sull'esecuzione delle sperimentazioni cliniche di farmaci per uso clinico;

VISTO il D.M. del 17.12.2004 "Prescrizioni e condizioni di carattere generale, relative all'esecuzione delle sperimentazioni cliniche di medicinali, con particolare riferimento a quelle ai fini del miglioramento della pratica clinica, quale parte integrante dell'assistenza sanitaria", nonché le linee guida che sul Decreto stesso la Regione Lombardia ha fornito con la circolare del 29.6.2005, protocollo 2005.0031947;

VISTO il Decreto della Direzione Generale della Sanità n. 11960 del 13.7.2004 relativo all'approvazione delle linee guida sugli studi "osservazionali" o "non interventistici", elaborazione di reports periodici ed istituzione del registro regionale sugli studi "osservazionali" o "non interventistici" effettuati in Regione Lombardia;

VISTA la Determinazione AIFA del 20/03/2008 – G.U. Serie Generale n.76 del 31/03/2008.

RICHIAMATA la determinazione di questo Istituto del 27.10.2006, n. 2556, con la quale sono state approvate le nuove procedure operative per l'avvio delle sperimentazioni, aggiornando, nel contempo, la tariffa minima per la valutazione delle stesse e le modalità di riparto degli introiti;

VISTA la nota datata 23/06/2011, corredata dalla relativa documentazione, con la quale il Prof. Aldo Bruno Gianni, Direttore U.O.C. Chirurgia Maxillo Facciale, chiede l'autorizzazione ad eseguire uno studio osservazionale spontaneo finanziato,

ATTESO che il Comitato di Etica ha espresso in data 12/07/2011 parere favorevole all'esecuzione dello studio;

CONSIDERATO che come dichiarato dal Prof. Aldo Bruno Gianni, Direttore U.O.C. Chirurgia Maxillo Facciale, nella lettera di presentazione datata 23/06/2011, in atti 1127/11 all.2 non sono previsti costi aggiuntivi per la Fondazione in quanto per la realizzazione del progetto di ricerca, unicamente risorse umane, saranno coperti da un finanziamento di € 75.000,00 (settantacinquemilaeuro), all. Exhibit A.2. della Convenzione in atti 1127/11;

RITENUTO di approvare la predetta richiesta di sperimentazione;

con i pareri favorevoli del Direttore Amministrativo, del Direttore Sanitario e del Direttore Scientifico;

DETERMINAZIONE N. 843 del 03 APR. 2012 Atti n. 1127/11

DETERMINA

1) di autorizzare, ai sensi della normativa in materia vigente, l'esecuzione dello studio osservazionale spontaneo finanziato

2) di prendere atto che lo studio, dichiarato osservazionale spontaneo finanaziato, non comporta oneri aggiuntivi per la Fondazione;

IL DIRETTORE GENERALE
Dr. Luigi Macchi

IL DIRETTORE SCIENTIFICO
Prof. Pier Mannuccio Mannucci

IL DIRETTORE AMMINISTRATIVO
Dott. Osvaldo Basilico

IL DIRETTORE SANITARIO
Dr.ssa Anna Pavan

REGISTRATA NELL'ELENCO DELLE DETERMINAZIONI
IN DATA 03 APR. 2012 AL N. 843

Responsabile del Procedimento: D.ssa F. Massacesi

ENGLISH TRANSLATION

Fondazione IRCCS Ca' Granda Ospedale Maggiore Policlinico di Milano, Milan, Italy

Decision no. 843 – date 03 April 2012 – 1127/11

FUNDED VOLUNTARY OBSERVATIONAL STUDY: "THE EVALUATION OF FACIAL MORPHOLOGY BEFORE AND AFTER ORGANIC SURGERY" – AT MAXILLO-FACIAL SURGERY UNIT

THE GENERAL DIRECTOR,

UNDER THE LAW dated 24.2.2003, n. 211, with which the community directive n. 2001/20 / EEC was received, about the execution of clinical trials of drugs for clinical use;

UNDER THE LAW dated 17.12.2004 "General prescriptions and conditions, related to the execution of clinical trials of medicines, with particular reference to those for the purpose of improving clinical practice, as an integral part of health care", as well as the guidelines on the same Decree that the Region Lombardia provided with the circular dated 29.6.2005, protocol 2005.0031947;

UNDER THE DECREE of the General Direction of Health n. 11960 of 13.04.2004 on the approval of the guidelines on "observational" or "non-interventional" studies, development of periodic reports and establishment of the regional register on "observational" or "non-interventional" studies carried out in the Lombardy Region;

SEEN the AIFA Determination of 20/03/2008 - G.U. General Series n.76 of 31/03/12008,

RECALLED the determination of this Institute of 27.10.2006, n. 2556, with which the new operating procedures were approved for the start of trials, updating, at the same time, the minimum rate for the evaluation of the same and the methods for allocating the revenues;

GIVEN the note dated 23106/2011, accompanied by the relative documentation, with which Prof. Aldo Bruno Gianni, Director of U.O.C. Maxillo Facial Surgery, asks permission to perform a funded voluntary observational study,

EXPECTED that the Ethics Committee has expressed a favorable opinion on the execution of the study on 12/07/2011;

CONSIDERED that as stated by Prof. Aldo Bruno Gianni, Director U.O.C. Maxillo Facial Surgery, in the letter of presentation dated 23/06/2011, in acts 1127/11 al1.2, there are not additional costs for the Foundation as for the realization of the research project, only human resources, will be covered by a loan of E 75,000.00 (seventy-five thousand euros), Enclosure. Exhibit A.2. of the Convention in Acts 1127/11;

CONSIDERED to approve the aforementioned experimentation request; with the favorable opinions of the Administrative Director, the Medical Director and the Scientific Director

DETERMINES

1) to authorize, under the regulations in force, the execution of the funded voluntary observational study

2) to acknowledge that the study, declared funded voluntary observational, does not entail additional burdens for the Foundation

Milano, 12 August 2018

Professor Nabil Samman
FRCS FDSRCS Dr hc
Editor-in-Chief

Dear professor Samman,

Please find enclosed the revised version of our Ms. Ref. No.: IJOMS-D-18-00154R1: 3D longitudinal evaluation of facial mimicry in orthognathic Class III surgery.

The manuscript was revised according to your precious suggestions and of those of the Reviewers. A detailed list of changes is included; the modified parts of the text are identified by the track change option.

We are grateful to you and the Reviewers for all the time and expertise you are devoting to our submission. We trust that the present version of MS will be suitable for publication in the International Journal of Oral & Maxillofacial Surgery.

With my personal best wishes for the current holiday season.

Sincerely,

Chiarella Sforza

Editor in Chief

Your manuscript was reviewed and comments received are copied below for your information. Regarding reviewer #3's comments, please see these for information only and we hope they are helpful to you.

A: Thank you for your precious advice, we attentively read the comments written by Reviewer #3 and made some modifications to the text (see below).

Q: I would like you to address reviewer #5's comments carefully as he is the journal statistical adviser. You are asked to modify the conclusion in the abstract and the results section as indicated by reviewer #5, and similarly any reference to this interpretation in the discussion. Also, please insert exact p values in the abstract and the tables and elsewhere as requested.

A: Done as kindly suggested, see details below.

Reviewers' comments:

Reviewer #3:

Q: Evaluating facial mimicry is interesting and the prospective approach used by the authors is commendable. However, there are major problems with the study design and interpretation of the results.

The authors have implemented a prospective study protocol to evaluate changes in mimicry following orthognathic surgery of Cl III patients compared with a normal study population.

