British Journal of Medicine & Medical Research
15(2): 1-11, 2016, Article no.BJMMR.25350
ISSN: 2231-0614, NLM ID: 101570965

SCIENCEDOMAIN *international*
www.sciencedomain.org

Evaluation of Soft Tissue Profile Change Following Bi-maxillary Surgery in Dento-skeletal Class III by Photogrammetric Analysis

Andrea Torroni[1], Giulio Gasparini[1*], Alessandro Moro[1], Gianmarco Saponaro[1], Enrico Foresta[1], Paolo De Angelis[1], Daniele Cervelli[1], Camillo Azzuni[1], Roberto Boniello[1], Luca Pallottini[2], Anna Borelli[2], Giulia Jafari[1], Sandro Pelo[1], Roberto Deli[2] and Giuliana Longo[1]

[1]U.O.C. Maxillo Facial Surgery, Catholic University Medical School, Largo Agostino Gemelli 1, 00168 Rome, Italy.
[2]School of Orthodontics, Catholic University Medical School, Largo Agostino Gemelli 1, 00168 Rome, Italy.

Authors' contributions

This work was carried out in collaboration between all authors. Authors AT, RD and SP designed the study, wrote the protocol and wrote the first draft of the manuscript. Authors GJ and GG managed the literature searches, analyses of the study and authors LP and AB managed the experimental process. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/BJMMR/2016/25350
Editor(s):
(1) Ibrahim El-Sayed M. El-Hakim, Ain Shams University, Egypt and Riyadh College of Dentistry and Pharmacy, Riyadh, Saudi Arabia.
Reviewers:
(1) Takahiro Kanno, Shimane University, Japan.
(2) Rodrigo Crespo Mosca, Sao Paulo University, Brazil.
(3) Babatunde O. Bamgbose, Bayero University, Kano, Nigeria.
Complete Peer review History: http://sciencedomain.org/review-history/14157

Received 28th February 2016
Accepted 5th April 2016
Published 14th April 2016

Original Research Article

ABSTRACT

3D analysis allows for simulation of orthognathic surgery and prediction of aesthetic and functional outcomes. Our study aims to find common and repeatable parameters on the behaviour of soft tissues following bone movement by pre- and post-treatment by photogrammetric analysis. Three representative patients who underwent bimaxillary surgery of advancement/retrusion of the jaws for correction of class III dento-skeletal malformation were presented. By overlapping pre-operative and post-operative 3D photos we obtained colour and millimetric maps that allowed the objective appreciation of facial soft tissues modification in all planes of the space after orthognathic surgery.

**Corresponding author: E-mail: giulio.gasparini@rm.unicatt.it;*

The study disclosed interesting insight into the soft tissue behaviour following orthognathic surgery and highlighted the possibility to draw reliable dissipation curves of facial skin after orthognathic surgery. This study also provided the base for future development of 3D images analysis (3D VTO) to plan and predict aesthetic outcomes of patients with dento-skeletal malformation.

Keywords: Dento-skeletal malformation; orthognatic surgery; preoperative planning; soft tissue behaviour; tri-dimensional analysis; photogrammetry.

1. INTRODUCTION

Although assessment of craniofacial morphology would always require a 3D approach, today the planning of orthognathic surgery is mostly performed with 2D methods, making it difficult to correctly evaluate the changes of thickness and position of soft tissue, and obtain reliable previsions of outcomes [1-5].

In recent years, application of 3D imaging has gained priority because of its advantages over the 2D techniques: It allows for simulation of surgery and prediction of aesthetic and functional outcomes, improving both the treatment planning and results [1].

Recognition of aesthetic factors and prediction of final facial profile plays an important role in orthognathic treatment planning, since the facial profile produced by orthognathic surgery is often of high importance for patients [2-4]; however, the effects of skeletal surgery on soft tissue profiles is not easy to predict [5].

Many strategies have been attempted to evaluate the relationship between hard tissue movement and its effect on overlying soft tissue for predicting facial changes. However, most of these studies involve the use of complex techniques that variously combine photo-grammetry, 3D laser, CT scan and / or CBTC, with considerable expenses and biological costs, exposing the patients to ionizing radiation [6-9]. Photogrammetry is a non-invasive and free of biological costs technique, which involves the use of digital photographs. The possibility to have a "3D photographic image" of the face opens new perspectives of diagnostic and therapeutic planning: 3D evaluation of soft tissue integrates the information from cephalometry, improving the diagnosis, treatment plan, and evaluation of results by comparing pre- and post-treatment conditions.

Photogrammetry is a valid alternative to laser scanning 3D, which is the technique used in the majority of three-dimensional analysis of the human body, although burdened by high costs of the equipment, long times of image acquisition, and also requiring a strict collaboration of the subject in exam [9-13]. Photogrammetry is an economical method, easy to use, with reduced acquisition time: Factors that increase patient compliance, repeatability, and accuracy [9]. In our hospital photogrammetry is an integral part of the orthognathic assessment, and is free of charge for the patient.

Our study aims to find common and repeatable parameters on the behaviour of soft tissues following the bone movement in the sagittal plan by pre- and post-treatment photogrammetric analysis. Dissipation curves of facial soft tissues pre- and post-orthognathic surgery were drawn and analysed on 45 consecutive cases, using photogrammetric assay; three representative cases were presented in detail to explain step by step our methodological approach. The proposed method, once validated, might provide useful information to develop 3D analysis for an accurate previewing of the face of patients undergoing orthognathic surgery.

