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Original Article

Evaluation of two different imaging software programs in planning orthognathic surgery cases

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Abstract

Aim: In this study, we aimed to compare the two-dimensional predictions made by two computer software packages with the postoperative values, and thus to evaluate the clinical reliability of digital orthognathic surgery planning.

Methodology: Orthodontic treatment was performed before orthognathic surgery, and the same surgical team performed double-jaw orthognathic surgeries. We included 20 individuals (10 females, 10 males) with skeletal Class III malocclusion. The average age of the individuals was 21.5 years. In our study, the amount of movement was determined using reference lines on lateral cephalometric radiographs obtained from the preoperative and postoperative Cone-Beam Computed Tomography (CBCT) records of 20 individuals. Prediction profiles were formed using Dolphin Imaging (Dolphin Imaging & Management Solutions, Chatsworth, CA, USA) and NemoFAB 2D (Software Nemotec, S.L, Spain) computer softwares. In this way, the reliability and consistency of two-dimensional prediction software were examined.

Results: The prediction profiles obtained from the computer software were compared with lateral cephalometric radiographs of the postoperative surgery results for 37 cephalometric parameters. There were no significant differences between software predictions and postoperative results in any cephalometric parameters.

Conclusion: The plans and predictions made with the two computer software packages were reliable and can be used clinically.

Keywords: Planning, orthognathic surgery, Class III anomaly, CBCT, Dolphin Imaging, NemoFAB

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Introduction

The most common disorders rehabilitated by orthognathic surgery are maxillary and mandibular retrusions (1). In functional Class III anomalies, the maxilla and mandible are of normal size, but the mandible is positioned anteriorly during closure due to factors such as early contact and hypertrophic tonsils. If functional Class III anomalies are not treated, they may turn into morphological anomalies (2, 3). Orthognathic surgery is indicated in the treatment of Class III malocclusion if growth and development have been completed (4). Bilateral sagittal split osteotomy is the most well-known orthognathic surgery performed on the mandible, and mandibular anomalies can be treated using this method. In the maxilla, this surgery is called Le Fort I osteotomy (5-7).

In orthognathic surgery applications, the final aesthetic result is determined by the movement of bone structures and the changes that occur in the surrounding soft tissues due to this movement. These soft tissues do not change by the same amount as the skeletal structure (8). Predicting these changes at a consistent level is critical to the success of orthognathic surgery. To predict final appearance after orthognathic surgery, traditional methods have lost popularity in the face of developing computer technologies. In addition to software that provides three-dimensional prediction, computer software that provides two-dimensional prediction based on lateral cephalometric films is frequently used to predict the outcome of surgery (9).

CBCT has an important role in diagnosis and treatment planning since the time it was introduced to the field of dentistry. Since its development, the CBCT has become widely used for the assessment of volumetric data, providing high quality images with low-dose radiation. Many imaging softwares have been developed since that time, presenting different sofware user interfaces, tools, and features that make imaging analysis relatively simple (10, 11).

In this study, two-dimensional predictions made with computer software were compared to postoperative values, to investigate whether orthognathic surgery predictions and plans made with programs are clinically safe and accurate.

Materials and Methods

Subjects

The study group consisted of patients who received orthodontic treatment at Dicle University, Faculty of Dentistry, Department of Orthodontics between 2014 and 2020, and whose orthognathic surgery was performed in Dicle University, Faculty of Medicine, Department of Plastic and Reconstructive Surgery. These patients had skeletal Class III anomalies, and CBCT records were obtained before and at least six months after surgery. This study followed the Declaration of Helsinki on medical protocol and ethics, and the regional Ethical Review Board of Dicle University approved the study (approval number 2019/02).

Computed tomography images were selected from archive data obtained using an i-CAT (Imaging Sciences International, Hatfield, PA) Cone-Beam Computed Tomography device in the Dicle University's Faculty of Dentistry, Department of Oral Diagnosis and Radiology. Tomography images were obtained by adjusting the device at the settings of 5.0 mA, 120 kV, voxel thickness of 0.3 mm, 360-degree rotation, and image to be taken in 9.6 seconds.

Attention was paid to the absence of a congenital anomaly (cleft lip and palate, a genetic syndrome, etc.), tumors, and so on. It was noted that subjects had completed their growth and development and had skeletal Class III malocclusion (ANB <0°), and no surgical application was performed before orthognathic surgical treatment in the upper and lower jaws. In double-jaw operations, attention was paid to the use of Le Fort I osteotomy in cases involving the maxilla, and sagittal split osteotomy was used in cases involving the mandible.

The experimental group of our study consisted of 20 cases (10 males, 10 females) with Class III skeletal anomalies, out of a total of 40 cases that met the inclusion criteria. The cases were divided into two groups: 10 cases who had undergone maxillary advancement and downgrade with mandibular set back (Group 1), and 10 cases who had undergone maxillary impaction and advancement with setback operation (in this group, after the maxilla has been brought forward and buried, the mandible is rotated counterclockwise and there is only an angular relative progression, but the surgical intervention in the mandible is basically the set-back procedure) (Group 2). The age statistics of the cases are shown below (Table 1). The same orthodontic treatment protocol was applied to all patients included in the study.

Operation

The surgical arch was prepared from 0.016 x 0.022 inch/stainless steel wire for 0.018" slot brackets. Lateral cephalometric radiographs, anteroposterior radiographs, panoramic films, and CBCT recordings were taken of the patients on the same day. To make surgical splints, measurements were taken from the patients and plaster models were obtained. The plaster models obtained were taken into articulators by means of a face arc. For this purpose, the SAM 3 professional articulator kit (SAM 3 AX MPS, SAM Dental, Gauting, Germany) was used. The splint production phase started after the surgical plan was made using the lateral cephalometric films taken from the patient, and after the amount of jaw movement was determined.