The major problem with this study is the lack of power as addressed in the first peer review by reviewer 2 along with errors in interpreting the statistical analysis of the results.

Regarding insufficient power of the study: I cannot see any rationale for enrolling 20 patients instead of 30, 40 or 10? There were no power calculation and therefore we must assume, that the authors have enrolled 20 patients because previous studies have done the same regardless of differences in study hypothesis, design and fluctuations in surgical complexity, which could influence variance in the sample. How was the sample of 20 patients derived?

A: According to the suggestion of the Editor in Chief, we acknowledge the precious comments of the reviewer, and we will attentively consider them for future studies.

Q: Regarding interpretation of non-significant result: The authors have interpreted the non-significant p-value as a confirmation of the null-hypothesis instead of saying the study failed to reject the null-hypothesis. Interpreting a non-significant p-value as a confirmation of the null-hypothesis is wrong and it is one of the most common errors encountered in interpreting statistical analysis. A non-significant p-value simply states that the null-hypothesis could not be rejected, but cannot be used to confirm that the null-hypothesis is true, since non-significant results can also be a result of insignificant power, small mean differences or large variations in the cohorts. This will be supported in any statistical book on interpreting non-significant p-values. Did the authors use professional statistical assistance?

A: Thank you for your helpful considerations, we made some modifications to the text, including our null hypothesis.

Q: I believe that the authors are trying to perform an equivalence or non-inferiority study, where a threshold for acceptable difference must be defined and the relevant testing performed (Relevant article link: https://www.ncbi.nlm.nih.gov/pubmed/18537788). Please note that a non-inferiority studies also requires a sample size estimation before the study is initiated and often requires more power than standard "superiority" studies.

Alternatively, the results from this study may be used in a case-control study instead. Since the authors have already performed studies on control subjects, then each of the study patients can be matched with 1, 2 or 3 controls regarding gender, age and other confounding factors. Thereby, the results from this study can be used to more appropriately analyze the study question. If this study design is chosen, please present the control cohort in a similar manner as the study cohort.

A: According to the suggestion of the Editor in Chief, we acknowledge the precious comments of the reviewer, and we will attentively consider them for future studies.

Q: Some minor points of consideration regarding the manuscript:

The use of a control group was used too sparingly. Only briefly in the results was the control group mentioned, without referencing the magnitude of the difference. Please use the control group to highlight the differences/equivalence between test and control both in the result section, tables, and figures. Also, the control group was referred to in article 25 and 29, then later in the manuscript only article 25.

A: Data from the control group (both references 25 and 29, thank you for pointing out this missing information) were used to compute the z-scores, as written in the text. This was further explained in the text, figure legend and table footnotes.

Q: I have difficulties interpreting figure 2. In the text, the symmetry index ranges from 0% = complete asymmetry, to 100% = complete symmetry. In the figure, the SI starts from 0 (I interpret this as complete asymmetry in all patients) and rises to 25% before reclining to approx. 18%. To me, this seems as though there are serious asymmetries in the patient cohort, that could not be solved satisfactory.

A: Figure 2 shows z-scores, that is an indication of the difference between the patient and control values. The relevant legend has been modified to avoid any misunderstandings.

Reviewer #4:

Q: Interesting and well written article
A: Thank you for your kind words.

Reviewer #5: Summary

The paper uses appropriate statistical methods to analyse the data, and the results are clearly presented. Some revisions to the interpretation of the results are suggested.

Q: Major Point

1. The Abstract reads that "the mobility of the buccal soft tissues was somewhat larger 24 months after than before surgery". A similar conclusion is indicated in the Results section. Such a conclusion is not backed up by the results of the statistical analysis, which suggests no significant change in outcome between timepoints. Therefore, the study conclusions should be revised to match the findings of the data analysis.

A: Thank you for your useful suggestion, the text was modified accordingly.

Q: Minor Point

2. It is preferable to report the actual p-values for non-significant results, not just NS. This will allow the reader to judge if the results are not at all significant (e.g. p=0.99), or very close to significance (e.g. p=0.06).

A: Thank you for indicating this point, the text ns tables were modified as suggested.

3D LONGITUDINAL EVALUATION OF FACIAL MIMICRY IN ORTHOGNATHIC CLASS III SURGERY.

Federico Cullati[1,2,]*, Francesca M.E. Rusconi[1]*, Andrea Mapelli[1]*, Matteo Zago[1,3], Giada A. Beltramini[2,4], Aldo Bruno Giannì[2,4] (ORCID 0000-0002-5983-9674), Chiarella Sforza[1] (ORCID 0000-0001-6532-6464)

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* Drs Cullati, Rusconi and Mapelli equally contributed to this investigation

Research paper IJOMS-D-18-00154 submitted to the International Journal of Oral and Maxillofacial Surgery on 18 February 2018 – First revision 13 June 2018 – Second revision 12 August 2018

Number of Figures: 2

Number of Tables: 3

Running title: Facial mimicry after orthognathic surgery.

Key words: Orthognathic surgery; motion capture; mimicry.

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ABSTRACT

The effect of bimaxillary orthognathic surgery on facial mimicry was longitudinally assessed in 15 patients with dentoskeletal Class III facial dysmorphosis (7 men, 8 women, mean age 28 years). The patients were analyzed pre-surgery and 6, 12 and 24 months post-surgery while performing verbal (five vowels) and nonverbal (open andmouth smile, closed mouth smile, lip purse) soft-tissue facial movements. The 3D motions of right and left naso-genian, crista philtri, cheilion and lower lip landmarks were detected by an optoelectronic instrument, and a total mobility index was obtained. SideThe differences between sides wereas quantified by an index of symmetry. Patients values were compared to those previously collected in healthy volunteers by computing z-scores. On average, 24 months after surgery no significant differences were found in the mobility of the buccal soft tissues (ANOVA p values range 0.075-0.808), with positive median z-scores (pooled mean value close to 0.6). for all facial animations but lip purse and vowel /u/, the mobility of the buccal soft tissues was somewhat larger 24 months after than before surgery, and their median z-scores were positive (pooled mean value close to 0.6). No significant differences were found (ANOVA, p>0.05). Symmetry indices ranged around the control reference values, showing no stage-related differences (Friedman test p values range 0.252-0.937, p>0.05), and exceeding 90% for all movements 24 months after surgery. Bimaxillary osteotomy does not compromize facial mimicry, in both verbal and nonverbal facial movements.

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INTRODUCTION

Esthetics and expression are the features first noticed when looking at a face.. Both of them play a major role in our life because they can deeply influence the ability of social interaction[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 maxillary bones is an important aspect of communication: maxillo-mandibular dysmorphoses can seriously compromise mimicry and esthetics, requiring orthopedic or surgical treatments[8]. Among other abnormalities of jaw bones, Class III malocclusions are of great interest for their esthetic impact, even if their prevalence in the population is not high: Angle Class III malocclusion incidence ranges approximately from 5% in Caucasians and Iranians to 15% in Asian population, and it is associated to skeletal Class III in 58% to 70% of patients across races and sexes[9–12].

Functional and esthetic problems of Class III malocclusions involving only teeth positions can be treated by orthodontics; when also jaw bones dimension and position are 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 maxilla and mandible, correcting dimensional abnormalities or asymmetry, in order to achieve a functional occlusion and a better esthetics[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 airways changes after orthognathic surgery, a few ones have analyzed changes in in verbal and nonverbal facial movements[16,20,21].