2. MATERIALS AND METHODS

Fortyfive consecutive patients who underwent bimaxillary surgery at the Department of Oral and Maxillofacial Surgery of the Catholic University of Sacred Heart from January 2011 to December 2012 were selected. Inclusion criteria were age ≥ 18 years, and linear movement of the maxillary segments on the sagittal plane (i.e. advancement/retrusion of the jaws) for correction of class III (twenty four cases) and class II (twenty one cases) dento-skeletal malformation (Fig. 1); in this preliminary study for the evaluation of soft tissue behaviour following orthognathic surgery by photogrammetry analysis, we voluntarily excluded cases with severe vertical discrepancies (impaction of the maxilla ≥ 4 mm) and asymmetric patients in order to reduce confounding factors. The study received IRB approval from the ethic committee of the Catholic University, and informed consent to the procedure and for publication of relevant clinical information and photos has been obtain by each participant.

Fig. 1. Pre-operative view of the three patients with class III dento- skeletral malformation

Imaging method: 3D photos were taken with the 3dMD Face Scan System; the 3dMD system is constituted by a pole stand with three supporting arms (one vertical and two lateral, left and right), containing three digital cameras (one colour and two black and white), and a projector that shows a reference grid on the face of the patient. The digital information obtained will subsequently be used for processing the images and realize the 3D model. The system also contains three flashes lights. The whole structure is connected to a computer that contains both the software for image acquisition (3dMD face) and the software for their processing (3dMD vultus).

The values of diaphragm overture, white balance and exposure time are set by the manufacturer company, and them cannot be modified.

The system requires, as all three-dimensional machinery, a calibration of the positioning sensors before use for achieve consistent results.

The calibration phase must be performed before each acquisition, and it consists of a photograph in two different positions of a panel with a calibration grid, placed exactly in the centre of the system. After that, the system is ready for the acquisition of the patient's images. The subjects are seated on a stool with adjustable height. The correct position of the head is checked on a monitor by the operator through the use of a webcam.

The presence of a reference grid that appears on the screen guides the proper position to be taken during the shooting procedure, with the head at the centre of the grid. After a simultaneous click three photographic images are immediately processed by the program 3dMD-face for the realization of 3D model. The models obtained are then imported into the 3dMD vultus software for the processing phase.

The system automatically measures both the points and the mutual distances between the points, in order to obtain distances, angles and volumetric measurements; the images obtained provide a faithful representation of the face and are therefore particularly suited to the analysis of soft tissues. Once the three dimensional surface of face has been created, it can be exported in wrml format and used for analysis on Geomagic.

Analysis method: Pre-op and post-op 3D photos acquired with the 3dMD system, were imported into Geomagic Qualify to perform the analysis of 3D deviations point by point between the two models; the pre- treatment model, based on the 3D image acquired at T0 time, was indicated as “reference model”, while the post-surgery model, whose image was obtained at list 6 months post-op (T1 time), was named “test model” (the model in which the changes have occurred).

Geomagic Studio is a software house that allows conversion of 3D images into polygons and Non Uniform Rational Basis-Splines (NURBS), and permits analysis on measurable data. For our analysis we used the latest version of Geomagic (12).

The analysis performed by Geomagic entailed 3 phases:

1) Optimized alignment: for optimal match of both the reference and test model of the face; for the accuracy of this phase it was important to select areas of the face which did not change after surgery; the areas selected for this matching process were: The forehead, nasal bones, and the upper part of zygomatic bone and zygomatic arch.
2) 3D Comparison: creation of a colour map that showed the deviations between test and reference models. The setting included the choice of colour range and the setting of the colour scale, with a critical minimum value, and maximum critical value (the latter used to set the range where at each value corresponded only one colour). Based on input data the program creates a colour map of the overlapping models as depicted in Fig. 2.
3) Section of overlapping models and measurements: The colour model was cut by 24 planes parallel to the horizontal plane XZ, not equally spaced, but adapted to the patient's face. In particular, we selected 9 nasal sections (from n1 to n9), taking care to include nostrils in sections from n7 to n9; 4 sections for upper lip (from ls10 to ls13) up to the apex of filter, 4 sections for the mouth (from b14 to b17) taking care to pass for labial commissure (b15), and 7 sections for lower lip and chin (up to skin menton) (Fig. 3).

Each cut obtained, called "colorimetric moustache" (Fig. 4), represented the transversal section of the model, characterized by different length and colour depending on 3D deviation in the space.

In every cut 23 equidistant points were identified, 11 to the right and 11 to the left, in addition to the central lying on sagittal cut; each point was then analysed to identify the total 3D deviation in space (Fig. 5).

The numeric data obtained for each patient were included in a table of our ideation (Fig. 6):

the rows were drawn according to the face sections previously described, while the columns were equidistant (topographically on the 3D model); the columns "C" identifying values of the sagittal plane, the columns "d" passing through the cutaneous portion immediately adjacent to the nostrils, the columns "e" passing through labial commissures, the columns "g" through cheekbone, the columns "h", "i", "j" through the zygomatic arch, and finally the columns "k" anterior to the tragus.

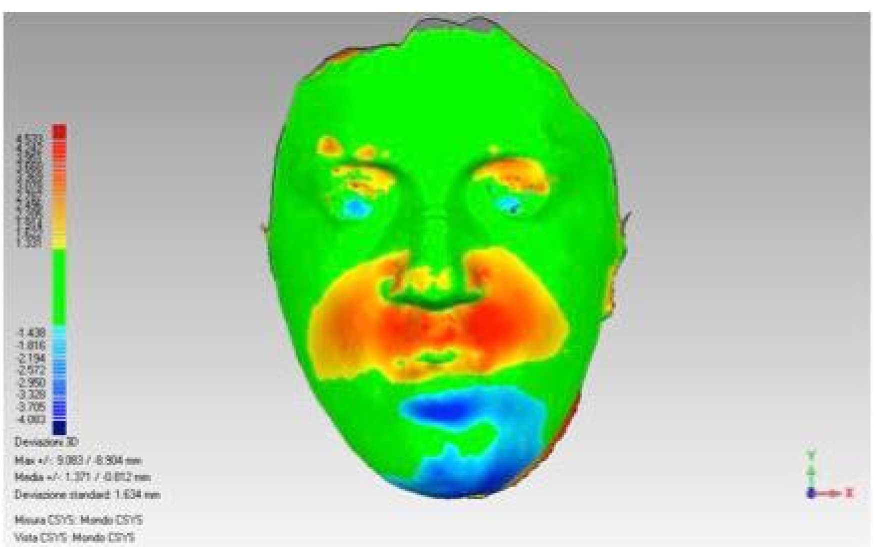

Fig. 2. Colour map obtained by overlapping pre-op and post photogrammetry showing the deviations between the test and the reference models and the visual appreciation of the facial soft tissues modification after orthognathic surgery

