ASDJ
AINSHAMS DENTAL JOURNAL

Print ISSN 1110-7642
Online ISSN 2735-5039

AIN SHAMS DENTAL JOURNAL
Official Publication of Ain Shams Dental School
September 2021 • Vol. XXIV

The Prediction Accuracy of soft tissue changes following orthognathic surgery using Dolphin 3D Software package; A pilot study

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Abstract:
The three-dimensional planning software packages are widely used for prediction planning of the soft tissue changes of orthognathic surgery. This study evaluated the accuracy of Dolphin 3D software in the prediction of facial soft tissue changes following bimaxillary osteotomy for the correction of dentofacial deformities. The study was conducted on seven class III patients who had undergone maxillary advancement and mandibular setback. All the study subjects had preoperative (T0) and at least 6 months postoperative (T1) cone-beam computed tomography scans for planning and postoperative evaluation. The actual surgical movements of the osteotomy segments were quantified to generate 3D soft tissue simulation using the software. The difference between the prediction and the actual soft tissue changes following surgery were measured at 13 cephalometric landmarks. The prediction accuracy was more accurate at certain landmarks than others. The mean prediction error was 2.78 mm. In conclusion, the software has a limited prediction accuracy of the soft tissue changes of bimaxillary osteotomy. This should be taken into consideration in clinical prediction planning of the surgical correction of dentofacial deformities.
Keywords: 3D assessment, Class III, Dentofacial deformity, Orthognathic surgery, Prediction.

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Introduction:

The utilization of digital workflow for orthognathic surgery planning for the correction of dentofacial deformities is the de facto standard for orthognathic surgery. Previous studies provided the clinician with some insight into the soft tissue response to the skeletal changes due to the surgical movements of osteotomy segments of the jawbones (1,2). The shortcomings of the two-dimensional (2D) software based on cephalometric analysis and treatment simulation are well reported. With the emergence of three-dimensional (3D) diagnostic methods and computerized analysis processes (3–5), the precision of 3D virtual planning proved to be more accurate than the 2D techniques (6–10). One of the main advantages of 3D imaging is the accurate recording of the natural head position of the patient and the visualization of the inter-occlusal relationship of the 3D dental models. (11) The superimposition of the soft tissue texture into the CBCT 3D facilitates virtual treatment planning. This is likely to improve the surgical outcomes and patients' satisfaction with the surgical treatment (12). This study aims to quantitatively evaluate the accuracy of the 3D soft tissue predictions generated of Dolphin 3D maxillofacial planning system (Dolphin Imaging & Management Solutions, Chatsworth, CA, USA) in patients who had had bimaxillary osteotomy for correction of dentofacial deformities.

MATERIALS & METHODS

This pilot study was conducted on seven patients who had undergone bimaxillary orthognathic surgery to correct maxilla-mandibular deformities. Based on 90% accuracy according to Resnick CM et al (2016), the expected effect size of the prediction accuracy of linear measurements was 1.05, at alpha (α) error of (5%) and Beta (β) error of (20%) i.e. power = 80%; the calculated sample size was 7 subjects (G*Power Version 3.1.9.2). The virtual simulation of the surgery and the soft tissue prediction were performed using Dolphin 3D software. The prediction planning was compared with the actual postoperative soft tissue changes to evaluate the software prediction accuracy. The patients were selected from the outpatient clinics of the Oral and Maxillofacial Surgery Department at the Faculty of Dentistry of Ain-Shams University. The study was reviewed by the Research Ethical Committee affiliated with the Faculty of Dentistry, Ain Shams University.

The following inclusion criteria were considered; Patients had facial deformity and had undergone bimaxillary orthognathic surgery, the availability of preoperative and at least 6 months postoperative CBCT scans. Exclusion criteria included Craniofacial anomalies, cleft lip/palate, Previous maxillofacial surgeries or facial scars, Multi-segment Le Fort I osteotomies. Orthodontic appliances removed at the time of T1 records.

Before capturing each CBCT image, the patients were asked to maintain the natural head position, and relax the facial muscles at the rest position. Reaching the natural head position of each patient was achieved by placing a full-length mirror in front of the patient and asking them to look straight at the mirror while sitting on the CBCT machine chair.