Johns et al.[20] evaluated the changes in muscular length after jaw bones osteotomy, showing how this can modify smile amplitude. They also assessed its effect on esthetics and suggested the need of a deeper pre-surgical analysis to predict its consequences on facial movements. More recently, Verzé et al. investigated the changes in facial nonverbal movements (smiling, frowning, grimace and lip purse): after some post-surgical altered activity, at one year follow up the patients recovered as they were before surgery[22]. In a longitudinal study with a one year follow-up, Al-Hiyali et al.[23] discovered that the correction of skeletal asymmetry can improve the symmetry of facial expressions, but investigations with a longer follow up are necessary.

The evaluation of mimicry changes is therefore increasingly prominent in orthognathic surgical planning, but the topic deems more detailed investigations with mid-term follows-up[24]. For instance, most investigations assessed only nonverbal animations[22,23], and did not test verbal movements. These last had been reported to be more reliable and reproducible[14,25-27].

Soft-tissue facial movements can be noninvasively captured and quantified by 3D motion analyzers[5,14,22,23,25-29]. Among others, optoelectronic motion systems offer a valuable support for extracting objective measurements by positioning markers in standardized anatomical points[23,27-31].

The aim of this longitudinal study is to analyze the pre-surgery versus post-surgery differences in verbal and nonverbal soft-tissue facial movements in a group of patients with dentoskeletal Class III, candidates to bimaxillary orthognathic surgery. We want to establish whether functional symmetry and movement balance of the lower two-thirds of the face changed after surgery, comparing our results to reference values obtained from healthy individuals[25,29]. Our null hypothesis is that bimaxillary orthognathic surgery does not change facial mimicry.

MATERIALS AND METHODS

Patients

From October 2013 until September 2016, 15 patients (7 men and 8 women, mean age 28 years, SD 4), natural speakers of Italian language, with a diagnosis of dento-skeletal Class III facial dysmorphosis, candidates to bimaxillary osteotomy at the Maxillo-Facial Surgery and Unit (Fondazione IRCCS Cà Granda Ospedale Maggiore Policlinico of Milan, University of Milan), were longitudinally evaluated.All patients were submitted to an Obwegeser/Dal Pont bilateral sagittal split osteotomy and a Le Fort I osteotomy. The direction and amount of movements performed on each patient, together with the anti-inflammatory and analgesic therapy and the postoperative physiotherapy, are detailed in Table 1. Intra-operative or post-operative complications were reported in six patients.

All patients were analyzed before and after surgery at six, 12 and 24 months 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 nonverbal activities were recorded using an optoelectronic three-dimensional motion analyzer (SMART-E, BTS, Garbagnate Milanese, Italy). To record lip movements[17,32-34], nine infrared sensitive CCD videocameras were deployed around a stool, and calibrated to create a 60 (width) cm x 60 (height) cm x 60 (depth) cm working volume; 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%[33]. A 60 Hz sampling ratio was used for all acquisitions.

Subjects sat on the stool inside the working volume and were asked to perform a series of standardized lip movements and speech pronunciation. During the execution of the movements, the cameras detected the positions of lightweight, 2-mm round, passive retro-reflective markers with 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 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 were carefully controlled to avoid any interference with lip and speech movements[32-36]. Subsequently, all the coordinates were converted to metric data, and a set of 3D coordinates for each landmark in each frame that constituted each movement was obtained.

The patients performed three standardized nonverbal 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 subjects, who practiced before data acquisition. For each animation, ten standardized maximum facial expressions from rest were made, without modifications of the markers positions[25,32,33,36-38].

For each subject, the recordings took approximately 30 minutes (considering also the time needed for subject's preparation). 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 completely described, written informed consent was obtained from each participant.

Data analysis

All buccal landmarks 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 nonverbal animations, and the magnitude of each 3D vector of maximum displacement from rest was calculated. A total mobility index was estimated as the sum of their maximum displacement. The difference between sides was quantified by an index of symmetry (SI), 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 set up in healthy subjects, intra-session technical error of single landmarks was smaller than 3.4 mm, while inter-session reproducibility of facial movements showed standard deviations lower than 1 mm[26].

Statistical analysis

For all subjects, the ten repetitions of verbal (vowels) and nonverbal (open and closed mouth smiles, lip purse) animations were averaged, and the mean value of each landmark's maximum displacements was used to compute the individual 3D total mobility and symmetry index for all pre- and post-surgery assessments.

Since no gender difference was previously observed in healthy subjects[25,33], male and female patients were pooled. Normality of data distribution was checked using the Kolmogorov-Smirnov test; several SI indices significantly deviated from normality. Therefore, mean and standard deviation (SD) were computed for Total mobility, and median and interquartile range (IQR) for SI. The four acquisitions were compared by repeated measures 1-way ANOVA for Total mobility and Friedman test for SI indices. The significance level was set at 5% for all analyses ($P<0.05$).

Patients' indices were also compared to those previously collected in 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 indicate that patients' values are overall smaller than the healthy reference mean values, while positive values indicate the opposite.

RESULTS

On average, for all verbal and nonverbal animations~~ but lip purse and vowel /u/~~, the mobility of the buccal soft tissues was similar before surgery and ~~larger~~ 24 months after surgery~~ than before surgery~~ (Table 2a, b). The~~, and their~~ median z-scores (difference relative to control subjects) were positive, with ~~reaching~~ a medianan~~an~~ value close~~d~~ to 0.6 when all animations were pooled (Figure 2). A large inter individual variability was found, without significant differences (ANOVA, p values range 0.075-0.808~~p > 0.05 in all occasions~~).

For closed mouth smile, on average performances ~~were lower than in healthy reference subjects before surgery and higher~~ increased 2 years after surgery. The mean increment was around 1 cm, being 12 of 15 patients able to improve their performance; only patient F8 had a decrement larger than 25%. The mean relative increment of the mobility was 19.7% (SD, 23%), with six patients (F2, F3, F7, M1, M4, M5) showing increments larger than 30% (highest increase, 62%).

For open mouth smile, ~~on average pre-surgical values were larger than in reference subjects;~~ 2 years after surgery~~,~~ patient M4 showed a relative increment of mobility larger than 30%. Before surgery, mobility during the performance of lip purse was superimposable in patients and reference subjects, it decreased during the post-surgical follow-up, with a final median z-score of -0.21.

For verbal animations, patients progressively increased their performances during the observation period, with final median z-scores ranging from 0.53 (/a/) to 1.22 (/i/). On average, the largest percentage increment was found for vowel /o/, with six patients out of 15 recording an increment larger 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 values range 0.252-0.937~~all values > 0.05~~) and exceeding 90% of symmetry for all verbal and nonverbal animations 2 years after surgery (Table 3a, b).

DISCUSSION

Mimicry is a critical factor that can influence both esthetic and 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 analyzed 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 the patients, who sought not only to recover a compromised function, but mostly to improve their appearance. As mimicry can modify facial esthetics, its post-surgical modifications, become a factor of primary interest for treatment planning. Literature underlines the need to study both verbal ~~–~~(vocals) and nonverbal (smiles, lip purse) facial movements: verbal movements should possess major reproducibility, being more natural and easy to perform; nonverbal ones give more realistic results of the evaluated performances[5–7,25,27].

In this study both the global esthetics and the motor function of mimic muscles were evaluated using respectively the symmetry index and the average mobility. Open mouth smile and vowel /a/ where performed with the widest 24-months total mobility, in accord 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 movement produced around the temporomandibular joint by masticatory muscles.