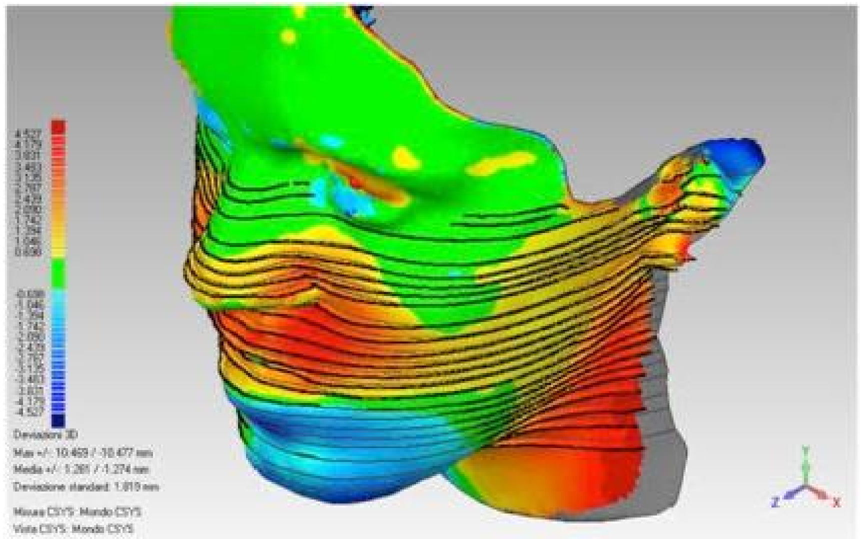

Fig. 3. Horizontal section of the colour map in 24 planes adapted to the patient's face

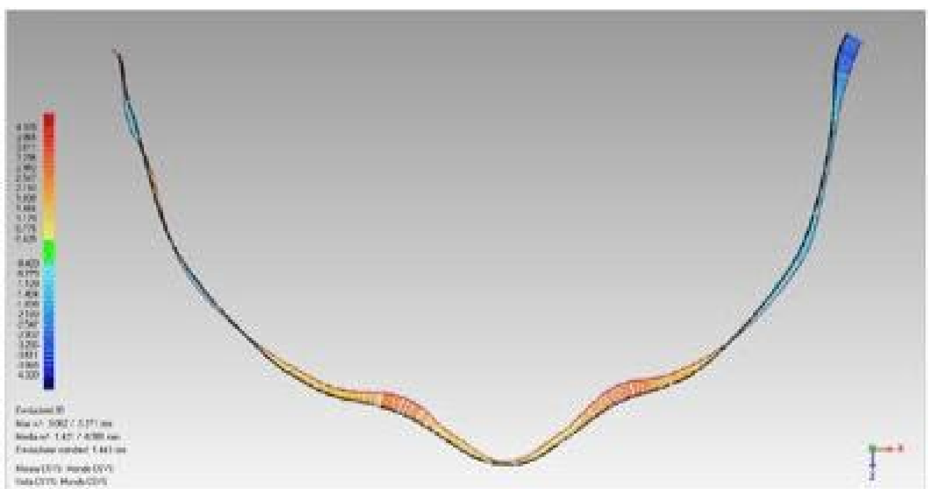

Fig. 4. Transversal section of the model characterized by different length and colour depending on the 3D deviation on the space

After filling the cells with the corresponding values, we created millimetred tables for each patient (Figs. 7A, 7B and 7C).

The tables reported empty spaces in the centre, where data were not included; these spaces corresponded to the nostrils and lips areas, and their values were not included because subjected to movement artefacts by the action of voluntary muscles.

3. RESULTS

From photogrammetric analysis we obtained two images at T0 and T1 time, which gave a faithful three- dimensional representation of the face of the patient. By overlapping the images we obtained colour maps that allowed the visual appreciation of facial soft tissues modification after orthognathic surgery (Figs. 8A, B and C).

The colour map was generated using a colour scale ranging from blue to red based on the displacement of soft tissues in the area; the coloured areas indicate respectively:

1. RED: T1 point is more external to T0 point, so there is a volume increase;
2. GREEN: the two images coincide, so there isn't substantial change between T1 and T0 images;

3. BLUE: T1 area is internal to T0, indicating a volume decrease.

We report three cases of skeletal Class III examined with the relative millimetered tables.

