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Examining facial soft tissue changes following orthognathic class III (bimax) surgeries applying structured light technique for the design and implementation of 3d facial modeling software

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ABSTRACT

Background: Improvement of facial beauty is a major reason why patients with dentofacial problems opt for orthognathic surgery. People are eventually judged by their facial appearance by themselves, their friends & family and even surgeons. With the recent developments in technology, we now have a 3D structure that can build and analyze 3D images before & after surgery and review the extent of changes taken place. Imaging techniques include: structured light photogrammetry, CT scan, 3D cephalometry, CBCT and other methods such as MRI and ultrasound. Structured light photogrammetry Using photography cameras (visible range) – without any harmful radiation – with 3D modeling of the face with high precision. The automatic operation of this procedure reduces human error and yields more accurate final results.

Materials and Methods: A 'before & after' clinical trial was conducted. Twenty four patients (17 females & 7 males) who were candidates of orthognathic Bimax surgery as a result of Class III malocclusion and who had attended Shariati Hospital's Maxillofacial Clinic were included in the study. The patients' surgical planning was the 'Lefort I osteotomy + Mandibular bilateral sagittal split osteotomy (BSSO). Photography was done through the photogrammetry method.

Results: 3D modeling of the patients' faces was done before & after surgery by photogrammetry. Changes following surgery were determined and their formula was calculated.

Conclusions: The resultant mathematical model can be used to build software for the 3D prediction of soft tissue changes following orthognathic surgery. However, it is better to evaluate the validity of the software and mathematical model in a separate study to apply the necessary changes if need be.

Keywords: orthognathic surgery, photography, photogrammetry, 3D face modeling.

Background

Orthognathic surgery has increased among patients with dentoskeletal problems in light of the developments made in the field and its improvement of facial beauty. However, orthognathic surgery should not be limited to surgery, fixation and improvement of long-term stability techniques; its prediction capability should be taken into account too. Since facial appearance is eventually judged by the patient, his friends & family and even surgeons, helping patients correctly understand the results of orthognathic surgery will contribute to the success of such treatment. Many surgeons routinely rely on photography for before & after surgical analysis and for the sake of documentation and legal issues. 3D imaging techniques include the following: 3D cephalometry [1,2], Superimposing of photographs with radiographs [3], Moire topography [2-7], CT (computed tomography) scan 3D imaging [8-10] Cone beam computed tomography (CBCT) [11-14], 3D ultrasonography [15,16], 3D laser scanning [17-21], and photogrammetry [22]. However, using 3D CT scans exposes patients to high doses of X-rays. In recent years developments in laser use have resulted in facial simulation via this tool which is a very expensive technique. Moreover, these techniques are very sensitive to patient movement, and the smallest movement can result in blurring of images.

Photogrammetry was first applied in medicine and dentistry in 1940 [22]. Stereophotogrammetry is a newer technique that uses two or more cameras to create accurate 3D images. This system is classified under structured light by projecting a specific light pattern on the patient's face. When the light pattern is projected on an object it changes on the basis of the object's shape i.e. it is distorted. Such information is useful for 3D modeling [23]. Stereophotogrammetry imaging functions like a human eye, where two regions are used to gather information from the image; this way the depth is also registered.

In this study we used photography cameras (visible range) – without any harmful radiation- and projectors imaging specifically shaped patterns to achieve very accurate 3D models of the patients' faces. The automatic operation of this procedure reduces human error and yields more accurate final results. We hope to be able to design software capable of predicting soft tissue changes following orthognathic surgery by 3D facial simulation through this technique, by examining the changes created and achieving the mathematical formula of these non-linear changes.

Methods and Methods

A 'before & after' clinical trial was conducted. Twenty four patients (17 females & 7 males) who were candidates of orthognathic Bimax surgery as a result of Class III malocclusion and who had attended Shariati Hospital's Maxillofacial Clinic were included in the study. The patients' surgical planing was the 'Lefort Iosteotomy + Mandibular setback' through BSSO.

The greatest standard deviation in soft tissue changes in earlier studies are related to chin soft tissue, as follows [24].

Soft tissue Pog = 0.95 * (man. Setback) – 0.15

Twenty four [24] patients were required to achieve a precision of 0.4 mm and confidence interval of 95%, and an a=0.05.