In their early post-surgery time, subjects treated for an Angle Class III malocclusion have been found to present a reduced vertical movements of the upper lip together with reduced lateral cheek movements. The frontal projection of the lower lip was reduced (perhaps a direct consequence of surgical movements) while the frontal projections of cheeks, labial commissures and soft tissues of the chin were increased[39]. In their pre-surgery assessments, the same subjects had greater vertical translation during lip protrusion and a greater lateral movement of the cheeks, with values higher than those of the control group. For these movements, our study reached rather overlapping results, with similar variations of their median z-score for vowel /i/ (Table 2b).

As regards facial mobility, we found no significant variations during the 24 months follow-up~~a fairly good overall improvement trend at 24 months~~ in all studied facial animations. Nonetheless, in most verbal ~~, except lip protrusion and vowel /u/. In all the other~~ animations (except vowel /u/) and in~~, and especially in~~ the smile~~nonverbal~~ ones, total mobility between 6 and 12 months after surgery showed a sharp increase and then returned to values similar to the pre-surgical ones in the 24 months evaluation. Literature reported considerable increases in bilateral mimic mobility 6 months after a bimaxillary osteotomy for Class III malocclusion: the surgical repositioning of the maxilla anteriorly and inferiorly stretches the mimic musculature, leading to larger facial movements, particularly evident during smile[20]. Similar findings were reported by Verzè et al.[22] 12 months after surgery. Additional elements that could affect facial mobility are the mechanical forces acting on soft tissues during surgery, when tractions, divarications and tissue manipulations lead to an increase in laxity and a greater degree of freedom of mimic muscles movements. This situation seems to last for the whole period in which the intervention area remains edematous and locally traumatized: up to 12 months according to Proffit et al.[40].

Considering individual results, after a massive surgical bone repositioning, the best 24-months improvements were observed in patient F3, who had increments in facial mobility for all animations up to

220% (/e/). Six patients had intra-operative or post-operative complications (Table 1). Patient F2 lamented 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 had increments in all three nonverbal animations (up to 42%).

Patient F8 had decrements in both closed mouth smile and lip purse (-25%), and vowel /u/ (approx. -45%). Her surgical treatment did not need large mandibular and maxillary movements but included genioplasty, and unfortunately she had a complication in her left side sagittal split osteotomy: both factors may had influenced the final mimicry result that was successful for the other vocals.

Also patient F5 underwent genioplasty; additionally, after surgery she had a temporary inferior alveolar nerve hypoesthesia and cervical pain. Physiotherapy sessions were included in her treatment. Overall, her 24-months mimicry 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 vowels pronunciations, M2 had a very successful outcome, with increments in all animations (up to +100%, vowel /u/) except open mouth smile (no variation). This patient underwent the largest mandibular set-back of the group.

Patient M6 had a severe bleeding after his Le Fort I osteotomy: even after 24 months his facial mobility for vowels pronunciations was impaired, with reductions up to 69% (vowels /e/, /u/). After undergoing the second largest mandibular set-back of the group, also patient M4 underwent physiotherapy sessions but mostly for professional reasons (water polo professional player); he regained his full facial mobility with improvements larger than 60% (closed smiles, /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 smiles, lip purse, vowels /e/ and /u/ were smaller than those recorded before surgery (up to -38%). Also patient F6 had 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 is the possibility to perform a global quantitative analysis of the impact on facial mimicry of orthognathic surgery. A final post-surgical observation period of 24 months seems to be adequate as the result of a good compromise between the time needed for soft tissue stabilization in the new skeletal balance and patient's compliance to the study. On average, the mobility of the buccal soft tissues was ~~larger~~ similar 24 months after surgery than before surgery, with ~~and their median z-scores were~~ positive median z-scores. ~~; for some movements (closed mouth smile, vowel /u/) performances were lower than in healthy reference subjects before surgery but became higher 2 years after surgery.~~ The only movement that had a reduced~~worsened its~~ performance at the final follow up examination was lip purse.~~-~~ In the different examined facial animations, the symmetry index objectified a common and shared well balanced motion of the facial muscles 24 months after surgery. Both the increased asymmetry in the intermediate follow-up examinations, and final average symmetry values, appear to perfectly fit within the normal range obtained in previous studies[22,23,29].

Nonetheless, inter-patient variability was high, and the present observations were not coupled with statistically significant differences; therefore, we could not reject our null hypothesis. In general, the worst 24-months mimicry performances were found in patients who had some 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 and amplitude of 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.

Some limitations should be noticed: the reduced number of examined patients may have a role in the lack of significant differences, and even if similar sample sizes were reported by other investigations[20,22,23], we should recruit additional subjects in our protocol. This may allow to better understand the relationships between clinical findings and mimicry assessments. Furthermore, we focused our analysis on landmark movements, while all 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 compromize facial mimicry, in both verbal and nonverbal facial movements. Optoelectronic motion capture systems can support the surgeon during the diagnosis and treatment planning, helping in a more customized therapy to improve the quality of life of patients with dysfunctional problems.

Conflict of interest

The authors have no conflict of interest to declare.

Role of the funding source

No funding sources.

Ethics

The investigation complies 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 by the 64th World Medical Assembly, Fontaleza, Brazil, October 2013.

Ethical approval obtained by Fondazione IRCCS Ca' Granda Ospedale Maggiore Policlinico di Milano, Milan, Italy #843 03 April 2012

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Figure legends

Figure 1. Experimental set up and position of the facial landmarks. The cameras surround the head of the subject and the working volume is shown.

Figure 2. Median z-scores pooled for all facial animations before surgery and during post surgery follow-up. The z-scores were computed using reference data[25,29] as patient value minus reference mean value divided by the relevant standard deviation.

P6, P12, P24 indicate 6, 12, 24 months after surgery.

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Table 1. Surgical interventions and clinical information for the 15 analyzed Class III patients.