During the operation, the maxilla was mobilized using the Le Fort I incision line with the help of osteotomes for maxillary advancement. The maxilla was fixed to the mandible with the help of the prepared splint and fixed in its new position with titanium plates and screws (L plate anteriorly, flat plate posteriorly), one of the rigid internal fixation methods. After maxillary movement, the mandible was mobilized with bilateral sagittal split osteotomy, then fixed to the maxilla by splint and fixed in its new position with plates and screws. Postoperative orthodontic treatment was started after an average of four weeks.

Lateral Cephalometric Radiographs

In our study, CBCT recordings were used, and cephalometric films of the patients recorded before and at least six months after the operation were obtained from these records using Dolphin Imaging 11.95 software.

Cephalometric Analysis

The same cephalometric analysis and anatomical landmarks were used in both the Dolphin Imaging prediction and the NemoFAB 2D prediction. The 24 soft tissue and hard tissue reference points that we used for this purpose are shown in Figure 1.

Changes were recorded by measuring the distances from hard tissue and soft tissue points to both horizontal and vertical reference planes as determined by using the cephalometric films obtained from the CBCT recordings taken before the surgery and at least six months after the surgery (Fig. 2).

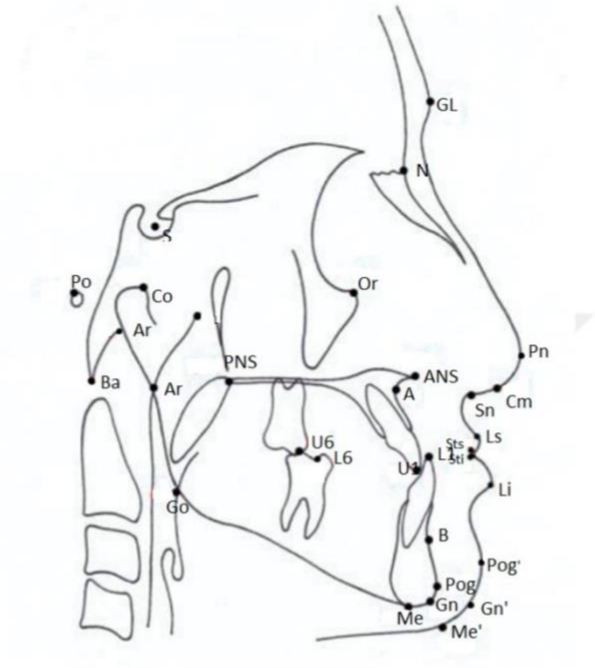

Figure 1. Reference points used in lateral cephalometric films

In order to determine the amount of linear and angular movement of the maxilla and mandible, cephalometric drawings were made before and after the operation using reference planes (Figs. 2 and 3). After this process, the amount of movement was determined by using the displacement amounts of the determined points. Prediction profiles and cephalometric data were obtained by recording the detected amounts of motion in the planning parts of the two software packages.

Some of the abbreviations used in this paper are as follows:

- SNA: the angle between the SN and NA planes.
- ANB: the angle between the NA and NB planes.
- FMA: the angle between the mandibular plane and FH.
- GoGnSN: angle between Go-Gn and SN planes.
- U1-NA: the perpendicular distance of the incisal point of the upper central incisor to the NA line.
- L1-NB: the perpendicular distance of the incisal point of the lower central incisor to the NB line.
- IMPA Angle: the angle between the most advanced lower incisor and the mandibular plane.

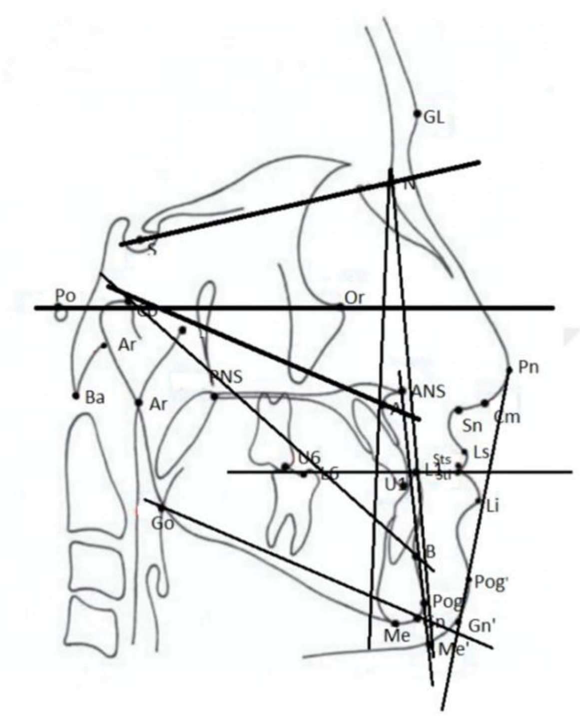

Figure 2. Some of the dimensional parameters used in lateral cephalometric films

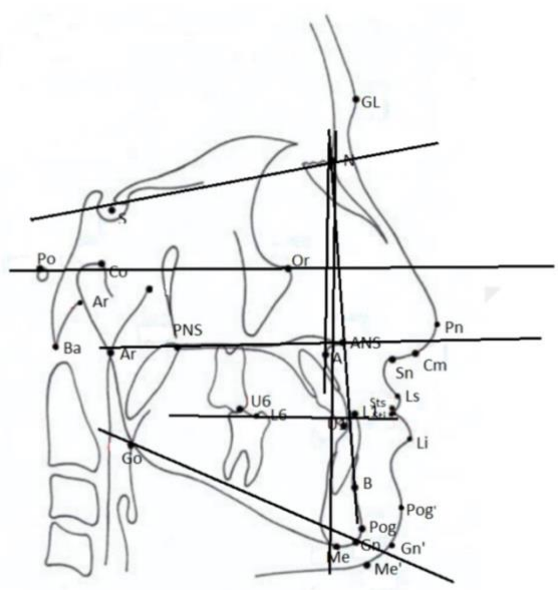

Figure 3. Some of the angular parameters used in lateral cephalometric films

Statistical analysis

The data were analyzed using the SPSS 25 software (IBM SPSS Inc., Armonk, NY, USA) at a confidence level of 95%. Mean (X) and standard deviation (SD) statistics are given for numerical (quantitative) variables. There were 10 patients in each group. Due to the low sample size (<30), nonparametric methods were used in the analysis.