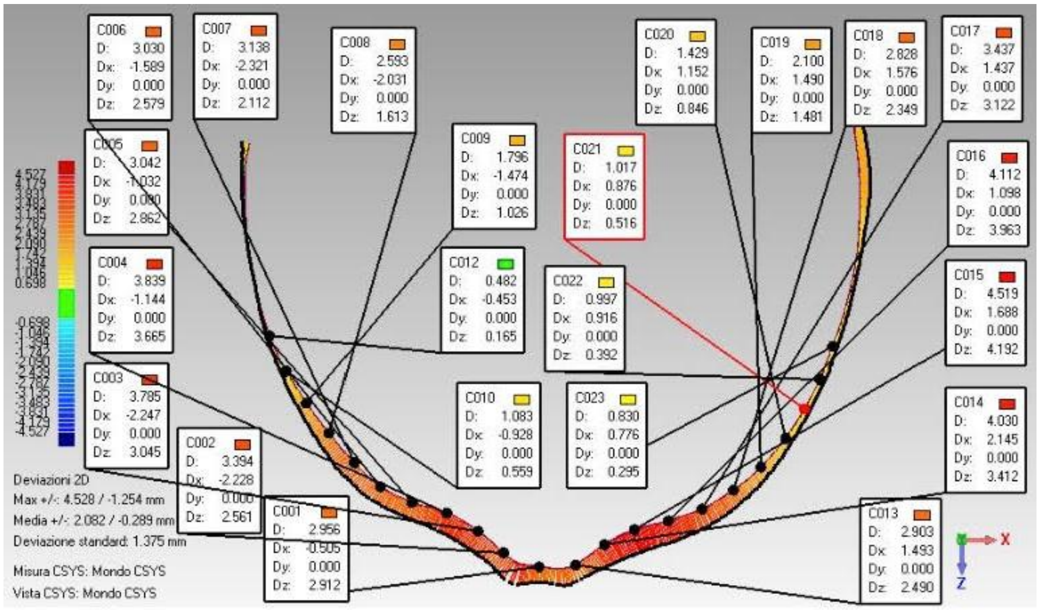

Fig. 5. 23 equidistant point highlighted on the transversal section of the model for the analysis of the total 3D deviation in the space

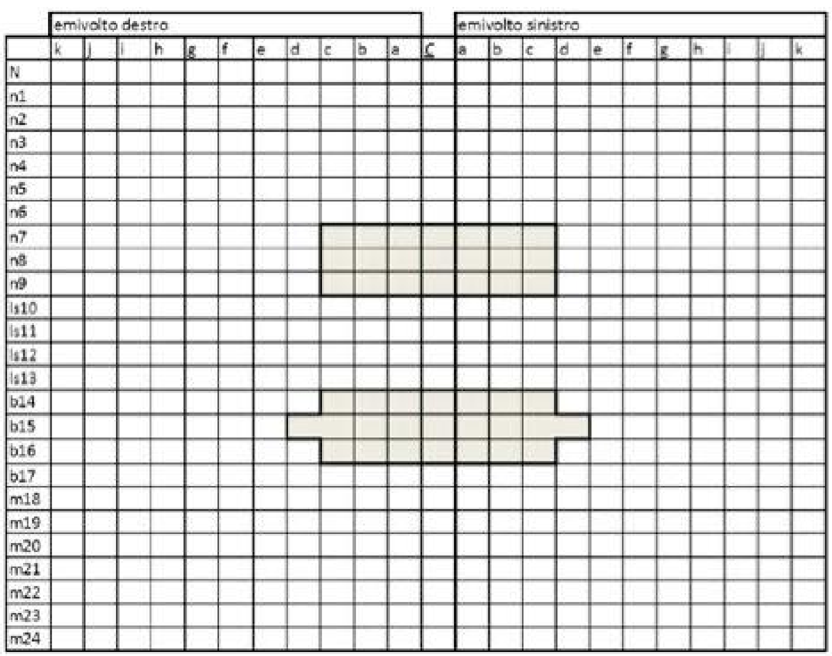

Fig. 6. Empty table of our ideation; B millimetred table results by inclusion of numeric data for each patient. The empty spaces in the centre without corresponded to the nostrils and lips areas

A

	emivolto destro												emivolto sinistro										
	k	j	i	h	g	f	e	d	c	b	a	C	a	b	c	d	e	f	g	h	i	j	k
N												0,0											
n1											0,1	0,1	0,1										
n2											0,1	0,2	0,1										
n3										0,1	0,2	0,4	0,2	0,1									
n4									0,1	0,2	0,5	1,0	0,5	0,2	0,1								
n5								0,1	0,5	0,9	1,8	2,0	1,8	0,9	0,5	0,1							
n6							0,7	1,4	2,0	2,0	1,7	1,5	1,7	2,0	2,0	1,4	0,7						
n7				0,5	1,2	1,3	2,5	2,8				1,2				2,8	2,5	1,3	1,2	0,5			
n8				0,6	1,6	2,2	2,6	2,9				2,1				2,9	2,6	2,2	1,6	0,6			
n9				0,3	1,6	2,6	3,2	3,8				3,4				3,8	3,2	2,6	1,6	0,3			
ls10					0,6	1,6	3,0	3,6	4,5	4,0	3,8	3,4	3,8	4,0	4,5	3,6	3,0	1,6	0,6				
ls11				0,6	1,3	2,1	3,1	3,9	4,1	3,8	4,2	5,0	4,2	3,8	4,1	3,9	3,1	2,1	1,3	0,6			
ls12				0,5	0,9	1,6	2,5	3,3	3,6	3,6	4,2	5,5	4,2	3,6	3,6	3,3	2,5	1,6	0,9	0,5			
ls13			0,4	0,7	1,0	1,7	2,5	2,9	3,2	2,7	3,6	5,8	3,6	2,7	3,2	2,9	2,5	1,7	1,0	0,7	0,4		
b14		0,3	0,9	1,3	2,4	3,7	3,3	2,8				5,8				2,8	3,3	3,7	2,4	1,3	0,9	0,3	
b15			0,6	1,4	1,8	2,4	2,6					3,6					2,6	2,4	1,8	1,4	0,6		
b16	2,0	1,6	0,2	-0,6	-0,7	-1,7	-1,9	-1,8				-2,5				-1,8	-1,9	-1,7	-0,7	-0,6	0,2	1,6	2,0
b17	1,7	1,9	1,9	0,9	-0,2	-0,5	-1,1	-1,5	-2,0	-3,0	-3,2	-2,5	-3,2	-3,0	-2,0	-1,5	-1,1	-0,5	-0,2	0,9	1,9	1,9	1,7
m18	1,9	1,9	1,8	1,2	-0,5	-1,0	-1,6	-1,7	-2,5	-3,5	-3,9	-3,2	-3,9	-3,5	-2,5	-1,7	-1,6	-1,0	-0,5	1,2	1,8	1,9	1,9
m19	2,0	1,8	1,7	1,2	-0,7	-1,1	-1,5	-2,0	-2,5	-3,7	-4,5	-3,8	-4,5	-3,7	-2,5	-2,0	-1,5	-1,1	-0,7	1,2	1,7	1,8	2,0
m20	3,2	2,5	1,7	1,7	1,6	1,0	-0,8	-1,0	-1,6	-2,4	-2,9	-3,3	-2,9	-2,4	-1,6	-1,0	-0,8	1,0	1,6	1,7	1,7	2,5	3,2
m21			2,0	1,9	1,7	-0,8	-0,3	-1,1	-1,7	-2,5	-2,8	-2,7	-2,8	-2,5	-1,7	-1,1	-0,3	-0,8	1,7	1,9	2,0		
m22				1,8	1,0	-0,6	-0,7	-1,0	-1,5	-2,4	-2,7	-2,1	-2,7	-2,4	-1,5	-1,0	-0,7	-0,6	1,0	1,8			
m23								-1,1	-1,5	-2,1	-2,5	-3,2	-2,5	-2,1	-1,5	-1,1	-0,9						
m24							-1,0	-1,8	-1,9	-2,1	-2,8	-3,9	-2,9	-2,0	-2,0	-1,9	-1,1						