Patient	Age (y)	Surgical techniques	Maxillary movements	Mandibular movements	Anti-inflammatory and Analgesic therapy	Corticosteroid therapy	Intra- /Post-operative Complications	Post-operative Physiotherapy
F1	34	BSSO+Le FI	Advancement: 3.0 mm Impaction: 2.6 mm	Impaction: 4.9 mm Rotation: 1.0 mm left	**P** 3 times/day for 2 days then once for 2 days; **K** twice for 1 day then once for 2 days	**D** 4 mg twice for 1 day then once for 1 day	Temporary (2 months) left IAN hypoesthesia	-
F2	24	BSSO+Le FI	Advancement: 5.1 mm Rotation: 1.7 mm left	Impaction: 0.8 mm Rotation: 5.0 mm left Set back: 2.8 mm	**P** twice for 4 days then once for 2 days; **K** twice for 2 day then once for 2 days	**D** 4 mg twice for 1 day then once for 1 day	Right TMJ disorder	N°10 physiotherapy sessions in first 6 post-operative weeks
F3	28	BSSO+Le FI	Advancement: 4.0 mm Impaction: 2.9 mm Rotation: 1.2 mm left	Impaction: 6.4 mm Rotation: 1.6 mm left Set back: 2.6 mm	**P** 3 times/day for 1 day then once for 3 days; **K** once for 1 day	**D** 4 mg twice for 1 day then once for 1 day	-	-
F4	26	BSSO+Le FI	Advancement: 4.3 mm Impaction: 0.2 mm	Advancement: 3.4 mm Impaction: 0.7 mm Rotation: 0.6 mm right	**P** twice for 2 days then once for 2 days; **K** once for 3 days	**D** 4 mg twice for 1 day then once for 1 day	-	-
M1	28	BSSO+Le FI	Advancement: 4.1 mm Impaction: 1.9 mm	Advancement: 0.5 mm Impaction: 3.1 mm Rotation: 3.0 mm left	**P** 3 times/day for 3 days then once for 2 days; **K** twice for 2 days then once for 2 days	**D** 8 mg twice for 1 day then 4 mg twice for 1 day then once for 1 day	-	-
F5	29	BSSO+Le FI + 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** 3 times/day for 2 days then once for 2 days; **K** twice for 1 day then once for 2 days	**D** 4 mg twice for 1 day then once for 1 day	Temporary (8 months) bilateral IAN hypoesthesia	N°4 physiotherapy sessions in first 4 post-operative weeks
F6	21	BSSO+Le FI+ genioplasty	Advancement: 2.0 mm Impaction: 2.0 mm	Impaction: 3.5 mm Rotation: 0.5 mm left Set back: 1.6 mm	**P** twice for 3 days then once for 1 day; **K** once for 3 days	**D** 4 mg twice for 1 day then once for 1 day	-	-
F7	23	BSSO+Le FI	Impaction: 0.8 mm Rotation: 3.2 mm left	Impaction: 3.0 mm Rotation: 3.1 mm left Set back: 2.7 mm	**P** twice for 3 days then once for 2 days	**D** 4 mg twice for 1 day then once for 1 day	-	-
M2	30	BSSO+Le FI	Advancement: 3.4 mm Rotation: 1.6 mm left	Rotation: 2.3 mm right Set back: 7.0 mm	**P** 3 times/day for 1 day then twice for 2 days; **K** twice for 1 day then once for 2 days	**D** 8 mg twice for 1 day then 4 mg twice for 1 day then once for 1 day	Temporary (6 months) left IAN hypoesthesia	-
M3	25	BSSO+Le FI	Advancement: 4.1 mm	Impaction: 1.8 mm Rotation: 2.0 mm left Setback: 0.8 mm	**P** 3 times/day for 2 days then once for 2 days; **K** once for 2 days	**D** 8 mg twice for 1 day then 4 mg twice for 1 day then once for 1 day	-	-
F8	26	BSSO+Le FI+ genioplasty	Advancement: 2.7 mm Impaction: 0.6 mm	Rotation: 0.6 mm right Setback: 1.5 mm	**P** twice for 3 days then once for 3 days; **K** twice for 3 days then once for 2 days	**D** 4 mg twice for 1 day then once for 1 day	Left bad split in SSO	-
M4	34	BSSO+Le FI	Advancement: 2.1 mm Rotation: 1.3 mm left	Impaction: 0.5 mm Rotation: 1.4 mm right Set back: 5.8 mm	**P** 3 times/day for 3 days then once for 2 days; **K** twice for 2 days then once for 2 days	**D** 8 mg twice for 1 day then 4 mg twice for 1 day then once for 1 day	-	N°5 physiotherapy sessions in first 4 post-operative weeks
M5	33	BSSO+Le FI	Advancement: 4.3 mm Impaction: 2.0 mm	Impaction: 2.6 mm Rotation: 2.4 mm right Setback: 1.4 mm	**P** 3 times/day for 1 day then twice for 2 days; **K** once for 1 day	**D** 8 mg twice for 1 day then 4 mg twice for 1 day then once for 1 day	-	-
M6	30	BSSO+Le FI	Advancement: 3.1 mm Rotation: 1.4 mm left	Impaction: 1.9 mm Rotation: 4.3 mm right Set back: 3.4 mm	**P** 3 times/day for 1 day then once for 2 days	**D** 8 mg twice for 1 day then 4 mg twice for 1 day then once for 1 day	Le Fort I osteotomy severe bleeding	-
M7	23	BSSO+Le FI	Advancement: 3.0 mm Impaction: 0.2 mm Rotation: 1.7 mm left	Impaction: 1.6 mm Setback: 2.8 mm	**P** twice for 2 days then once for 2 days; **K** once for 2 days	**D** 8 mg twice for 1 day then 4 mg twice for 1 day then once for 1 day	-	-

Age at surgery.
BSSO+Le FI: Obwegeser/Dal Pont bilateral sagittal split osteotomy and Le Fort I osteotomy.
P, Paracetamol 1000 mg, intravenous; **K,** Ketorolac Tromethamine 30 mg, intravenous; **D,** Dexamethasone 8 mg or 4 mg, intravenous; TMJ: temporomandibular joint; IAN, inferior alveolar nerve

Table 2a. 3D total labial mobility before surgery and during post surgery follow-up in nonverbal animations.

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 (ANOVA)	~~NS~~0.808				0.189~~NS~~				0.356~~NS~~			
median z-score	0.50	0.79	0.43	0.57	-0.11	0.17	0.29	0.24	-0.06	-0.43	-0.41	-0.21

The z-scores were computed using reference data[25,29] as patient value minus reference mean value divided by the relevant standard deviation. P6, P12, P24 indicate 6, 12, 24 months after surgery

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~~NS, not significant, p > 0.05~~

Table 2b. 3D total labial mobility before surgery and during post surgery follow-up in verbal animations.

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	POST
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 (ANOVA)	~~NS~~0.642				~~NS~~0.463				~~NS~~0.428				~~NS~~0.075				~~NS~~0.605			
median z-score	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

P6, P12, P24 indicate 6, 12, 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. ~~NS, not significant, p > 0.05~~

Table 3a. 3D symmetry index before surgery and during post surgery follow-up in nonverbal animations.

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 (Friedman-test)	~~NS~~0.915				0.534~~NS~~				0.252~~NS~~			
median z-score	0.33	0.25	0.44	0.54	-0.29	-0.33	-0.11	0.08	-0.92	-0.30	-0.22	-0.50

IQR. interquartile range; P6, P12, P24 indicate 6, 12, 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. ~~NS, not significant, p > 0.05~~

Table 3b. 3D symmetry index before surgery and during post surgery follow-up in verbal animations.

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 (Friedman-test)	NS0.553				0.937NS				0.492NS				0.661NS				NS0.661			
median z-score	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

IQR. interquartile range; P6, P12, P24 indicate 6, 12, 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. NS, not significant, $p > 0.05$

3D 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 longitudinally assessed in 15 patients with dentoskeletal Class III facial dysmorphosis (7 men, 8 women, mean age 28 years). The patients were analyzed pre-surgery and 6, 12 and 24 months post-surgery while performing verbal (five vowels) and nonverbal (open and closed mouth smile, lip purse) soft-tissue facial movements. The 3D motions of right and left naso-genian, crista philtri, cheilion and lower lip landmarks were detected by an optoelectronic instrument, and a total mobility index was obtained. Side differences were quantified by an index of symmetry. Patients values were compared to those previously collected in healthy volunteers by computing z-scores. On average, 24 months after surgery no significant differences were found in the mobility of the buccal soft tissues (ANOVA p values 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 values range 0.252-0.937), and exceeding 90% for all movements 24 months after surgery. Bimaxillary osteotomy does not compromize facial mimicry, in both verbal and nonverbal facial movements.

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INTRODUCTION

Esthetics and expression are the features first noticed when looking at a face. Both of them play a major role in our life because they can deeply influence the ability of social interaction[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 maxillary bones is an important aspect of communication: maxillo-mandibular dysmorphoses can seriously compromise mimicry and esthetics, requiring orthopedic or surgical treatments[8]. Among other abnormalities of jaw bones, Class III malocclusions are of great interest for their esthetic impact, even if their prevalence in the population is not high: Angle Class III malocclusion incidence ranges approximately from 5% in Caucasians and Iranians to 15% in Asian population, and it is associated to skeletal Class III in 58% to 70% of patients across races and sexes[9–12].