In the study, the Mann-Whitney test, the Wilcoxon test, and the Spearman correlation test were used. The Mann-Whitney test was used to determine method error, the Wilcoxon test was used to compare Dolphin Imaging 11.95 and NemoFAB 2D preoperative cephalometric values with postoperative cephalometric values, and the Spearman correlation test was used to test the success of the programs.

Results

There were no statistically significant differences between the real groups and method groups in Group 1 and Group 2 separately in terms of preoperative and postoperative Dolphin Imaging 11.95 and NemoFAB 2D measurements ($p>0.05$) (Supplementary Table 1). Actual measurements and computer-modeled measurements did not differ in either group. There was no method error. The preoperative and postoperative measurements in Group 1 and Group 2 and the differences between these values are shown in Table 2.

Mean and standard deviation statistics of postoperative measurements, Dolphin Imaging 11.95 and NemoFAB 2D measurements, and statistics of normal and standard deviation values are shown in Table 3.

In Group 1, there was a significant and strong association between postoperative measurements and Dolphin Imaging 11.95 and NemoFAB 2D program measurements of the following parameters ($p<0.05$): NA perpendicular-A (mm), SNA (°), ANB (°), SNB (°), mandibular length (Co-Gn) (mm), convexity angle (NA-APo) (°), maxillary height angle (N-CF-A) (°), effective maxillary length (Co-A) (mm), Wits appraisal (mm), occlusal plane/SN angle (°), lower anterior facial height (ANS-Me)(mm), palatal-mandibular plane angle (PP-MP) (°), FMA angle (MP-FH) (°), articular angle (°), gonial angle (°), SN-GoGn (°), sum of posterior angles (°), Jarabak ratio (%), U1-NA (mm), interincisal angle (U1-L1) (°), nasolabial angle (Col-Sn-UL) (°), Pog-NB (mm), overjet (mm), overbite (mm), Co-B value (mm), NA perpendicular-Pg (mm), posterior facial height (S-Go) (mm), and anterior facial height (NaMe) (mm) (Table 4). No parameters gave highly inconsistent results.

In Group 2, there was a significant and strong association between postoperative measurements and Dolphin Imaging 11.95 and NemoFAB 2D program measurements of the following parameters ($p<0.05$): NA perpendicular-A (mm), SNA (°), ANB (°), SNB (°), maxillary depth angle (FH-NA) (°), mandibular length (Co-Gn) (mm), convexity angle (NA-APo) (°), effective maxillary length (Co-A) (mm), Wits appraisal (mm), occlusal plane/SN angle (°), SN-palatal plane angle (°), facial axis angle (NaBa-PtGn) (°), palatal-mandibular plane angle (PP-MP) (°), FMA angle (MP-FH) (°), saddle angle (SN-Ar) (°), articular Angle (°), SN-GoGn (°), sum of posterior angles (°), Jarabak ratio (%), IMPA angle (°), Pog-NB (mm), Overjet (mm), Co-B value (mm), NA perpendicular-Pg (mm), posterior facial height (S-Go) (mm), and anterior facial height (NaMe) (mm) (Table 4). The programs gave very consistent results for these measurements. No parameters gave highly inconsistent results.

In the advanced correlation test (comparing program success within groups and between groups), the success of the Dolphin Imaging 11.95 and NemoFAB 2D measurements in Group 1 did not show a significant difference ($p>0.05$). In Group 2, the success of the Dolphin Imaging 11.95 and NemoFAB 2D measurements did not show a significant difference ($p>0.05$). The success of the Dolphin Imaging 11.95 measurements in Group 1 and the success of the Dolphin Imaging 11.95 measurements in Group 2 did not show a significant difference ($p>0.05$). The success of the NemoFAB 2D measurements in Group 1 and the success of the NemoFAB 2D measurements in Group 2 did not show a significant difference ($p>0.05$).

On the basis of these results, it was determined that the programs were successful in many measurements in both groups. The programs did not show any differences in terms of success within the groups or between the groups.

Table 1. Age statistics for individuals at the beginning and end of treatment

	Group 1 (n=10)	Group 2 (n=10)	Group 1 (n=10)	Group 2 (n=10)
	Mean	Std. Deviation	Mean	Std. Deviation
Pre-operation	21.40	2.95	23.40	8.49
Post-operation	21.70	3.09	23.90	8.43