Assessment of the actual skeletal movements

The pre and post-operative CBCT scans were imported to Dolphin 3D software. The preoperative CBCT scans were selected to be the primary image for the superimposition of the postoperative one. The region of interest was selected as a 3D box involving the anterior cranial base then automated voxel-based registration was performed. The Direct slice landmarking using Dolphin 3D software, these were used to measure the magnitude and direction of the actual maxillary and mandibular movements. This technique was applied by identifying Eight landmarks (3 in the maxilla and 5 in the mandible) on the preoperative DICOM images. The 3D coordinates (x, y, and z) of the 8 landmarks were exported to Microsoft EXCEL (Microsoft®, Redmond, CA) for further analyses. The same procedure was repeated for the post-operative slice images, then the actual surgical movement in each dimension of space was calculated and saved.

Table 1: Characteristics of the study sample

No.	*Gender*	*Age*	*Sagittal maxilla*	*Sagittal mandible*	*Vertical maxilla*	*Vertical mandible*
1	Female	17.2	6	4	0	4
2	Male	21.7	4	6.5	7	1.7
3	Female	19.3	5	13	1	1.5
4	Female	19.7	4.5	1.5	0	1.5
5	Female	18.5	6	3.5	1	3
6	Male	23.1	4	3	3	7
7	female	28.2	5	4	0	1

Simulation of soft tissue changes:

A virtual orthognathic surgery was performed on the preoperative CBCT scans to mimic the actual skeletal movements using the virtual surgical planning tool of Dolphin 3D software and a 3D prediction planning was. The CBCTs were segmented into separate anatomical units (maxilla, mandible), exported as an STL file then virtual osteotomies were performed on the T0 CBCT volumes using the 3D surgical planning facility of the software "Dolphin 3D surgery module". The preoperative maxillary and mandibular segments were virtually moved according to the measured surgical movements, this generated a 3D soft tissue prediction image (TP).

Assessment of the prediction accuracy

The inaccuracies of the soft tissue prediction between the simulated (TP) and the actual changes were measured for each case at each of 13 standard anthropometric or cephalometric landmarks, Nine midline and four lateral (Table 2). (13,14) .

Table 2: Points Of Analysis

1	*Rhinion (R)*	Junction of the bony and cartilaginous nasal dorsum
2	*Pronasale (P)*	Most protruded point of the apex nasi
3	*Subnasale (Sn)*	The midpoint of the angle at the columella base where the lower border of the nasal septum and the surface of the upper lip meet
4	*Soft tissue A point (A')*	Point of greatest concavity on the contour of the upper lip
5	*Soft tissue B point (B')*	Point of greatest concavity on the contour of the lower lip
6	*Labrale Superioris (Ls)*	Most anterior point of the upper lip at the mucocutaneous junction
7	*Labrale Inferioris (Li)*	Most anterior point of the lower lip at the mucocutaneous junction
8	*Soft tissue pogonion (Pg')*	*Most anterior point of the soft tissue chin*
9	*Stomion Superioris (Stms)*	The lowest point of the upper lip vermilion
10	*Subalare (sbal) right side*	Most lateral point in the curved baseline of each ala
11	*Subalare (Sbal) left side*	Most lateral point in the curved baseline of each ala
12	*Chelion (Ch.r) right side*	The point located at each labial commissure
13	*Chelion (Ch.l) left side*	The point located at each labial commissure

Landmarking errors

To assess the landmarking error a set of 13 landmarks were re-digitized by the same researcher twice at two-week interval. The shortest distances between the repeated landmarks were calculated using the Pythagoras equation and the statistical significance of the positional differences of the repeated landmark digitization was analyzed.

Distance errors larger than 2 mm were considered clinically significant, a reasonable threshold of the visually noticeable facial change (15). Color maps were generated to visually evaluate the difference between the actual postoperative and the simulation STLs. (Fig.1) Using VRMESH software, the differences in the corresponding vertices position was analyzed. The distances between the simulation and postoperative STLs were measured in millimeters and displayed in a color map ranging from red color over prediction to blue color representing under prediction, the green color represented an excellent match between the two surface meshes denoting perfect prediction. The color intensity on both sides of the scale represents the magnitude of the disparity between the two surface meshes. The statistical analyses were performed using IBM SPSS Statistics version 21.0 (IBM Corp., Armonk, NY, USA).