B

	emivolto destro												emivolto sinistro										
	k	j	i	h	g	f	e	d	c	b	a	C	a	b	c	d	e	f	g	h	i	j	k
N												0,0											
n1											0,1	0,1	0,1										
n2											0,1	0,1	0,1										
n3										0,2	0,2	0,2	0,2	0,2									
n4							0,2	0,5	0,9	0,6	0,4	0,4	0,4	0,7	1,0	0,7	0,2						
n5							0,4	1,5	1,8	1,7	0,9	0,4	0,9	1,7	1,8	1,5	0,4						
n6						0,2	1,0	1,9	2,5	2,0	1,2	1,4	1,2	2,0	2,5	1,9	1,0	0,2					
n7				0,2	0,6	1,4	1,8	2,6				1,2				2,6	1,8	1,4	0,6	0,2			
n8				0,2	0,6	1,9	2,5	2,8				1,2				2,8	2,5	1,9	0,6	0,2			
n9			0,2	1,2	2,1	3,0	3,0	3,2				1,8				3,2	3,0	3,0	2,1	1,2	0,2		
ls10			0,3	0,7	1,6	2,7	3,1	2,5	3,6	2,4	2,8	1,8	2,8	2,4	3,6	2,5	3,1	2,7	1,6	0,7	0,3		
ls11			0,5	1,3	2,0	2,8	3,0	3,0	3,8	3,8	3,3	2,9	3,3	3,8	3,8	3,0	3,0	2,8	2,0	1,3	0,5		
ls12			0,5	0,7	1,5	2,3	2,9	3,0	3,3	3,7	3,5	3,5	3,5	3,7	3,3	3,0	2,9	2,3	1,5	0,7	0,5		
ls13		0,4	1,0	1,8	2,2	2,6	2,8	2,9	3,3	3,3	2,6	2,9	2,6	3,3	3,3	2,9	2,8	2,6	2,2	1,8	1,0	0,4	
b14		0,8	1,0	1,1	1,4	1,5	2,0	3,2				2,0				3,2	2,0	1,5	1,4	1,1	1,0	0,8	
b15	0,4	0,7	1,4	1,5	1,6	1,6	2,0					1,7					2,0	1,6	1,6	1,5	1,4	0,7	0,4
b16	2,8	1,5	0,0	-0,3	-0,4	-0,7	-0,8	-0,6				-1,3				-0,6	-0,8	-0,7	-0,4	-0,3	0,0	1,5	2,8
b17		3,0	3,1	1,5	0,6	0,2	-0,3	-0,7	-1,3	-1,5	-1,8	-1,3	-1,8	-1,5	-1,3	-0,7	-0,3	0,2	0,6	1,5	3,1	3,0	
m18		4,0	3,2	2,3	0,8	-0,6	-1,4	-1,8	-2,0	-2,1	-2,9	-2,9	-2,9	-2,1	-2,0	-1,8	-1,4	-0,6	0,8	2,3	3,2	4,0	
m19		3,8	2,7	2,1	0,5	-0,5	-1,4	-1,8	-2,0	-1,9	-3,2	-3,9	-3,2	-1,9	-2,0	-1,8	-1,4	-0,5	0,5	2,1	2,7	3,8	
m20		4,0	3,9	3,1	1,3	0,3	-0,7	-1,5	-1,6	-1,7	-2,2	-3,1	-2,2	-1,7	-1,6	-1,5	-0,7	0,3	1,3	3,1	3,9	4,0	
m21		4,2	3,8	3,1	1,7	0,3	-0,5	-0,9	-1,7	-1,4	-0,6	-1,1	-0,6	-1,4	-1,7	-0,9	-0,5	0,3	1,7	3,1	3,8	4,2	
m22			3,9	3,4	1,9	0,1	-1,0	-1,7	-1,9	-1,9	-1,0	-1,4	-1,0	-1,9	-1,9	-1,7	-1,0	0,1	1,9	3,4	3,9		
m23			3,5	2,9	0,9	-0,5	-0,9	-1,3	-1,5	-1,7	-1,8	-1,9	-1,8	-1,7	-1,5	-1,3	-0,9	-0,5	0,9	2,9	3,5		
m24						-0,3	-0,7	-1,4	-1,9	-2,1	-2,7	-3,0	-2,7	-2,1	-1,9	-1,4	-0,7	-0,3					