Table 2. Comparison of preoperative and postoperative measurements

		Group 1			Group 2		
		Real mean±sd	Norm±sd	p-value	Real mean±sd	Norm±sd	p-value
Na Perpendicular-A (mm)	Pre-operation	0.34±4.35	0±2	0.007*	-0.08±6.15	0±2	0.005*
	Post-operation	5.74±4.02	0±2		6.19±4.5	0±2	
SNA (°)	Pre-operation	78.22±3.58	82±3.5	0.005*	77.07±6.47	82±3.5	0.005*
	Post-operation	82.64±3.63	82±3.5		84.39±5.37	82±3.5	
ANB (°)	Pre-operation	-4.34±2.6	1.6±1.5	0.005*	-3.98±2.37	1.6±1.5	0.005*
	Post-operation	0.66±2.39	1.6±1.5		2.24±1.68	1.6±1.5	
SNB (°)	Pre-operation	82.57±5.08	80.9±3.4	0.385	81.05±5.79	80.9±3.4	0.138
	Post-operation	81.98±4.83	80.9±3.4		82.12±5.13	80.9±3.4	
Maxillary depth angle (FH-NA) (°)	Pre-operation	90.35±4.33	90±3	0.007*	90.1±5.92	90±3	0.007*
	Post-operation	95.68±3.82	90±3		96.46±4.8	90±3	
Mandibular length value (Co-Gn) (mm)	Pre-operation	128.4±5.62	120.5±4	0.721	128.59±7.06	120.5±4	0.262
	Post-operation	126.51±7.41	120.8±4		127.51±7.58	120.8±4	
Convexity angle (NA-APo) (°)	Pre-operation	-11.74±4.3	1.1±2.5	0.005*	-10.88±5.29	1.1±2.5	0.005*
	Post-operation	-1.63±4.24	1.1±2.5		1.08±4.91	1.1±2.5	
Effective maxillary length (Co-A) (mm)	Pre-operation	80.51±2.74	90±5	0.005*	80.44±5.17	90±5	0.007*
	Post-operation	85.78±3.95	90±5		85.39±5.05	90±5	
Wits appraisal (mm)	Pre-operation	-9.32±5.8	-1±1	0.028*	-9.91±4.31	-1±1	0.005*
	Post-operation	-4.57±3.34	-1±1		-3.92±4.63	-1±1	
Occlusal plane/SN angle (°)	Pre-operation	15.01±4.66	14.4±2.5	0.515	17.05±9.1	14.4±2.5	0.721
	Post-operation	16.26±5.85	14.4±2.5		16.95±8.56	14.4±2.5	
Lower facial height (ANS-Me) (mm)	Pre-operation	68.29±6.27	70.4±5	0.221	71.75±7.09	70.4±5	0.307
	Post-operation	66.31±4.91	70.4±5		70.92±7.83	70.4±5	
SN-Palatal plane angle (°)	Pre-operation	9.29±3.49	7.3±3.5	0.022*	7.97±5.04	7.3±3.5	0.959
	Post-operation	12.93±3.4	7.3±3.5		7.14±6.51	7.3±3.5	
Facial axis angle (NaBa-PtGn) (°)	Pre-operation	91.39±3.55	90±3.5	0.203	86.31±4.44	90±3.5	0.953
	Post-operation	89.54±2.84	90±3.5		86.45±2.89	90±3.5	
Palatal/Mandibular plane angle (PP-MP) (°)	Pre-operation	26.35±8.37	25±6	0.760	30.61±8.14	25±6	0.575
	Post-operation	25.64±5.79	25±6		30.12±6.59	25±6	
FMA angle (MP-FH) (°)	Pre-operation	23.52±8.91	23.9±4.5	0.114	24.59±7.24	23.9±4.5	0.683
	Post-operation	25.54±8	23.9±4.5		24.15±5.83	23.9±4.5	
Saddle angle (SN-Ar) (°)	Pre-operation	125.81±6.27	124±5	0.507	122.9±6.76	124±5	0.012*
	Post-operation	126.54±7.76	124±5		120.96±6.93	124±5	
Maxillary height angle (N-CF-A) (°)	Pre-operation	58.88±4.05	55.5±3	0.110	63.78±2.87	55.5±3	0.114
	Post-operation	60.54±2.32	55.5±3		61.08±6.05	55.5±3	
Articular angle (°)	Pre-operation	137.74±4.81	141±6	0.610	138.1±6.17	141±6	0.047*
	Post-operation	136.25±9.08	140.8±6		139.55±7.35	140.8±6	
Gonial angle (°)	Pre-operation	132.26±8.21	x±x	0.007*	137.01±6.12	x±x	0.037*
	Post-operation	136.31±7.68	x±x		135.21±4.84	x±x	
SN - GoGn (°)	Pre-operation	32.72±7.01	32.9±5.2	0.013*	35.1±8.39	32.9±5.2	0.475
	Post-operation	35.27±6.93	32.9±5.2		34.5±5.28	32.9±5.2	
Sum of posterior angles (°)	Pre-operation	395.65±7.4	388.6±6	0.015*	397.58±9.07	388.6±6	0.646
	Post-operation	398.59±6.67	388.2±6		397.23±6.21	388.2±6	
Jarabak ratio (%)	Pre-operation	69.51±7.39	64.5±1.5	0.021*	67.92±8.66	64.5±1.5	0.507
	Post-operation	66.77±6.67	63.5±1.5		66.77±6.43	63.5±1.5	
Mandibular Plane/Occlusal plane angle (°)	Pre-operation	20.65±7.09	17.04±5	0.285	20.55±3.56	17.04±5	0.646
	Post-operation	22.34±4.06	17.1±5		20.3±4.45	17.1±5	
U1 - N A (mm)	Pre-operation	7.52±2.66	4.3±2.7	0.021*	5.67±3.35	4.3±2.7	0.203
	Post-operation	5.86±2.43	4.3±2.7		4.11±1.78	4.3±2.7	
L1 - NB (mm)	Pre-operation	3.49±1.55	4±1.8	0.514	5.02±1.27	4±1.8	0.609
	Post-operation	3.93±1.33	4±1.8		4.72±0.95	4±1.8	
IMPA angle (°)	Pre-operation	83.21±8.29	90±4.5	0.445	86.3±6.76	90±4.5	0.037*
	Post-operation	81.73±6.03	90±4.5		82.78±5.94	90±4.5	
Interincisal angle (U1-L1) (°)	Pre-operation	134.07±7.28	130±6	0.878	131.71±7.38	130±6	0.508
	Post-operation	133.89±6.08	130±6		133.9±8.76	130±6	