$n = [Z1\text{-}\alpha/2 \text{ x sd / d}]2 \approx 24$

After taking informed consent from patients to take images, they were photographed in the photography & modeling studio of Shariati Hospital's Maxillofacial Ward. The studio is a 2×2 m room, in the corner of which is a permanent chair. The height of the chair however, is adjustable. The chair's position remains stable before & after surgery. The required hardware was: two digital non-metric cameras (Canon S5) for taking pictures, and a digital projector with a 600 × 800 differentiation power for pattern imaging. The projector was placed 50 cm in front of the patient and the two cameras were placed at the patient's left and right at 45 degree angles from the projector-connecting line. After calibrating the cameras and regulating the intensity and direction of light two images were consecutively taken by the two cameras.

The 3D modeling technique makes use of structured light. It is done by projecting linear lines of various thicknesses on the patient's face with the projector and taking multiple photos from two angles. The 3D model of the face is constructed using conditional linear equations.

Diagram 1: The patient is seated on the special chair in the studio.

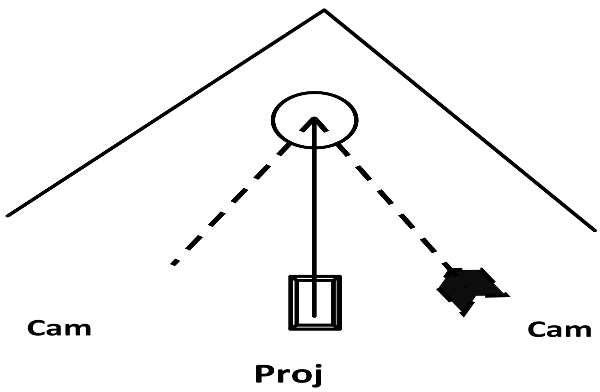


Diagram 2: The projector & cameras' positioning around the should be taken into account too. Since facial appearance is eventually judged by the patient, his friends & family and even surgeons, helping patients correctly understand the results of orthognathic surgery will contribute to the success of such

treatment. patient. The day before surgery 5 points on the patient's forehead were chosen on a non-linear basis and marked with a marker. The day before surgery, on the patient's forehead 5 points on a non-linear basis were chosen and marked with a marker Then, the distance between these points and the medial and lateral canthi of both eyes (as permanent points that do not change following orthognathic surgery) and other selective points (for easier determination of points in post-op imaging) were measured by a caliper. Manual measurements and photography were performed by a single person. The patients did not have any make-up on and their hair was loosely tied at the back of their heads.

Using the computer, images were taken by two cameras on the patient's two sides at the same time the striped patterns were projected on the patient's face by the projector. The patient remained motionless during the imaging. We took 40 images with each camera (i.e. an overall 80 images in each imaging session). A 6-second time gap existed between the images, which was set automatically by the computer. During this time gap the next light pattern would be projected on the patient's face.

The same method of imaging was applied to take pictures 6 months after surgery. The initial points were marked on the forehead using the pervious measurements. 3D models were made for before & after surgery. This way, all the soft tissue changes in the face (cheeks, jaw & chin) were measurable. Eventually, the soft tissue changes were shown on the 3D model using different shades of grey.

The degree and direction of jaw displacement was determined in each patient by taking into account the treatment plan, the appropriate splint arranged and the degrees of jaw displacement during surgery. To confirm the accuracy of the values determined for each patient, his/her before & after lateral cephalometry radiographs were superimposed on each other. Then, the extent of upper jaw displacement was calculated upon considering the antero-posterior & supero-inferior displacement of incisal edge of the anterior teeth, tip of the mesiobuccal cusp of the maxillary teeth 6, ANS and PNS. The lower jaw displacement was determined upon considering point B's displacement, incisal edge of the anterior teeth and the pogonion point.

Method of imaging & modeling

In this study we applied the 'structured coded light' technique. A coded light pattern was projected on the patient's face and then images were taken from different angles by the camera. We used a projector to create coded patterns (laser cannot be used to create coded points). Moreover, we used phase transmission in the periodic pattern. In such patterns a specific code is repeated after a specific time period. To use the periodic pattern we first project a pattern on the patient's face and take a picture, and then the pattern is transmitted as much as a single pixel and again it is projected and photographed. This process continues until the whole face is scanned. This method of coding (binary coding and phase transmission) has good precision and the density of the points whose 3D positions can be determined is high.