C

	emivolto destro												emivolto sinistro										
	k	j	i	h	g	f	e	d	c	b	a	C	a	b	c	d	e	f	g	h	i	j	k
N												0,0											
n1											0,2	0,3	0,2										
n2											0,4	0,8	0,4										
n3										0,4	0,5	1,0	0,5	0,4									
n4							0,4	1,7	2,2	1,7	0,9	1,1	0,9	1,7	2,2	1,7	0,4						
n5							0,5	2,0	2,5	2,5	1,7	1,6	1,7	2,5	2,5	2,0	0,5						
n6						0,1	1,0	2,0	2,7	2,3	1,6	2,1	1,6	2,3	2,7	2,0	1,0	0,1					
n7				0,5	1,2	1,8	2,9	3,6				2,4				3,6	2,9	1,8	1,2	0,5			
n8				0,4	1,2	2,5	3,1	3,5				2,8				3,5	3,1	2,5	1,2	0,4			
n9			0,1	0,8	1,7	2,6	2,8	4,3				3,2				4,5	2,8	2,6	1,7	0,8	0,1		
ls10			0,2	0,4	1,1	2,1	2,8	2,6	3,5	2,7	2,9	3,2	2,9	2,7	3,5	2,6	2,8	2,1	1,1	0,4	0,2		
ls11			0,3	0,9	1,5	2,2	2,6	2,9	3,4	3,3	3,9	4,8	4,0	3,3	3,4	2,9	2,6	2,2	1,5	0,9	0,3		
ls12			0,2	0,5	1,0	1,6	2,2	2,5	2,7	3,1	4,5	5,1	4,3	3,4	2,7	2,5	2,2	1,6	1,0	0,5	0,2		
ls13		0,2	0,6	1,2	1,5	1,9	2,2	2,4	2,6	2,5	3,9	4,7	4,1	2,5	2,6	2,4	2,2	1,9	1,5	1,2	0,6	0,2	
b14		0,7	1,0	1,2	1,7	2,2	2,5	3,3				4,7				3,3	2,5	2,2	1,7	1,2	1,0	0,7	
b15	0,2	0,4	0,9	1,1	1,3	1,4	1,7					2,7					1,7	1,4	1,3	1,1	0,9	0,4	0,2
b16	0,7	0,4	0,0	-0,1	-0,1	-0,3	-0,3	-0,3				-0,7				-0,3	-0,3	-0,3	-0,1	-0,1	0,0	0,4	0,7
b17	0,2	0,7	0,7	0,4	0,1	0,0	-0,2	-0,3	-0,4	-0,5	-0,6	-0,7	-0,6	-0,5	-0,4	-0,3	-0,2	0,0	0,1	0,4	0,7	0,7	0,2
m18	0,2	0,8	0,7	0,5	0,0	-0,2	-0,4	-0,5	-0,6	-0,7	-0,9	-1,2	-0,9	-0,7	-0,6	-0,5	-0,4	-0,2	0,0	0,5	0,7	0,8	0,2
m19	0,4	1,1	0,9	0,7	0,0	-0,3	-0,6	-0,8	-0,9	-1,1	-1,5	-2,3	-1,5	-1,1	-0,9	-0,8	-0,6	-0,3	0,0	0,7	0,9	1,1	0,4
m20	2,0	1,5	0,7	0,6	0,3	0,1	-0,2	-0,3	-0,4	-0,5	-0,6	-1,1	-0,6	-0,5	-0,4	-0,3	-0,2	0,1	0,3	0,6	0,7	1,3	1,8
m21		2,5	2,0	1,6	1,0	0,0	-0,3	-0,6	-1,0	-1,0	-0,7	-1,4	-0,7	-1,0	-1,0	-0,6	-0,3	0,0	1,0	1,6	2,0	2,4	
m22			1,6	1,9	1,0	-0,1	-0,6	-1,0	-1,2	-1,4	-1,1	-1,7	-1,1	-1,4	-1,2	-1,0	-0,6	-0,1	1,0	1,9	1,6		
m23			1,2	1,0	0,3	-0,2	-0,3	-0,7	-0,8	-1,0	-1,2	-2,0	-1,2	-1,0	-0,8	-0,7	-0,5	-0,2	0,3	1,0	1,2		
m24						-0,1	-0,5	-1,0	-1,2	-1,3	-1,7	-3,2	-1,8	-1,3	-1,2	-1,0	-0,5	-0,1					