Upper Lip -E plane (mm)	Pre-operation Post-operation	-7.56±1.5 -4.61±1.93	-5.41±2 -5.52±2	0.005*	-9.28±1.82 -5.83±2.15	-5.41±2 -5.52±2	0.005*
Lower lip -E- plane (mm)	Pre-operation Post-operation	-1.22±1.1 -1.69±2.18	-2±2 -2±2	0.358	-2.56±2.6 -2.88±2.84	-2±2 -2±2	0.540
Nasolabial angle (Col-Sn-UL) (°)	Pre-operation Post-operation	95.27±10.11 94.99±11.34	102±8 102±8	0.759	100.93±11.11 100.68±9.32	102±8 102±8	0.959
Pog - NB (mm)	Pre-operation Post-operation	2.92±1.93 2.83±1.89	154±1.7 154±1.7	1.000	2.97±1.94 3.45±2.31	154±1.7 154±1.7	0.343
Overjet (mm)	Pre-operation Post-operation	-1.86±4.64 2.83±1.96	2.5±2.5 2.5±2.5	0.017*	-5.08±2.29 2.4±1.4	2.5±2.5 2.5±2.5	0.005*
Overbite (mm)	Pre-operation Post-operation	-0.69±2.19 -0.57±1.35	2.5±2 2.5±2	0.959	-1.37±1.38 -0.25±1.01	2.5±2 2.5±2	0.074
CO - B value (mm)	Pre-operation Post-operation	105.87±4.26 104.6±5.68	98.5 ±4.0 98.0 ±4.0	0.683	105.86±5.91 103.74±5.73	98.5 ±4.0 98.0 ±4.0	0.013*
Na perpendicular-Pg (mm)	Pre-operation Post-operation	12.67±10.48 12.39±9	-4±5.3 -4±5.3	0.646	10.83±9.45 11.49±8.43	-4±5.3 -4±5.3	0.959
Posterior facial height (SGo) (mm)	Pre-operation Post-operation	79.26±8.02 76.85±6.65	80.25±5 80.65±5	0.005*	81.14±10.29 78.8±10.71	80.25±5 80.65±5	0.005*
Anterior facial Height (N-Me) (mm)	Pre-operation Post-operation	118.30±5.79 118.34±5.83	126.25±5 126.65±5	0.984	120.22±9.7 119.34±7.47	126.25±5 126.65±5	0.999

*p<0.05 significant difference, p>0.05 no significant difference; Wilcoxon test

Table 3. Comparison of postoperative measurement means with Dolphin Imaging 11.95 and NemoFAB 2D measurement means

		Group 1		Group 2	
		Real mean±sd	Norm±sd	Real mean±sd	Norm±sd
Na perpendicular-A (mm)	Post-operation Dolphin Imaging 11.95 NemoFAB 2D	5.74±4.02 6.45±2.38 6.59±1.58	0±2	6.19±4.5 7.3±3.86 6.9±3.25	0±2
SNA (°)	Post-operation Dolphin Imaging 11.95 NemoFAB 2D	82.64±3.63 82.64±4.37 82.43±5.88	82±3.5	84.39±5.37 84.38±5.12 83.27±5.66	82±3.5
ANB (°)	Post-operation Dolphin Imaging 11.95 NemoFAB 2D	0.66±2.39 0.89±2.63 1.02±2.62	1.6±1.5	2.24±1.68 2.24±1.39 2.23±1.18	1.6±1.5
SNB (°)	Post-operation Dolphin Imaging 11.95 NemoFAB 2D	81.98±4.83 81.78±5.46 82.61±5.1	80.9±3.4	82.12±5.13 82.65±5.31 81.04±5.83	80.9±3.4
Maxillary depth angle (FH-NA) (°)	Post-operation Dolphin Imaging 11.95 NemoFAB 2D	95.68±3.82 95.82±3.12 96.4±2.73	90±3	96.46±4.8 97.38±3.87 96.67±4.32	90±3
Mandibular length value (Co-Gn) (mm)	Post-operation Dolphin Imaging 11.95 NemoFAB 2D	126.51±7.41 126.16±6.48 125.07±6.87	120.5±4	127.51±7.58 126.15±6.3 124.76±6.56	120.5±4
Convexity angle (NA-APo) (°)	Post-operation Dolphin Imaging 11.95 NemoFAB 2D	-1.63±4.24 -1.21±4.7 -0.87±4.01	1.1±2.5	1.08±4.91 1.73±3.98 1.63±4.17	1.1±2.5
Effective maxillary length (Co-A) (mm)	Post-operation Dolphin Imaging 11.95 NemoFAB 2D	85.78±3.95 85.31±2.86 86.68±3.7	90±5	85.39±5.05 87.01±4.91 85.86±4.39	90±5
Wits appraisal (mm)	Post-operation Dolphin Imaging 11.95 NemoFAB 2D	-4.57±3.34 -3.61±4.27 -4.13±4.49	-1±1	-3.92±4.63 -4.77±4.52 -5.07±4.69	-1±1
Occlusal plane/SN angle (°)	Post-operation Dolphin Imaging 11.95 NemoFAB 2D	16.26±5.85 15.39±7.55 14.92±4.61	14.4±2.5	16.95±8.56 18.55±9.75 16.77±9.4	14.4±2.5
Lower facial height (ANS-Me) (mm)	Post-operation Dolphin Imaging 11.95 NemoFAB 2D	66.31±4.91 65.32±5.33 69.22±6.61	70.4±5	70.92±7.83 69.64±7.38 76.27±10.2	70.4±5