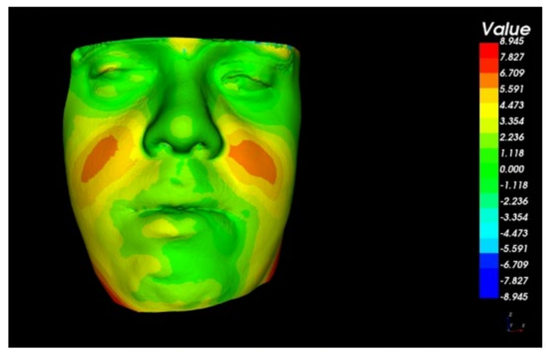

Figure 1: A colour map showing the error of prediction

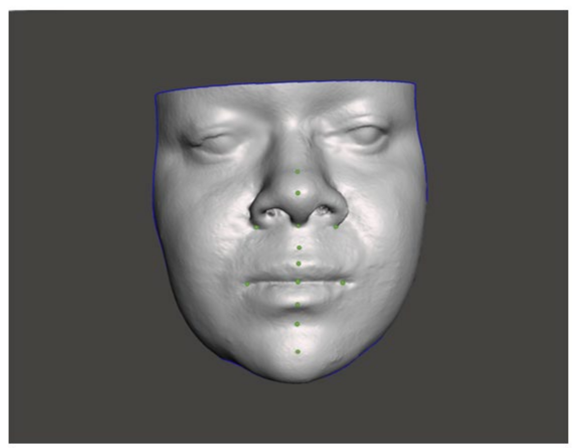

Figure 2 Three Dimensional Points for measurement.

Results:

The average age for the study sample was 21.1 years at the time of the surgery. Five (71.4%) were female. All the subjects presented with maxillary sagittal hypoplasia and mandibular prognathism. The T0 images were captured at a mean of 1.1 months before the surgery, and the postoperative CBCTs were captured at a mean of 14 months postoperatively. The average skeletal changes of the maxilla were 4.9mm of sagittal advancement and 1.7 mm of vertical shortening measured at ANS. The average posterior surgical movements of the mandibular osteotomy was 5.17 mm setback, and 2.9 mm vertical shortening measured at the pogonion. The overall mean prediction error across all linear measurements of corresponding landmarks was 2.8 mm. The mean prediction error for points in the midline was 2.47 mm and for lateral points, it was 3.6 mm. In the midsagittal points, the least difference between the TP and T1 images was seen at rhinion (mean error 1.5 mm) and the greatest prediction error was at Labrale superiors (mean error 3.1 mm). Of the lateral points, the most accurate prediction was at the left cheilion (mean error 3.1 mm) and the least accurate was the lateral left ala (mean error 4.1 mm). The mean prediction errors of the midline points exceeded 2 mm, but these were not statistically significant ($P > 0.05$). While the inaccuracies in the prediction of the lateral soft tissue points exceeded the 2 mm linear error threshold ($p< 0.05$). The mean landmarking error for all the set of used points was 0.63 mm ± 0.22 mm.

Discussion

With the quantum technological leap that was observed in the last two decades in the field of volumetric bony and soft tissue capturing, the paradigm has been shifted in the planning of orthognathic surgery cases using 3D virtual prediction planning which was the topic of our study. We followed strict inclusion criteria in this research to maximize the homogeneity of the sample. Only patients who had CBCT scans taken no more than 3 months preoperatively and at least 6 months postoperatively were included. The preoperative CBCT scans were acquired one month preoperatively to avoid any changes in the soft tissue due to preoperative orthodontic movements. The postoperative CBCT scans were acquired more than six months postoperatively to make sure that all soft tissue edema has subsided.(16) It has been reported that the post-operative swelling declines to about 90% within 3 months after bimaxillary surgery (17) and fully recovers 6 months following surgery. (18) CBCT facial scans were validated for their accuracy in capturing facial images (19–24). Farman et al., 2006 reported that the soft tissue definition of the CBCT was sufficient to determine soft tissue air boundaries (23). Moerenhout et al., 2009 used a dummy head to evaluate the 3D surface accuracy of soft tissue obtained from a CBCT scan. They found that the 3D surface of the facial soft tissues segmented out of CBCT scans was precise and equivalent to a laser surface scan (22). Kau et al., 2005 stated that The CBCT is a superior for capturing hard and soft tissues (20). Furthermore, it offers less radiation dose in comparison to the CT scans (20,25,26) and produces fewer artifacts. This is desirable as to minimize the steak artifacts of the metallic orthodontic brackets, especially with the presence of the built-in artifact reduction protocol of the ICAT machine. The sitting position for capturing the CBCT scans has the advantage of capturing the soft tissue profile of the patient in the natural head position without deformation which may occur with the supine position in the CT machine gantry.