Data were processed with Australis software after determining the photographic coordinates of the light targets (figure 2).

Therefore, to prevent errors in reading the points a semi-automatic algorithm implemented in MATLAB software was used. After this stage the created system is ready to produce the patient's 3D data.

Photographic observations are usually subject to random and systematic errors. The least squares method is applied to remove these random errors, but there are different methods for removing systematic errors. The most important of these errors are: radial and lens distortion, difference between lens center and image center, difference of scale in two directions.

We applied the 'conditional linear equations' method in our study (equation 1).

$$x + \Delta x = -c\,\frac{m_{11}(X - Xc) + m_{12}(Y - Yc) + m_{13}(Z - Zc)}{m_{31}(X - Xc) + m_{32}(Y - Yc) + m_{33}(Z - Zc)}$$

$$y + \Delta y = -c\,\frac{m_{21}(X - Xc) + m_{22}(Y - Yc) + m_{23}(Z - Zc)}{m_{31}(X - Xc) + m_{32}(Y - Yc) + m_{33}(Z - Zc)}$$

Results

Since there were 40 images of horizontal stripes and 40 images of vertical stripes (on average for each patient), the aforementioned algorithm was repeated for all image couples –which were 1600- and the points of intersection of stripes were determined in the images. The numbers of points extracted for each image couple were on average 350 – 400, and the overall number of points extracted was 600000. Around 500 – 1000 points were used in each patient upon simplifying and reducing the points (to facilitate the use and implementation of the algorithms).

The system created was capable of producing high density 3D data of the patient's face with uniform color across the entire predicted surface.

After the 3D model was produced from the patient's face-before & after orthognathic surgery- the nonlinear changes in points showed that these changes were consistent with the following formula:

First-order approximation method

$U = a_u x + b_u y + c_u z + d_u$

$V = a_v x + b_v y + c_v z + d_v$

$W= a_w x + b_w y + c_w z + d_w$

(Equation 2)

Using the curve fitting toolbox the following quantitative equations may be achieved:

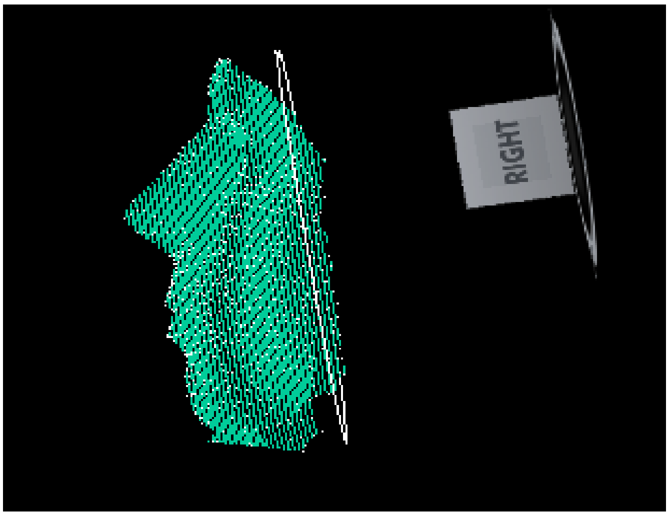
au , bu, cu, du

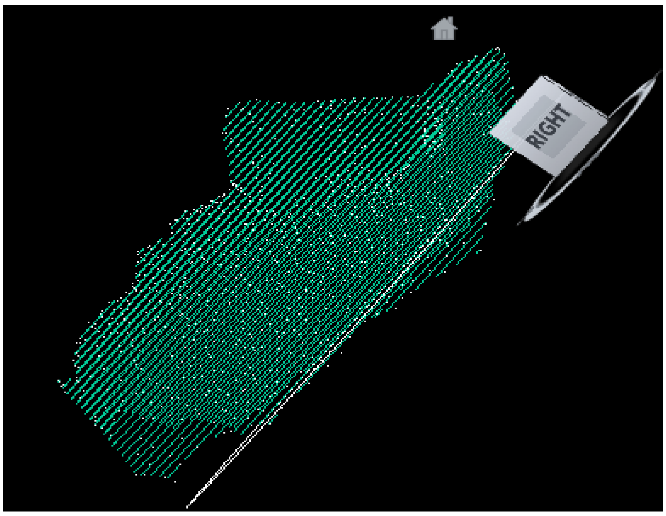
av , bv, cv, dv

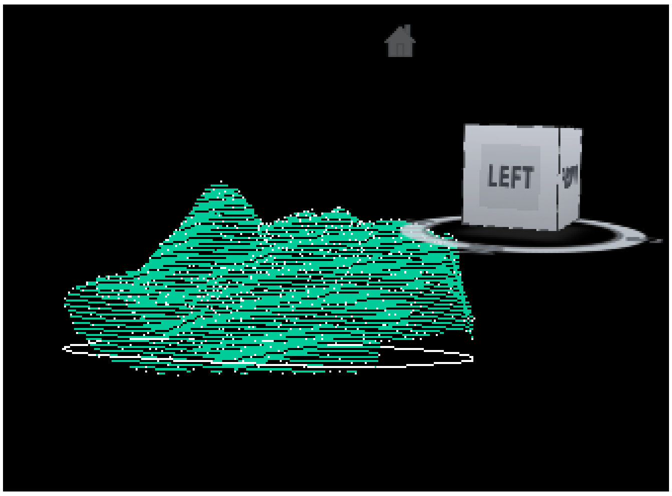
aw , bw, cw, dw

On the whole, 24 patients including 17 females and 7 males with a mean age of 21 (minimum 18 & maximum 31) who possessed the inclusion criteria were examined in this study.

Considering the low number of upper displacements this displacement has the least effect on the extent of changes in the 3D model.







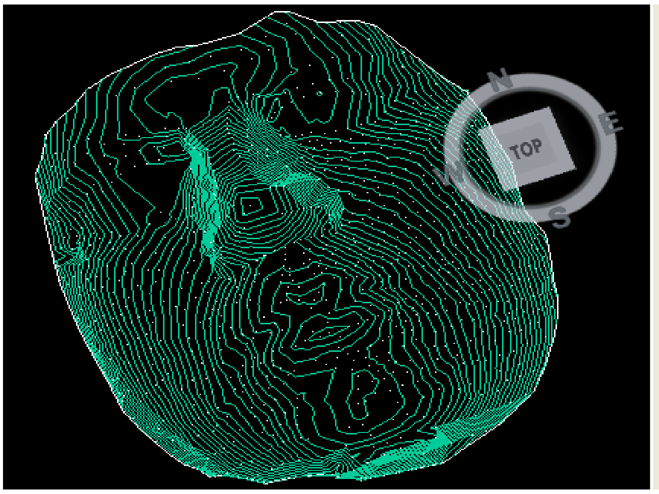


Diagram 3: 3D simulation of patient's face.

Discussion

Before & after surgery imaging is a must in all cosmetic surgeries. In this study we chose spectrophotometry as, compared to other 3D imaging techniques, it is not associated with extra costs and has no side effects for the patient. in 1996 Ras et al used spectrophotometric imaging for the measurement of facial morphology and dimensional changes during growth and development. Like us, they used landmarks that were easily measurable by others such as the lateral canthus [25-27]. Many CT Scan-associated techniques have been introduced for examining soft tissue changes with respect to the underlying bone structure. We did not superimpose hard tissue data on 3D images, and only used before & after cephalometry (measured for all patients) for approving the extent of jaw displacement. The bony structure is not accessible or palpable in 3D photography. However, setting soft tissue landmarks in the 3D model is precise, as J. M Plooji et al showed in 2009, that setting soft tissue landmarks in 3D imaging was precise and reliable. According to this study hard tissue data are not necessary for accurate soft tissue analyses [28]. However, determining bone-related landmarks such as gonion soft tissue requires greater precision. As aforementioned, using methods like laser CT scan has certain advantages but also has its own disadvantages. By superimpose CT scan images on photographs in 2000, Xia et al introduced a new method for prediction of soft tissue changes following orthognathic surgery –in line with the treatment plan. The surgical plan was simulated in a 3D model by the CT scan, which is a lengthy procedure [8-10]. In 2001 Gust et al introduced a new method for predicting soft-tissue-changes following orthognathic surgery. Measurements of facial surface before & after surgery were made once manually and once by laser scanning in the form of a 3D model. Manual measurements can be done only for a limited number of points, and the movement of the point is not examinable in the 3D environment [29].