SN-Palatal plane angle (°)	Post-operation	12.93±3.4		7.14±6.51	
	Dolphin Imaging 11.95	9.88±3.86	7.3±3.5	6.92±4.99	7.3±3.5
	NemoFAB 2D	7.95±3.05		6.98±5.31	
Facial axis angle (NaBa-PtGn) (°)	Post-operation	89.54±2.84		86.45±2.89	
	Dolphin Imaging 11.95	90.92±3.11	90±3.5	88.52±3.52	90±3.5
	NemoFAB 2D	91.41±3.45		86.41±4.36	
Palatal/Mandibular plane angle (PP-MP) (°)	Post-operation	25.64±5.79		30.12±6.59	
	Dolphin Imaging 11.95	25.97±5.76	25±6	26.72±5.95	25±6
	NemoFAB 2D	23.9±8.19		28.64±7.49	
FMA angle (MP-FH) (°)	Post-operation	25.54±8		24.15±5.83	
	Dolphin Imaging 11.95	22.27±4.32	23.9±4.5	24.38±5.7	23.9±4.5
	NemoFAB 2D	23.55±9.14		24.44±7	
Saddle angle (SN-Ar) (°)	Post-operation	126.54±7.76		120.96±6.93	
	Dolphin Imaging 11.95	126.33±6.83	124±5	122.9±6.76	124±5
	NemoFAB 2D	125.46±6.35		123.22±5.54	
Maxillary height angle (N-CF-A) (°)	Post-operation	60.54±2.32		61.08±6.05	
	Dolphin Imaging 11.95	58.88±3.4	55.5±3	58.78±4.03	55.5±3
	NemoFAB 2D	57.89±4.41		62.17±4.13	
Articular angle (°)	Post-operation	136.25±9.08		139.55±7.35	
	Dolphin Imaging 11.95	137.86±3.46	141±6	142.1±6.17	141±6
	NemoFAB 2D	138.53±4.35		134.55±31.66	
Gonial angle (°)	Post-operation	136.31±7.68		135.21±4.84	
	Dolphin Imaging 11.95	131.75±5.89	123±7.0	130.21±5.28	123±7.0
	NemoFAB 2D	132.25±9.51		129.08±7.65	
SN - GoGn (°)	Post-operation	35.27±6.93		34.5±5.28	
	Dolphin Imaging 11.95	32.85±5.41	32.9±5.2	31.47±6.49	32.9±5.2
	NemoFAB 2D	32.95±7.04		35.22±9.09	
Sum of posterior angles (°)	Post-operation	398.59±6.67		397.23±6.21	
	Dolphin Imaging 11.95	395.84±5.51	388.6±6	393.67±7.07	388.6±6
	NemoFAB 2D	397.13±6.7		396.53±9.92	
Jarabak ratio (%)	Post-operation	66.77±6.67		66.77±6.43	
	Dolphin Imaging 11.95	69.48±6.08	63.5 ±1.5	70.32±7.75	63.5 ±1.5
	NemoFAB 2D	67.45±5.85		64.76±8.63	
Mandibular plane/occlusal plane angle (°)	Post-operation	22.34±4.06		20.3±4.45	
	Dolphin Imaging 11.95	20.45±3.8	17.04±5	19.62±3.98	17.04±5
	NemoFAB 2D	20.81±5.77		21.02±3.39	
U1 - NA (mm)	Post-operation	5.86±2.43		4.11±1.78	
	Dolphin Imaging 11.95	5.5±2.71	4.3±2.7	3.82±1.28	4.3±2.7
	NemoFAB 2D	7.35±2.6		5.63±2.85	
L1 - NB (mm)	Post-operation	3.93±1.33		4.72±0.95	
	Dolphin Imaging 11.95	4.31±1.25	4±1.8	5.22±3.99	4±1.8
	NemoFAB 2D	3.45±1.78		5.32±1.7	
IMPA angle (°)	Post-operation	81.73±6.03		82.78±5.94	
	Dolphin Imaging 11.95	83.3±4.17	90±4.5	83.29±5.52	90±4.5
	NemoFAB 2D	85.5±10.05		86.52±7.53	
Interincisal angle (U1-L1) (°)	Post-operation	133.89±6.08		133.9±8.76	
	Dolphin Imaging 11.95	136.02±6.2	130±6	137.21±7.06	130±6
	NemoFAB 2D	133.04±9.22		133.94±7.82	
Upper lip -E plane (mm)	Post-operation	-4.61±1.93		-5.83±2.15	
	Dolphin Imaging 11.95	-4.78±1.86	-5.41±2	-4.89±2.15	-5.41±2
	NemoFAB 2D	-6.27±0.76		-5.48±2.52	
Lower lip -E-plane (mm)	Post-operation	-1.69±2.18		-2.88±2.84	
	Dolphin Imaging 11.95	-2.1±1.9	-2±2	-4.05±2.03	-2±2
	NemoFAB 2D	-1.27±1.13		-3.54±2.97	
Nasolabial angle (Col-Sn-UL) (°)	Post-operation	94.99±11.34		100.68±9.32	
	Dolphin Imaging 11.95	96.23±12.87	102±8	94.27±8.02	102±8
	NemoFAB 2D	91.18±13.77		96.62±10.89	
Pog - NB (mm)	Post-operation	2.83±1.89		3.45±2.31	
	Dolphin Imaging 11.95	2.9±2.21	154±1.7	2.8±2.2	154±1.7
	NemoFAB 2D	3.3±1.83		3.13±1.76	
Overjet (mm)	Post-operation	2.83±1.96	2.5±2.5	2.4±1.4	2.5±2.5

	Dolphin Imaging 11.95	2.98±1.44		3.04±1.77	
	NemoFAB 2D	2.64±1.56		3.1±1.48	
Overbite (mm)	Post-operation	-0.57±1.35		-0.25±1.01	
	Dolphin Imaging 11.95	0.76±1.21	2.5±2	0.77±0.7	2.5±2
	NemoFAB 2D	0.48±0.62		0.53±0.25	
CO - B value (mm)	Post-operation	104.6±5.68		103.74±5.73	
	Dolphin Imaging 11.95	104.89±5.12	x±x	104.48±5.18	x±x
	NemoFAB 2D	104.61±5.43		103.77±4.27	
Na perpendicular-Pg (mm)	Post-operation	12.39±9		11.49±8.43	
	Dolphin Imaging 11.95	11.39±4.21	-4±5.3	12.61±7.87	-4±5.3
	NemoFAB 2D	12.9±3.33		12.59±7.36	
Posterior facial height (S-Go) (mm)	Post-operation	76.85±6.65		78.8±10.71	
	Dolphin Imaging 11.95	74±7.41	80.25±5	76.62±9.57	80.25±5
	NemoFAB 2D	75.11±8.71		77.77±10.52	
Anterior facial height (N-Me) (mm)	Post-operation	118.34±5.83		119.34±7.47	
	Dolphin Imaging 11.95	120.52±5.68	126.25±5	119.56±6.87	126.25±5
	NemoFAB 2D	118.02±4.47		118.01±5.74	