Fig. 7A, B and C. Millimetered tables

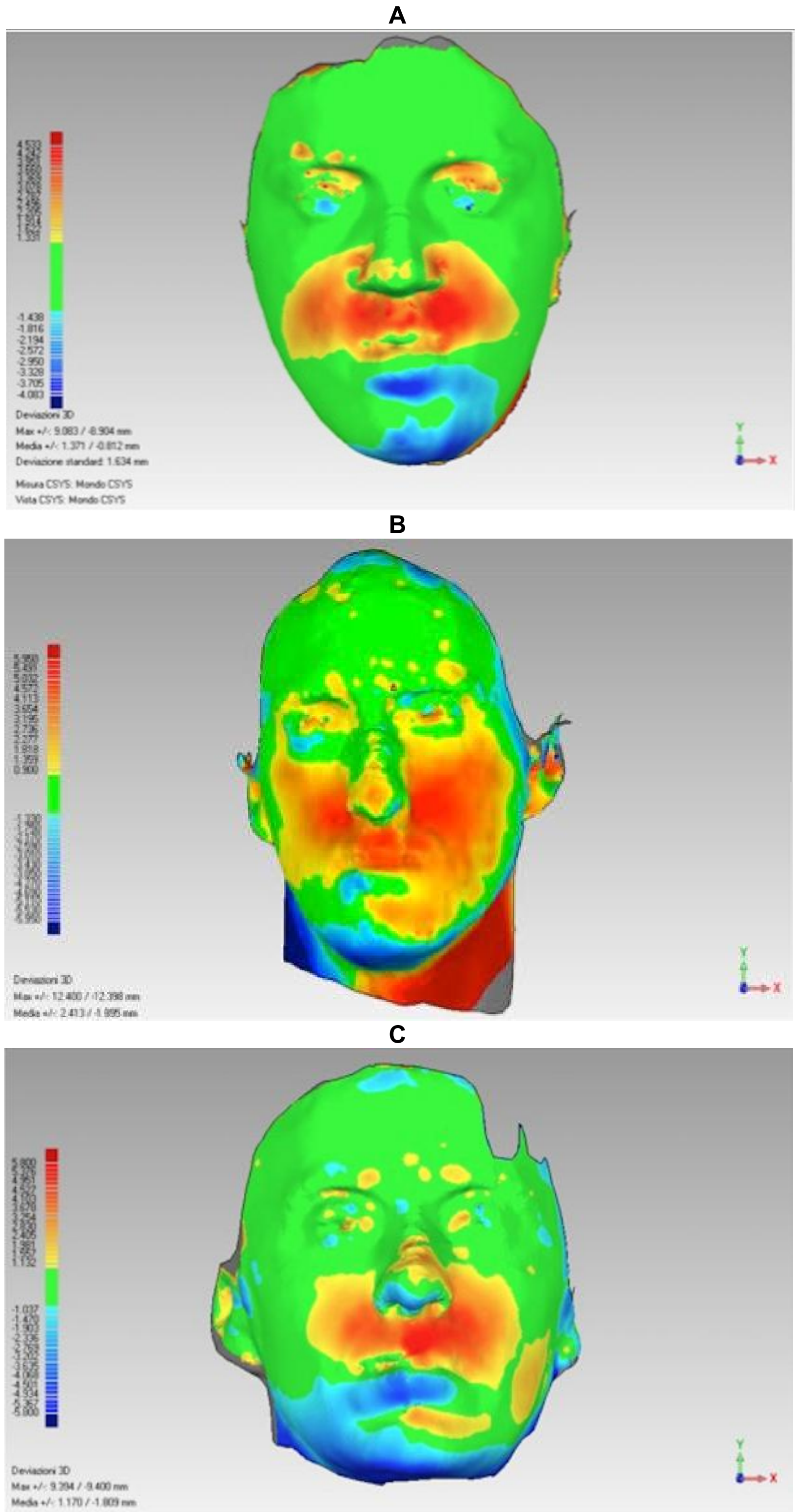

Fig. 8A, B and C. Three cases of skeletal class III, colour map

Interesting data come from the observation of these tables, in particular:

1) The skin displacements along the facial profile does not behave in a uniform manner, but follows different dissipation coefficients; then to a givenΔx on the sagittal profile corresponds different Δx' (points to the right and left of the midface, lying on the same cut), different in the entity and in dissipation (i.e. the skin of the face does not behave as a tent sustained by the underlying bone frame).
2) The skin behaviour seemed to be similar in all the analysed subjects showing peculiar characteristics; considering the rows we found:

   a) From n1 to n5, corresponding to the high paralateral nasal region, the skin projection showed a strong increase (up to 210% respect to those of the median sagittal profile), even for modest advancement of the underlying bone;
   b) From n6 to n9 the skin millimetric values around the nostrils (paralateral nasal) are up to 200% of those of the sagittal profile;
   c) In the LS12 and LS13 and from b14 to b17 the sagittal changes are maintained and regularly dissipated.
   d) It is also interesting to note the skin behaviour of mandibular angles. In particular, we observed the "filling" of the mandibular angle up to 180% of the value of Δx on the median sagittal profile.

   As regards the columns:

   e) The skin Δx of dissipation at level of the nose is completed at zygomatic level (column g);
   f) The Δx dissipation of skin profile on the lower third of the face is gradually completed far more posteriorly, at level of the mandibular angles (over the columns k).

In addition to the expected effects of orthognathic surgery on the perioral and chin soft tissues, it is interesting to note a significant "filling" effect of the skin around the nostrils and up to the lower portion of cheekbones; a clear objectivity of this detection may be obtained only by photogrammetry analysis and not from 2D photos.

4. DISCUSSION

To accurately predict the aesthetic outcome after orthognathic surgery is of paramount importance to clearly understand the behaviour of soft tissues secondary to the bone-frame displacement.

Many studies have attempted to evaluate the relationship between hard tissue movement and its effect on the overlying soft tissue for predicting facial changes. However, most of these studies used complex techniques with association of photogrammetry, 3D laser, CT and / or CTBC scan, with considerable expense and biological costs, exposing the patients to ionizing radiation [6-9].

Westermark et al. [10] in their pre-surgery simulations found a good correlation between simulation and outcome in 15 patients. However, the soft tissue changes that accompanied the movements of the facial bones were not accurately predicted.

Kaipatur et al performed a literature review of computerized prediction programs in relation to hard tissue points, and found that all the programs could not consistently predict skeletal changes after orthognathic surgery, but their results may be considered inside a clinically acceptable range. Last-minute changes by the surgeons could also explain the differences [11].

Kaipatur and Flores-Mir performed a systematic review to investigate the accuracy of computer programs in predicting soft tissue response subsequent to skeletal changes after orthognathic surgery; out of the 40 initially identified articles only 7 articles fulfilled the final selection criteria. They found that the area of most significant error in prediction was the lower lip, because of the difficulty in controlling the action of voluntary muscles, which gave “movement artefacts” and spoiled the accuracy of the analysis; for the same reason we decided to not include data corresponding to the areas of nostrils and lips in our study.

The 7 studies considered showed accurate prediction of outcomes (less than 2 mm) compared with the actual results in both directions, horizontal and vertical. Although the individual errors were almost always minimal, their sum could lead to discrepancies between the prediction and the actual outcome of the aesthetic outcome of clinical relevance [12].

Marchetti et al. [13] evaluated the use of SurgiCase-CMF software (Materialise, Leuven, Belgium) for soft tissue simulation and found a reliability of 91%, which they judged to be realistic enough to form an accurate forecast of the patient's facial appearance after surgery, but their analysis involved the use of cephalometric analysis and CT scans pre and post-surgery, with considerable biologic costs for the patients in terms of radiation exposure.