In this study surgical treatment planning was done on the basis of surgical approach was selected according to the numerical analyses of cephalometry tracings and the patient's clinical pictures. The correlation between soft and hard tissue changes still persists as the limitation of all prediction studies, as shown in earlier studies as well. Here we tried to achieve a mathematical model for soft-tissue-changes following orthognathic Class III (BiMax) surgeries, to improve the software predicting soft-tissue-changes following surgery in the future. Only a handful of studies have presented a real mathematical model for non-linear soft-tissue-changes, such as that conducted by Xia, wherein computer-assisted color simulation of the face was done [8-10].

We studied surgeries of both jaws simultaneously in this study. Prediction studies conducted on the simultaneous surgery of both jaws versus that of one jaw showed that prediction was less possible in the former. The greatest error in prediction by computer-based programs was for the lower lip –with a<2 mm error [30]. In the current study we tried to have uniform degrees of soft tissue dissection and periosteal reflection, however, the ratio of hard tissue effect on soft tissue –which is associated with factors such as preoperative soft tissue thickness, time lapsed since surgery, post operative wound healing, differences in treatment plans and degrees of displacement were different in each patients. Rigid fixation was applied in all patients in the same manner (two L-shaped and two 4-hole straight titanium plates were used in the upper jaw and two 2.0 mm position screws were placed in the lower jaw at the superior border of the osteotomy site). To reduce error, photography was done by a single person, and the distance between the cameras was kept constant. To achieve an optimal stereoscopic effect photographs were taken simultaneously from two directions to prevent the effect of facial muscular changes. Moreover, to reduce the relapse rate regular orthodontic follow-up was advised.

References

[1] Grayson B, Cutting C, Bookstein FL, Kim H, McCarthy JG. The three-dimensional cephalogram: theory, technique, and clinical application. Am J Orthod Dentofacial Orthop. 1988 Oct; 94(4):327-37.

[2] Hajeer MY, Ayoub AF, Millett DT, Bock M, Siebert JP. Three-dimensional imaging in orthognathic surgery: the clinical application of a new method. Int J Adult Orthodon Orthognath Surg. 2002; 17(4):318-30.

[3] Ayoub AF, Wray D, Moos KF, Siebert P, Jin J, Niblett TB, Urquhart C, Mowforth R. Three-dimensional modeling for modern diagnosis and planning in maxillofacial surgery. Int J Adult Orthodon Orthognath Surg. 1996; 11(3): 225-33.

[4] Kawai T, Natsume N, Shibata H, Yamamoto T. Three-dimensional analysis of facial morphology using moire stripes. Part I. Method. Int J Oral Maxillofac Surg. 1990 Dec; 19(6):356-8.

[5] Takasaki H. Moire topography. Appl Opt. 1970 Jun 1; 9(6):1467-72.

[6] Motoyoshi M, Namura S, Arai HY. A three-dimensional measuring system for the human face using three-directional photography. Am J Orthod Dentofacial Orthop. 1992 May;101(5):431-40.

[7] Ohta N, Okada M, Sakuma K, Ide Y. A cross-sectional study of facial growth with the Moire camera. Bull Tokyo Dent Coll. 1982 Feb; 23(1):25-35.

[8] Xia J, Ip HH, Samman N, Wang D, Kot CS, Yeung RW, Tideman H. Computer-assisted three-dimensional surgical planning and simulation: 3D virtual osteotomy. Int J Oral Maxillofac Surg. 2000 Feb; 29(1):11-7.

[9] Xia J, Samman N, Yeung RW, Shen SG, Wang D, Ip HH, Tideman H. Three-dimensional virtual reality surgical planning and simulation workbench for orthognathic surgery. Int J Adult Orthodon Orthognath Surg. 2000 Winter; 15(4):265-82.

[10] Xia J, Samman N, Yeung RW, Wang D, Shen SG, Ip HH, Tideman H. Computer-assisted three-dimensional surgical planing and simulation. 3D soft tissue planning and prediction. Int J Oral Maxillofac Surg. 2000; 29(4):250-8.