Table 4. Comparison of success of computer software success

	Group 1		Group 2		Success comparisons			
	Dolphin Imag. 11.95 R1	NemoFAB 2D R2	Dolphin Imag. 11.95 R3	NemoFAB 2D R4	R1-R3 p	R2-R4 p	R1-R2 p	R3-R4 p
Na perpendicular-A (mm)	.723*	.657*	.912*	.698*	0.242	0.888	0.810	0.207
SNA (°)	.976*	.830*	.939*	.818*	0.373	0.944	0.307	0.280
ANB (°)	.973*	.972*	.906*	.817*	0.230	0.077	0.575	0.503
SNB (°)	.988*	.827*	.964*	.867*	0.298	0.067	0.059	0.204
Maxillary depth angle (FH-NA) (°)	.659*	0.462	.867*	.661*	0.322	0.582	0.589	0.327
Mandibular length value (Co-Gn) (mm)	.657*	.673*	.894*	.717*	0.222	0.872	0.960	0.312
Convexity angle (NA-APo) (°)	.806*	.864*	.964*	.915*	0.098	0.646	0.718	0.406
Effective maxillary length (Co-A) (mm)	.661*	.857*	.648*	.894*	0.968	0.764	0.362	0.211
Wits appraisal (mm)	.891*	.924*	.879*	.802*	0.952	0.617	0.726	0.617
Occlusal plane/SN angle (°)	.939*	.915*	.924*	.891*	0.833	0.810	0.749	0.726
Lower face height (ANS-Me) (mm)	.736*	.705*	.915*	.588	0.205	0.703	0.904	0.099
SN-Palatal plane angle (°)	.612	.588	.881*	.909*	0.207	0.114	0.944	0.794
Facial axis angle (NaBa-PtGn) (°)	.491	.438	.588	.794*	0.795	0.251	0.896	0.447
Palatal/Mandibular plane angle (PP-MP) (°)	.839*	.648*	.915*	.869*	0.522	0.298	0.407	0.142
FMA angle (MP-FH) (°)	.793*	.835*	.867*	.721*	0.652	0.582	0.818	0.441
Saddle angle (SN-Ar) (°)	.709*	.624	.939*	.915*	0.114	0.121	0.771	0.749
Maxillary height angle (N-CF-A) (°)	.648*	.564	.782*	.610	0.603	0.896	0.803	0.522

Articular angle (°)	.821*	.742*	.924*	.790*	0.395	0.826	0.704	0.307
Gonial angle (°)	.729*	.875*	.503	.515	0.483	0.142	0.646	0.976
SN - GoGn (°)	.952*	.951*	.903*	.867*	0.497	0.327	0.984	0.756
Sum of posterior angles (°)	.964*	.888*	.903*	.891*	0.337	0.976	0.276	0.905
Jarabak ratio (%)	.952*	.745*	.754*	.930*	0.103	0.193	0.095	0.204
Mandibular plane/occlusal plane angle (°)	0.462	.782*	.766*	.323	0.337	0.180	0.303	0.207
U1 - NA (mm)	.657*	.821*	.650	.529	0.984	0.285	0.484	0.726
L1 - NB (mm)	.559	.340	.401	.601	0.696	0.522	0.603	0.617
IMPA angle (°)	.527	.782*	.888*	.855*	0.121	0.675	0.384	0.795
Interincisal angle (U1-L1) (°)	.675*	.796*	.709*	.588	0.904	0.441	0.617	0.696
Upper lip -E plane (mm)	.699*	.616	.442	.612	0.465	0.992	0.787	0.660
Lower lip -E plane (mm)	.648*	.610	.555	.723*	0.787	0.704	0.905	0.589
Nasolabial angle (Col-Sn-UL) (°)	.806*	.867*	.709*	.588	0.667	0.227	0.704	0.697
Pog - NB (mm)	.915*	.948*	.942*	.866*	0.711	0.352	0.631	0.412
Overjet (mm)	.780*	.661*	.924*	.784*	0.285	0.624	0.638	0.294
Overbite (mm)	.675*	.796*	.709*	.588	0.904	0.441	0.617	0.696
CO - B value (mm)	.891*	.939*	.964*	.952*	0.254	0.818	0.568	0.787
Na perpendicular-Pg (mm)	.669*	.685*	.942*	.758*	0.087	0.772	0.952	0.152
Posterior facial height (S-Go) (mm)	.888*	.906*	.948*	.961*	0.503	0.183	0.803	0.080
Anterior facial height (N-Me) (mm)	.813*	.830*	.927*	.831*	0.347	0.920	0.400	0.407

*$p<0.05$ significant association, $p>0.05$ no significant association; Spearman correlation test

Discussion

In this study, we compared the two-dimensional predictions made by two different computer software packages with postoperative values to evaluate whether digital orthognathic surgery plans were clinically reliable. The CBCT records of 20 individuals with skeletal Class III anomalies who had undergone double jaw orthognathic surgery were evaluated before and after bimaxillary orthognathic surgery, and 37 cephalometric values were compared. The movements in the maxilla and mandible of the cases were repeated for each individual using the software, and the reliability and consistency of the predictions of the surgery results were observed digitally by the two software packages.

There are similar studies in the literature. Çelik et al. compared digital and conventional cephalometric analyses. Their study involved an evaluation of angular and linear measurements of 125 individuals. They reported that the nasolabial angle showed low reproducibility in both methods, but other parameters were correlated (12). Polat-Özsoy et al. examined lateral cephalometric radiographs taken before and after the treatment of 30 individuals. They found significant differences between the methods in Cd-A, Cd-Gn, FMA, SN-PP, SNB, Wits appraisal, and LI-NB (mm) parameters in the examinations performed using digital and conventional methods. On the other hand, they concluded that pre- and post-treatment changes could be detected consistently in both methods, and based on this information, both methods were clinically acceptable (13). For predictions made on lateral cephalometric drawings of cases to be compatible with each other, the cephalometric analysis should generate cephalometric measurements very close to each other using different software packages. Çelik et al. evaluated the cephalometric analyses of four different software packages and found a high degree of similarity (12). Although the software used in that study was not as up to date as the software used in our study, the results were similar to those of our study.