Functional and esthetic problems of Class III malocclusions involving only teeth positions can be treated by orthodontics; when also jaw bones dimension and position are 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 maxilla and mandible, correcting dimensional abnormalities or asymmetry, in order to achieve a functional occlusion and a better esthetics[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 airways changes after orthognathic surgery, a few ones have analyzed changes in verbal and nonverbal facial movements[16,20,21].

Johns et al.[20] evaluated the changes in muscular length after jaw bones osteotomy, showing how this can modify smile amplitude. They also assessed its effect on esthetics and suggested the need of a deeper pre-surgical analysis to predict its consequences on facial movements. More recently, Verzé et al. investigated the changes in facial nonverbal movements (smiling, frowning, grimace and lip purse): after some post-surgical altered activity, at one year follow up the patients recovered as they were before surgery[22]. In a longitudinal study with a one year follow-up, Al-Hiyali et al.[23] discovered that the correction of skeletal asymmetry can improve the symmetry of facial expressions, but investigations with a longer follow up are necessary.

The evaluation of mimicry changes is therefore increasingly prominent in orthognathic surgical planning, but the topic deems more detailed investigations with mid-term follows-up[24]. For instance, most investigations assessed only nonverbal animations[22,23], and did not test verbal movements. These last had been reported to be more reliable and reproducible[14,25-27].

Soft-tissue facial movements can be noninvasively captured and quantified by 3D motion analyzers[5,14,22,23,25-29]. Among others, optoelectronic motion systems offer a valuable support for extracting objective measurements by positioning markers in standardized anatomical points[23,27-31].

The aim of this longitudinal study is to analyze the pre-surgery versus post-surgery differences in verbal and nonverbal soft-tissue facial movements in a group of patients with dentoskeletal Class III, candidates to bimaxillary orthognathic surgery. We want to establish whether functional symmetry and movement balance of the lower two-thirds of the face changed after surgery, comparing our results to reference values obtained from healthy individuals[25,29]. Our null hypothesis is that bimaxillary orthognathic surgery does not change facial mimicry.

MATERIALS AND METHODS

Patients

From October 2013 until September 2016, 15 patients (7 men and 8 women, mean age 28 years, SD 4), natural speakers of Italian language, with a diagnosis of dento-skeletal Class III facial dysmorphosis, candidates to bimaxillary osteotomy at the Maxillo-Facial Surgery and Unit (Fondazione IRCCS Cà Granda Ospedale Maggiore Policlinico of Milan, University of Milan), were longitudinally evaluated.All patients were submitted to an Obwegeser/Dal Pont bilateral sagittal split osteotomy and a Le Fort I osteotomy. The direction and amount of movements performed on each patient, together with the anti-inflammatory and analgesic therapy and the postoperative physiotherapy, are detailed in Table 1. Intra-operative or post-operative complications were reported in six patients.

All patients were analyzed before and after surgery at six, 12 and 24 months 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 nonverbal activities were recorded using an optoelectronic three-dimensional motion analyzer (SMART-E, BTS, Garbagnate Milanese, Italy). To record lip movements[17,32-34], nine infrared sensitive CCD videocameras were deployed around a stool, and calibrated to create a 60 (width) cm x 60 (height) cm x 60 (depth) cm working volume; 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%[33]. A 60 Hz sampling ratio was used for all acquisitions.

Subjects sat on the stool inside the working volume and were asked to perform a series of standardized lip movements and speech pronunciation. During the execution of the movements, the cameras detected the positions of lightweight, 2-mm round, passive retro-reflective markers with 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 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 were carefully controlled to avoid any interference with lip and speech movements[32-36]. Subsequently, all the coordinates were converted to metric data, and a set of 3D coordinates for each landmark in each frame that constituted each movement was obtained.

The patients performed three standardized nonverbal 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 subjects, who practiced before data acquisition. For each animation, ten standardized maximum facial expressions from rest were made, without modifications of the markers positions[25,32,33,36-38].

For each subject, the recordings took approximately 30 minutes (considering also the time needed for subject's preparation). 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 completely described, written informed consent was obtained from each participant.

Data analysis

All buccal landmarks 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 nonverbal animations, and the magnitude of each 3D vector of maximum displacement from rest was calculated. A total mobility index was estimated as the sum of their maximum displacement. The difference between sides was quantified by an index of symmetry (SI), 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 set up in healthy subjects, intra-session technical error of single landmarks was smaller than 3.4 mm, while inter-session reproducibility of facial movements showed standard deviations lower than 1 mm[26].

Statistical analysis

For all subjects, the ten repetitions of verbal (vowels) and nonverbal (open and closed mouth smiles, lip purse) animations were averaged, and the mean value of each landmark's maximum displacements was used to compute the individual 3D total mobility and symmetry index for all pre- and post-surgery assessments.

Since no gender difference was previously observed in healthy subjects[25,33], male and female patients were pooled. Normality of data distribution was checked using the Kolmogorov-Smirnov test; several SI indices significantly deviated from normality. Therefore, mean and standard deviation (SD) were computed for Total mobility, and median and interquartile range (IQR) for SI. The four acquisitions were compared by repeated measures 1-way ANOVA for Total mobility and Friedman test for SI indices. The significance level was set at 5% for all analyses ($P<0.05$).

Patients' indices were also compared to those previously collected in 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 indicate that patients' values are overall smaller than the healthy reference mean values, while positive values indicate the opposite.

RESULTS

On average, for all verbal and nonverbal animations, the mobility of the buccal soft tissues was similar before surgery and 24 months after surgery (Table 2a, b). The median z-scores (difference relative to control subjects) were positive, with a median value close to 0.6 when all animations were pooled (Figure 2). A large inter individual variability was found, without significant differences (ANOVA, p values range 0.075-0.808).

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

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

For verbal animations, patients progressively increased their performances during the observation period, with final median z-scores ranging from 0.53 (/a/) to 1.22 (/i/). On average, the largest percentage increment was found for vowel /o/, with six patients out of 15 recording an increment larger 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 values range 0.252-0.937) and exceeding 90% of symmetry for all verbal and nonverbal animations 2 years after surgery (Table 3a, b).

DISCUSSION

Mimicry is a critical factor that can influence both esthetic and 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 analyzed 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 the patients, who sought not only to recover a compromised function, but mostly to improve their appearance. As mimicry can modify facial esthetics, its post-surgical modifications, become a factor of primary interest for treatment planning. Literature underlines the need to study both verbal (vocals) and nonverbal (smiles, lip purse) facial movements: verbal movements should possess major reproducibility, being more natural and easy to perform; nonverbal ones give more realistic results of the evaluated performances[5–7,25,27].

In this study both the global esthetics and the motor function of mimic muscles were evaluated using respectively the symmetry index and the average mobility. Open mouth smile and vowel /a/ where performed with the widest 24-months total mobility, in accord 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 movement produced around the temporomandibular joint by masticatory muscles.

In their early post-surgery time, subjects treated for an Angle Class III malocclusion have been found to present a reduced vertical movements of the upper lip together with reduced lateral cheek movements. The frontal projection of the lower lip was reduced (perhaps a direct consequence of surgical movements) while the frontal projections of cheeks, labial commissures and soft tissues of the chin were increased[39]. In their pre-surgery assessments, the same subjects had greater vertical translation during lip protrusion and a greater lateral movement of the cheeks, with values higher than those of the control group. For these movements, our study reached rather overlapping results, with similar variations of their median z-score for vowel /i/ (Table 2b).