[11] Sukovic P. Cone beam computed tomography in craniofacial imaging. Orthod Craniofac Res. 2003;6 Suppl 1:31-6; discussion 179-82.

[12] Kau CH, Richmond S, Palomo JM, Hans MG. Three-dimensional cone beam computerized tomography in orthodontics. J Orthod. 2005 Dec; 32(4):282-93.

[13] Mah JK, Danforth RA, Bumann A, Hatcher D. Radia-

tion absorbed in maxillofacial imaging with a new dental computed tomography device. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2003 Oct; 96(4):508-13.

[14] Quereshy FA, Savell TA, Palomo JM. Applications of cone beam computed tomography in the practice of oral and maxillofacial surgery. J Oral Maxillofac Surg. 2008 Apr; 66(4):791-6.

[15] Hell B. 3D sonography. Int J Oral Maxillofac Surg. 1995 Feb; 24(1 Pt 2):84-9.

[16] Sader R, Zeilhofer HF, Horch HH, Krol Z, Hoffmann KH, Michaelis M, Nuber B, Dettmar P. [Diagnostic possibilities of 3-dimensional imaging of ultrasound image data in mouth-, jaw- and facial surgery]. Biomed Tech (Berl). 1997;42 Suppl:211-2.

[17] Halazonetis DJ. Acquisition of 3-dimensional shapes from images. Am J Orthod Dentofacial Orthop. 2001; 119(5):556-60.

[18] Hill DL, Berg DC, Raso VJ, Lou E, Durdle NG, Mahood JK, Moreau MJ. Evaluation of a laser scanner for surface topography. Stud Health Technol Inform. 2002;88:90-4.

[19] Hayashi K, Mizoguchi I. Scanning facial surfaces with a three-dimensional laser scanner. J Clin Orthod. 2003 Jun; 37(6):299-301.

[20] Kau CH, Richmond S, Zhurov AI, Knox J, Chestnutt I, Hartles F, Playle R. Reliability of measuring facial morphology with a 3-dimensional laser scanning system. Am J Orthod Dentofacial Orthop. 2005 Oct; 128(4):424-30.

[21] Harrison JA, Nixon MA, Fright WR, Snape L. Use of hand-held laser scanning in the assessment of facial swelling: a preliminary study. Br J Oral Maxillofac Surg. 2004 Feb; 42(1):8-17.

[22] Tanner JM, Weiner JS. The reliability of the photogrammetric method of anthropometry, with a description of a miniature camera technique. Am J Phys Anthropol. 1949 Jun; 7(2):145-86.

[23] Khambay B, Nebel JC, Bowman J, Walker F, Hadley DM, Ayoub A. 3D stereophotogrammetric image superimposition onto 3D CT scan images: the future of orthognathic surgery. A pilot study. Int J Adult Orthodon Orthognath Surg. 2002; 17(4):331-41.

[24] Parhiz A, Bayat M (Superviser). Facial soft tissue changes determination following orthognathic class III (Bimax) surgeries applying photogrammetry. MS, Thesis on Oral and Maxillofacial surgery. Dental School, Tehran University of Medical Sciences, 2009, 75 pages

[25] Ras F, Habets LL, van Ginkel FC, Prahl-Andersen B. Method for quantifying facial asymmetry in three dimensions using stereophotogrammetry. Angle Orthod. 1995; 65(3):233-9.

[26] Ras F, Habets LL, van Ginkel FC, Prahl-Andersen B. Quantification of facial morphology using stereophotogrammetry--demonstration of a new concept. J Dent. 1996 Sep; 24(5):369-74.

[27] Ras F, Habets LL, van Ginkel FC, Prahl-Andersen B. Longitudinal study on three-dimensional changes of facial asymmetry in children between 4 to 12 years of age with unilateral cleft lip and palate. Cleft Palate Craniofac J. 1995 Nov; 32(6): 463-8.

[28] Plooij JM, Swennen GR, Rangel FA, Maal TJ, Schutyser FA, Bronkhorst EM, Kuijpers-Jagtman AM, Berge SJ. Evaluation of reproducibility and reliability of 3D soft tissue analysis using 3D stereophotogrammetry. Int J Oral Maxillofac Surg. 2009 Mar; 38(3):267-73.