Dolphin software is one of the most widely spread used 3D virtual planning software worldwide and many studies were conducted to prove its prediction accuracy. Several studies evaluated the 3D soft-tissue simulation accuracy using the CBCT segmented (7,27–29). Wang and Yang reported an absolute prediction error less than 0.5 mm using a finite element morphing algorithm, (30) others assessed the soft tissue prediction accuracy in orthognathic surgery using mass-spring model and reported prediction errors of 0.27-1.17 mm. (31,32) Liebregts and colleagues studied the errors associated with the mass-spring model and reported a mean soft tissue prediction error of only 0.81 mm; but the heterogeneity of the study sample was a major limitation. Comparing the magnitude of prediction errors and with other studies based on various orthognathic software was challenging due to the heterogeneity in the study groups, the type of the studied deformity, the wide range regarding the magnitude and direction of the surgical correction, and method used for analysis. It is the authors opinion that the soft tissue prediction errors of Dolphin software were higher than other orthognathic packages was due to the inherent weakness in the soft tissue prediction algorithm of dolphin software that does not take in consideration the geometrical characteristics and variations of soft tissue morphology.

Several studies reported the limited prediction accuracy of the Delphin software package.(33,34) Resnick et al , reported limited accuracy with single jaw maxillary advancement with an overall error across all the facial landmarks of 2.91mm which was in accordance with the results of our study. Knoops etal (35) applied the generic facial mesh to assess the simulation error of soft tissue changes and reported an overall RMS error after single jaw maxillary advancement surgery of 1.8 mms. They studied the prediction accuracy of soft tissue changes following orthognathic surgery, in their analysis they included all the mesh nodes in the area of the midface involving those with minimal or no change which diluted the prediction error. This is different from our study where the evaluation of the prediction included the set of the landmarks which are directly affected by the surgical movements. Elshebiny et al., in 2018 (33) concluded an overall limited prediction accuracy for dolphin 3D when used a set of linear distances and angular measurements for the analysis of the prediction accuracy.

The absolute measurements were considered in our study, irrespective of the direction. The signed measurements would have underestimated the prediction errors as the positive and negative values would have cancelled each other.

The small sample size in this study was the main limitation, this was secondary to the strict inclusion criteria which were considered to minimize cohort variability. In addition, the use of limited set of anatomical landmarking for the analysis is an added weakness as it under-utilizes the 3D captured data. Only few landmarks were digitized to describe a complex facial surface. The positional changes of these landmarks describe a change in an isolated point not the change in surface morphology. The associated error of landmark identification, despite being acceptable, added to the overall error of this method of analysis.

The statistical findings of the study indicate that the clinician can cautiously rely on dolphin 3D software for soft tissue prediction in class III cases for the midline regions but less reliable at the lateral facial regions. The most accurate prediction was at the left cheilion (mean error 3.12 mm) and the least accurate was the lateral left ala (mean error 4.10 mm). The difference between the two sides of the face is due to the fact that in some of the cases there were artefacts at the region of the left ala which made the landmarking process more challenging and may have contributed to the slightly higher prediction error at the left ala region.

The future research studies should be directed towards individual patient prediction planning according to the soft tissue characteristics of the nasolabial region. One of the promising soft tissue computational strategies is the "Probabilistic finite element model" introduced in 2018 by knoops etal (36). This algorithm used optimized population-specific soft tissue material properties to offer a more customized soft tissue prediction and also respects different factors and uncertainties in the patient, planning, simulation, and execution processes that contributes to the accuracy of soft tissue simulation.

In conclusion, this study showed that the limited accuracy of Dolphin 3D in soft tissue prediction of bimaxillary orthognathic surgery, this was more pronounced at the lateral points of the face.

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