As regards facial mobility, we found no significant variations during the 24 months follow-up in all studied facial animations. 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 returned to values similar to the pre-surgical ones in the 24 months evaluation. Literature reported considerable increases in bilateral mimic mobility 6 months after a bimaxillary osteotomy for Class III malocclusion: the surgical repositioning of the maxilla anteriorly and inferiorly stretches the mimic musculature, leading to larger facial movements, particularly evident during smile[20]. Similar findings were reported by Verzè et al.[22] 12 months after surgery. Additional elements that could affect facial mobility are the mechanical forces acting on soft tissues during surgery, when tractions, divarications and tissue manipulations lead to an increase in laxity and a greater degree of freedom of mimic muscles movements. This situation seems to last for the whole period in which the intervention area remains edematous and locally traumatized: up to 12 months according to Proffit et al.[40].

Considering individual results, after a massive surgical bone repositioning, the best 24-months improvements were observed in patient F3, who had increments in facial mobility for all animations up to 220% (/e/). Six patients had intra-operative or post-operative complications (Table 1). Patient F2 lamented 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 had increments in all three nonverbal animations (up to 42%).

Patient F8 had decrements in both closed mouth smile and lip purse (-25%), and vowel /u/ (approx. -45%). Her surgical treatment did not need large mandibular and maxillary movements but included genioplasty, and unfortunately she had a complication in her left side sagittal split osteotomy: both factors may had influenced the final mimicry result that was successful for the other vocals.

Also patient F5 underwent genioplasty; additionally, after surgery she had a temporary inferior alveolar nerve hypoesthesia and cervical pain. Physiotherapy sessions were included in her treatment. Overall, her 24-months mimicry 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 vowels pronunciations, M2 had a very successful outcome, with increments in all animations (up to +100%, vowel /u/) except open mouth smile (no variation). This patient underwent the largest mandibular set-back of the group.

Patient M6 had a severe bleeding after his Le Fort I osteotomy: even after 24 months his facial mobility for vowels pronunciations was impaired, with reductions up to 69% (vowels /e/, /u/). After undergoing the second largest mandibular set-back of the group, also patient M4 underwent physiotherapy sessions but mostly for professional reasons (water polo professional player); he regained his full facial mobility with improvements larger than 60% (closed smiles, /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 smiles, lip purse, vowels /e/ and /u/ were smaller than those recorded before surgery (up to -38%). Also patient F6 had 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 is the possibility to perform a global quantitative analysis of the impact on facial mimicry of orthognathic surgery. A final post-surgical observation period of 24 months seems to be adequate as the result of a good compromise between the time needed for soft tissue stabilization in the new skeletal balance and patient’s compliance to the study. On average, the mobility of the buccal soft tissues was similar 24 months after surgery than 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 examined facial animations, the symmetry index objectified a common and shared well balanced motion of the facial muscles 24 months after surgery. Both the increased asymmetry in the intermediate follow-up examinations, and final average symmetry values, appear to perfectly fit within the normal range obtained in previous studies[22,23,29].

Nonetheless, inter-patient variability was high, and the present observations were not coupled with statistically significant differences; therefore, we could not reject our null hypothesis. In general, the worst 24-months mimicry performances were found in patients who had some 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 and amplitude of 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.

Some limitations should be noticed: the reduced number of examined patients may have a role in the lack of significant differences, and even if similar sample sizes were reported by other investigations[20,22,23], we should recruit additional subjects in our protocol. This may allow to better understand the relationships between clinical findings and mimicry assessments. Furthermore, we focused our analysis on landmark movements, while all 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 compromize facial mimicry, in both verbal and nonverbal facial movements. Optoelectronic motion capture systems can support the surgeon during the diagnosis and treatment planning, helping in a more customized therapy to improve the quality of life of patients with dysfunctional problems.

Conflict of interest

The authors have no conflict of interest to declare.

Role of the funding source

No funding sources.

Ethics

The investigation complies 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 by the 64th World Medical Assembly, Fontaleza, Brazil, October 2013.

Ethical approval obtained by Fondazione IRCCS Ca' Granda Ospedale Maggiore Policlinico di Milano, Milan, Italy #843 03 April 2012

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Figure legends

Figure 1. Experimental set up and position of the facial landmarks. The cameras surround the head of the subject and the working volume is shown.

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

Table 1. Surgical interventions and clinical information for the 15 analyzed Class III patients.

Patient	Age (y)	Surgical techniques	Maxillary movements	Mandibular movements	Anti-inflammatory and Analgesic therapy	Corticosteroid therapy	Intra- /Post-operative Complications	Post-operative Physiotherapy
F1	34	BSSO+Le FI	Advancement: 3.0 mm Impaction: 2.6 mm	Impaction: 4.9 mm Rotation: 1.0 mm left	**P** 3 times/day for 2 days then once for 2 days; **K** twice for 1 day then once for 2 days	**D** 4 mg twice for 1 day then once for 1 day	Temporary (2 months) left IAN hypoesthesia	-
F2	24	BSSO+Le FI	Advancement: 5.1 mm Rotation: 1.7 mm left	Impaction: 0.8 mm Rotation: 5.0 mm left Set back: 2.8 mm	**P** twice for 4 days then once for 2 days; **K** twice for 2 day then once for 2 days	**D** 4 mg twice for 1 day then once for 1 day	Right TMJ disorder	N°10 physiotherapy sessions in first 6 post-operative weeks
F3	28	BSSO+Le FI	Advancement: 4.0 mm Impaction: 2.9 mm Rotation: 1.2 mm left	Impaction: 6.4 mm Rotation: 1.6 mm left Set back: 2.6 mm	**P** 3 times/day for 1 day then once for 3 days; **K** once for 1 day	**D** 4 mg twice for 1 day then once for 1 day	-	-
F4	26	BSSO+Le FI	Advancement: 4.3 mm Impaction: 0.2 mm	Advancement: 3.4 mm Impaction: 0.7 mm Rotation: 0.6 mm right	**P** twice for 2 days then once for 2 days; **K** once for 3 days	**D** 4 mg twice for 1 day then once for 1 day	-	-
M1	28	BSSO+Le FI	Advancement: 4.1 mm Impaction: 1.9 mm	Advancement: 0.5 mm Impaction: 3.1 mm Rotation: 3.0 mm left	**P** 3 times/day for 3 days then once for 2 days; **K** twice for 2 days then once for 2 days	**D** 8 mg twice for 1 day then 4 mg twice for 1 day then once for 1 day	-	-
F5	29	BSSO+Le FI + 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** 3 times/day for 2 days then once for 2 days; **K** twice for 1 day then once for 2 days	**D** 4 mg twice for 1 day then once for 1 day	Temporary (8 months) bilateral IAN hypoesthesia	N°4 physiotherapy sessions in first 4 post-operative weeks
F6	21	BSSO+Le FI+ genioplasty	Advancement: 2.0 mm Impaction: 2.0 mm	Impaction: 3.5 mm Rotation: 0.5 mm left Set back: 1.6 mm	**P** twice for 3 days then once for 1 day; **K** once for 3 days	**D** 4 mg twice for 1 day then once for 1 day	-	-
F7	23	BSSO+Le FI	Impaction: 0.8 mm Rotation: 3.2 mm left	Impaction: 3.0 mm Rotation: 3.1 mm left Set back: 2.7 mm	**P** twice for 3 days then once for 2 days	**D** 4 mg twice for 1 day then once for 1 day	-	-
M2	30	BSSO+Le FI	Advancement: 3.4 mm Rotation: 1.6 mm left	Rotation: 2.3 mm right Set back: 7.0 mm	**P** 3 times/day for 1 day then twice for 2 days; **K** twice for 1 day then once for 2 days	**D** 8 mg twice for 1 day then 4 mg twice for 1 day then once for 1 day	Temporary (6 months) left IAN hypoesthesia	-
M3	25	BSSO+Le FI	Advancement: 4.1 mm	Impaction: 1.8 mm Rotation: 2.0 mm left Setback: 0.8 mm	**P** 3 times/day for 2 days then once for 2 days; **K** once for 2 days	**D** 8 mg twice for 1 day then 4 mg twice for 1 day then once for 1 day	-	-
F8	26	BSSO+Le FI+ genioplasty	Advancement: 2.7 mm Impaction: 0.6 mm	Rotation: 0.6 mm right Setback: 1.5 mm	**P** twice for 3 days then once for 3 days; **K** twice for 3 days then once for 2 days	**D** 4 mg twice for 1 day then once for 1 day	Left bad split in SSO	-
M4	34	BSSO+Le FI	Advancement: 2.1 mm Rotation: 1.3 mm left	Impaction: 0.5 mm Rotation: 1.4 mm right Set back: 5.8 mm	**P** 3 times/day for 3 days then once for 2 days; **K** twice for 2 days then once for 2 days	**D** 8 mg twice for 1 day then 4 mg twice for 1 day then once for 1 day	-	N°5 physiotherapy sessions in first 4 post-operative weeks
M5	33	BSSO+Le FI	Advancement: 4.3 mm Impaction: 2.0 mm	Impaction: 2.6 mm Rotation: 2.4 mm right Setback: 1.4 mm	**P** 3 times/day for 1 day then twice for 2 days; **K** once for 1 day	**D** 8 mg twice for 1 day then 4 mg twice for 1 day then once for 1 day	-	-
M6	30	BSSO+Le FI	Advancement: 3.1 mm Rotation: 1.4 mm left	Impaction: 1.9 mm Rotation: 4.3 mm right Set back: 3.4 mm	**P** 3 times/day for 1 day then once for 2 days	**D** 8 mg twice for 1 day then 4 mg twice for 1 day then once for 1 day	Le Fort I osteotomy severe bleeding	-
M7	23	BSSO+Le FI	Advancement: 3.0 mm Impaction: 0.2 mm Rotation: 1.7 mm left	Impaction: 1.6 mm Setback: 2.8 mm	**P** twice for 2 days then once for 2 days; **K** once for 2 days	**D** 8 mg twice for 1 day then 4 mg twice for 1 day then once for 1 day	-	-