[29] Guest E, Berry E, Morris D. Novel methods for quantifying soft tissue changes after orthognathic surgery. Int J Oral Maxillofac Surg. 2001 Dec; 30(6):484-9.

[30] Kaipatur N, Al-Thomali Y, Flores-Mir C. Accuracy of computer programs in predicting orthognathic surgery hard tissue response. J Oral Maxillofac Surg. 2009 Aug; 67(8):1628-39.

[31] Ferrario VF, Sforza C, Serrao G, Ciusa V, Dellavia C. Growth and aging of facial soft tissues: A computerized three-dimensional mesh diagram analysis. Clin Anat. 2003 Sep; 16(5): 420-33.

[32] Gur RC, Sara R, Hagendoorn M, Marom O, Hughett P, Macy L, Turner T, Bajcsy R, Posner A, Gur RE. A method for obtaining 3-dimensional facial expressions and its standardization for use in neurocognitive studies. J Neurosci Methods. 2002 Apr 15; 115(2):137-43.

[33] Okada E. Three-dimensional facial simulations and measurements: changes of facial contour and units associated with facial expression. J Craniofac Surg. 2001 Mar; 12(2): 167-74.

[34] Buckley PF, Dean D, Bookstein FL, Han S, Yerukhimovich M, Min KJ, Singer B. A three-dimensional morphometric study of craniofacial shape in schizophrenia. Am J Psychiatry. 2005 Mar; 162(3):606-8.

[35] Krimmel M, Kluba S, Bacher M, Dietz K, Reinert S. Digital surface photogrammetry for anthropometric analysis of the cleft infant face. Cleft Palate Craniofac J. 2006 May;

43(3): 350-5.

[36] Ferrario VF, Sforza C, Dellavia C, Tartaglia GM, Colombo A, Caru A. A quantitative three-dimensional assessment of soft tissue facial asymmetry of cleft lip and palate adult patients. J Craniofac Surg. 2003 Sep; 14(5): 739-46.

[37] Ferrario VF, Sforza C, Dellavia C, Vizzotto L, Caru A. Three-dimensional nasal morphology in cleft lip and palate operated adult patients. Ann Plast Surg. 2003 Oct; 51(4): 390-7.

[38] Ferrario VF, Sforza C, Dellavia C, Tartaglia GM, Sozzi D, Caru A. A quantitative three-dimensional assessment of abnormal variations in facial soft tissues of adult patients with cleft lip and palate. Cleft Palate Craniofac J. 2003 Sep; 40(5): 544-9.

[39] Ferrario VF, Sforza C, Tartaglia GM, Sozzi D, Caru A. Three-dimensional lip morphometry in adults operated on for cleft lip and palate. Plast Reconstr Surg. 2003 Jun; 111(7): 2149-56.

[40] Ji Y, Zhang F, Schwartz J, Stile F, Lineaweaver WC. Assessment of facial tissue expansion with three-dimensional digitizer scanning. J Craniofac Surg. 2002 Sep;13(5):687-92.

[41] Akazaki S, Nakagawa H, Kazama H, Osanai O, Kawai M, Takema Y, Imokawa G. Age-related changes in skin wrinkles assessed by a novel three-dimensional morphometric analysis. Br J Dermatol. 2002 Oct;147(4):689-95.

[42] Ferrario VF, Serrao G, Ciusa V, Morini M, Sforza C. Cephalometric and in vivo measurements of maxillomandibular anteroposterior discrepancies: a preliminary regression study. Angle Orthod. 2002 Dec; 72(6): 579-84.

[43] Grenness MJ, Osborn JE, Tyas MJ. Mapping tooth surface loss with a fixed-base stereo camera. Photogrammetric Record. 2008 Jun; 23(122): 194-207.

[44] Moss JP, Ismail SF, Hennessy RJ. Three-dimensional assessment of treatment outcomes on the face. Orthod Craniofac Res. 2003; 6 Suppl 1:126-31; discussion 79-82.

[45] Chong AK, Milburn P, Newsham-West R, ter Voert M. High-Accuracy Photogrammetric Technique for Human Spine Measurement. Photogrammetric Record. 2009 Sep; 24(127): 264-79.

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