Schendel et al. [14] fused the photogrammetric scan and cone-beam CT for each of the 23 patients examined, creating a patient-specific images. The surgery was simulated in 3D form and the simulated face was compared with the actual facial scan obtained 6 months postoperatively by calculating the difference between the post-operative changes and those simulated. For 15 landmarks, the difference between actual and simulated measurements was smaller than 0.5 mm. Only 3 landmarks had a difference of 0.5 mm, and these were in the region of the labial landmarks; considering the whole face of the patient, this method produced an error of 1.8 mm.

The analysis of 3D images presented in this preliminary study, offers millimetric data of the facial soft tissue displacement after orthognathic surgery in all planes of space. Moreover, the constant development of not invasive and low-cost devices for acquisition and development of 3D computer imaging makes possible to use this technique with reduced costs and without paying any biological price; those characteristics makes the procedure particularly suitable when the subjects investigated are children, or in cases of complex craniofacial syndromes that require serial and frequent investigations. In addition 3D images acquiring is a not invasive procedure, it does not cause discomfort to the patient and is quickly performed, allowing repetition at short intervals.

The presented preliminary study, which is based on the simple analysis of 3D pictures, showed the possibility to find some objective and repeatable parameters on the behaviour of facial soft tissues after orthognathic surgery; with the 3D analysis of images we were able to appreciate and objectively quantify a significant "filling" effect of the skin around the nostrils and up to the lower portion of cheekbones, in addition to the expected effects of orthognathic surgery on the perioral and chin soft tissues; a result impossible to achieve rom a standard 2D photos analysis. Moreover our analysis has the advantage of being simple and quick, with reduced economic and biological cost. Despite those advantages, however the photogrammetry evaluation has several drawbacks: 1. it was performed only on simple dento-skeletal malformations, forcing to consider a small sample of patients; 2. the procedure did not overcome the problem of analysing areas subjected to strong muscular action (i.e. lips and nostrils), which were therefore excluded from the analysis; all aspects that will require further investigations on larger pool of patients.

This study shows that data otherwise “hidden” in the routine 2D photos can be obtained by 3D measurements and their analysis. In addition all data comparable with 2D are more reliable in 3D images, because of the missing "projection" artefacts of sizes and shapes that occur in 2D photos; we have highlighted the possibility to mathematically quantify the displacement of facial soft tissue and create reliable dissipation curves of the various facial districts after orthognathic surgery, on the basis of simple 3D images analysis.

This study disclosed interesting insight into the soft tissue behaviour following orthognathic surgery providing the base for future development of 3D images analysis (3D VTO) to plan and reliably predict aesthetic outcomes of patients affected by dento-skeletal malformation requiring orthognathic surgical treatment.

5. CONCLUSION

Photogrammetry is a promising and cost effective method to predict soft tissue profile changes following orthognathic surgery. With further validation by larger clinical trials it could became a precious tool to perform a comprehensive 3D-planning of orthognathic cases, and offering more reliable prevision of the aesthetic outcome.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Papadopoulos MA, Christou PK, Christou PK, Athanasiou AE, Boettcher P, Zeilhofer HF, Sader R, Papadopulos NA. Three-

dimensional craniofacial reconstruction imaging. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2002;93:382-93.
2. Jacobson A. Psychological aspects of dentofacial esthetics and orthognathic surgery. Angle Orthod. 1984;54:18–35.
3. Kiyak HA, West RA, Hohl T, McNeill RW. The psychological impact of orthognathic surgery: A 9-month follow-up. Am J Orthod. 1982;81:404–412.
4. Rustemeyer J, Eke Z, Bremerich A. Perception of improvement after orthognathic surgery: The important variables affecting patient satisfaction. Oral Maxillofac Surg. 2010;14:155–162.
5. Legan HL, Burstone CJ. Soft tissue cephalometric analysis for orthognathic surgery. J Oral Surg. 1980;38:744-751.
6. Chou JI, Fong HJ, Kuang SH, Gi LY, Hwang FY, Lai YC, Chang RC, Kao SY. A retrospective analysis of the stability and relapse of soft and hard tissue change after bilateral sagittal split osteotomy for mandibular setback of 64 Taiwanese patients. J Oral Maxillofac Surg. 2005; 63:355–361.
7. Enacar A, Taner T, Toroğlu S. Analysis of soft tissue profile changes associated with mandibular setback and double-jaw surgeries. Int J Adult Orthod Orthognath Surg. 1999;14:27–35.
8. Koh CH, Chew MT. Predictability of soft tissue profile changes following bimaxillary surgery in skeleta1 class III Chinese patients. J Oral Maxillofac Surg. 2004; 62:1505–1509.
9. Rustemeyer J, Martin A. Soft tissue response in orthognathic surgery patients treated by bimaxillary osteotomy: Cephalometry compared with 2-D photogrammetry. Oral Maxillofac Surg. 2003;17:33–41.
10. Westermark A, Zachow S, Eppley BL. Three-dimensional osteotomy planning in maxillofacial surgery including soft tissue prediction. J Craniofac Surg. 2005;16: 100-4.
11. Kaipatur N, Al-Thomali Y, Flores-Mir C. Accuracy of computer programs in predicting orthognathic surgery hard tissue response. J Oral Maxillofac Surg. 2009;67:1628.
12. Kaipatur NR, Flores-Mir C. Accuracy of computer programs in predicting orthognathic surgery soft tissue response. J Oral Maxillofac Surg. 2009;67:751-9.
13. Marchetti C, Bianchi A, Muyldermans L, Di Martino M, Lancellotti L, Sarti A. Validation of new soft tissue software in orthognathic surgery planning. Int J Oral Maxillofac Surg. 2011;40:26-32.
14. Schendel SA, Jacobson R, Khalessi S. Dimensional facial simulation in orthognathic surgery: Is it accurate? J Oral Maxillofac Surg. 2013;71:1406-14.

Peer-review history:
The peer review history for this paper can be accessed here:
http://sciencedomain.org/review-history/14157