Age at surgery.

BSSO+Le FI: Obwegeser/Dal Pont bilateral sagittal split osteotomy and Le Fort I osteotomy.

P, Paracetamol 1000 mg, intravenous; **K,** Ketorolac Tromethamine 30 mg, intravenous; **D,** Dexamethasone 8 mg or 4 mg, intravenous; TMJ: temporomandibular joint; IAN, inferior alveolar nerve

Table 2a. 3D total labial mobility before surgery and during post surgery follow-up in nonverbal animations.

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 (ANOVA)	0.808				0.189				0.356			
median z-score	0.50	0.79	0.43	0.57	-0.11	0.17	0.29	0.24	-0.06	-0.43	-0.41	-0.21

The z-scores were computed using reference data[25,29] as patient value minus reference mean value divided by the relevant standard deviation. P6, P12, P24 indicate 6, 12, 24 months after surgery

Table 2b. 3D total labial mobility before surgery and during post surgery follow-up in verbal animations.

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	POST
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 (ANOVA)	0.642				0.463				0.428				0.075				0.605			
median z-score	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

P6, P12, P24 indicate 6, 12, 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.

Table 3a. 3D symmetry index before surgery and during post surgery follow-up in nonverbal animations.

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 (Friedman-test)	0.915				0.534				0.252			
median z-score	0.33	0.25	0.44	0.54	-0.29	-0.33	-0.11	0.08	-0.92	-0.30	-0.22	-0.50

IQR. interquartile range; P6, P12, P24 indicate 6, 12, 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.

Table 3b. 3D symmetry index before surgery and during post surgery follow-up in verbal animations.

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 (Friedman-test)	0.553				0.937				0.492				0.661				0.661			
median z-score	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

IQR. interquartile range; P6, P12, P24 indicate 6, 12, 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.

Figure 1 color
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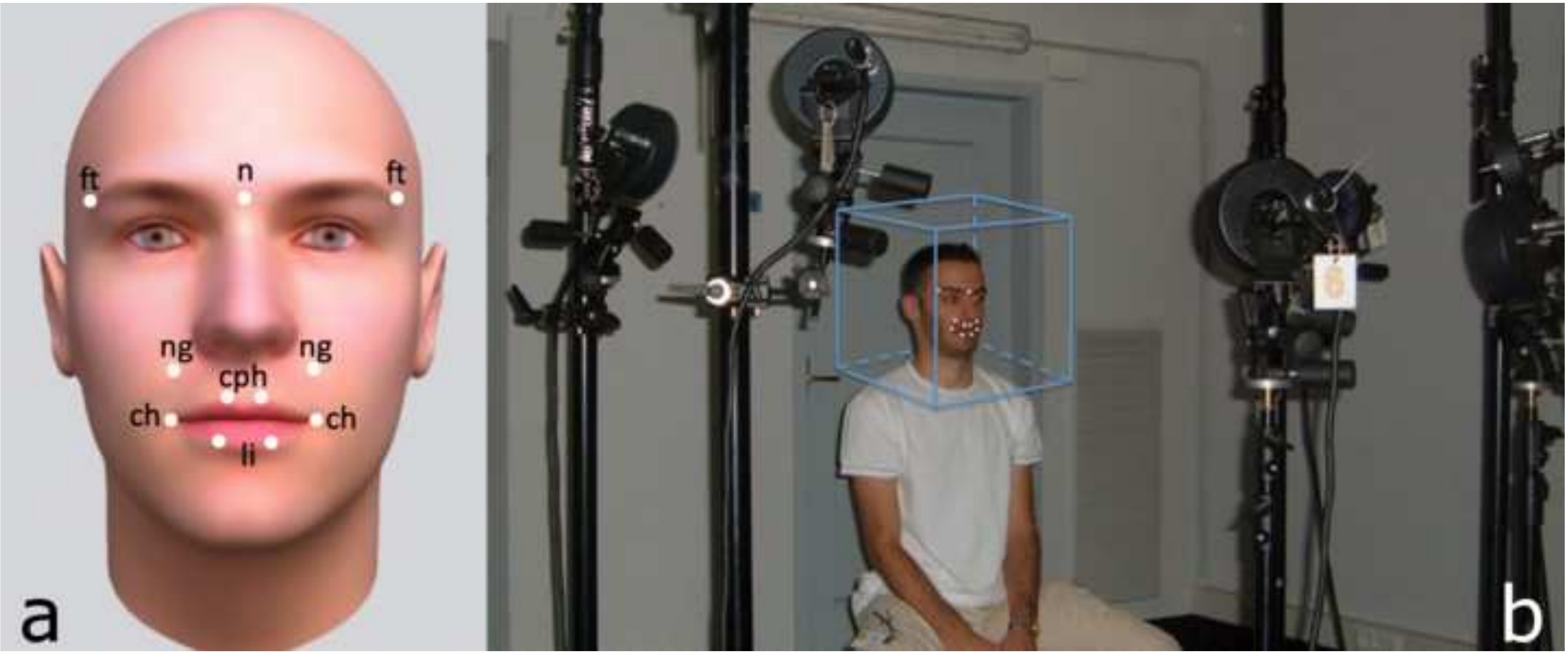

Figure 1 bw

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Figure 2
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