Pektaş et al. reported that software gave satisfactory results in predicting the soft tissue differences that occur at the end of orthognathic surgery. In their study, the lateral cephalometric radiographs of 11 adults were collected before and at least 1 year after surgery and were evaluated using the Dolphin Imaging (version 10.0) program. Investigators collected lateral cephalometric radiographs at least one year after surgery so that soft tissue edema would not adversely affect the results. Similarly, in our study, the CBCT recordings taken after orthognathic surgery were collected at least six and, on average, ten months after surgery. Researchers also found that software predictions were more successful in the sagittal plane than in the vertical plane (14). In our study, both software packages were also found to be successful in soft tissue parameters in the sagittal plane. However, there was no significant difference between the software and surgery results in terms of soft tissue parameters in the vertical plane. We believe that our use of the most up-to-date versions of the software and our materials and methods, which minimized the error rate in the records and drawings, were highly effective in achieving a successful foresight.

Kaipatur et al. tried to reveal the extent to which orthognathic surgery predictions made using software reflect the changes that occur after an operation on soft tissues (15). Based on an evaluation of 40 scientific articles, they found that the soft tissue predictions of software following orthognathic surgery were at a clinically reasonable level of consistency in both the vertical and horizontal planes. They reported changes of greater than 2 mm in some specific cephalometric points and that changes smaller than 2 mm were not clinically significant. They also found deviations of 2.2 mm in the lower lip, 2.2 mm at the pogonion point, 2.6 mm horizontally at the stomion superior point, and 2.1 mm vertically at the stomion inferior point.

Soydan et al. examined success in predicting maxillary advancement and maxillary impaction movements in Le Fort 1 osteotomy. The investigators divided 31 cases into two groups according to their perpendicular dimensions: hypodivergent (GoGn/SN ≤38°) and hyperdivergent (GoGn/SN≥38°). They found that the maxillary impaction movement could be estimated with a margin of error of 1 mm at a rate of 35% in the posterior region and 51% in the anterior region. They also reported that maxillary advancement movement could be estimated with an error margin of 2 mm (51%) and 1 mm (29%) 16). In our study, the amount of movement and lateral cephalometric radiographs before and after the operation were registered using Dolphin Imaging software. Unlike in many other studies, these values were calculated digitally, not manually, to minimize the error rate of the researcher.

Gossett et al. evaluated the reliability of orthognathic surgery plans made using software. They analyzed the lateral cephalometric radiographs of 31 cases and used Dolphin Imaging (version 8.0) software for orthognathic surgery predictions. They found that although they had detected statistically significant differences in the SNB, U1-NA, Pog-NB, and Nperp-Pog parameters in the prediction of surgery, these were not clinically significant (17). However, our study found no statistically significant difference between the predictions made by the software and the outcome of operations in the four parameters related to the study. This may be due to two differences. First, Gossett et al. included individuals who had undergone single jaw maxilla, single chin mandible, double chin orthognathic, and genioplasty surgeries in their study groups. In our study, this issue was handled meticulously from the beginning, and different types of operations were grouped into two groups. In addition, postoperative lateral cephalometric radiographs of the cases were collected in the first month following the operations. As mentioned earlier, it is recommended that records be collected, at the earliest, six months postoperatively to obtain accurate predictions.

Power et al. compared the conventional prediction method with Dolphin Imaging (version 8.0) software in their study by examining the lateral cephalometric radiographs of 60 cases. They reported that the computer software was more unsuccessful in surgical predictions of SNA and SNB parameters compared to the conventional method, while they found that the computer software produced more accurate predictions in U1-NA and IMPA parameters (18). Unlike the results of their research, in our study, the predictions of SNA, SNB, U1-NA, and IMPA parameters made by the computer software were found to be compatible with the surgical outcomes. We employed the latest Dolphin Imaging program (version 11.95) released in 2017; the NemoFAB 2D software released in 2019, the latest and most up-to-date NemoCeph software; and the Virtual Imaging Software and Treatment Objective (VTO) add-on module developed for the current version (11.95) of the Dolphin Imaging software. Our use of updated software might have led to the more accurate results obtained from the software in our study. In addition, employing lateral cephalometric recordings garnered from CBCT recordings, instead of using routine lateral cephalometric radiographs of patients, might have affected this error rate difference.

Rustemeyer et al. evaluated the reliability of two-dimensional prediction methods made with computer software when performing routine orthognathic surgery planning. Of the 54 individuals examined in the study, 33 had double-chin orthognathic surgery and 21 had bilateral sagittal split ramus osteotomy. While working on SNA, SNB, and ANB parameters in the sagittal plane, Ar-Me-Go, ML-NSL, and NL-NSL parameters were evaluated in the vertical plane. Researchers compared digital predictive and postoperative values for each parameter. It was determined that surgery prediction could be made with a standard deviation of 2.2° in patients undergoing double-chin orthognathic surgery and 1.1° in bilateral sagittal split ramus osteotomies. However, standard deviation values of 8.5° were observed in only one individual. As a result, the researchers reported that two-dimensional predictions made with computer software were clinically sufficient in most cases, but three-dimensional methods were needed for more detailed examinations in some cases (19).

In a recent systematic review, 392 articles were scanned and results from 12 different studies that met the inclusion criteria were evaluated. CBCT was found to be generally used as an imaging protocol in virtual planning, a deviation of <2 mm was clinically acceptable, and surgery planning using software was an accurate and reliable methodology for orthognathic treatment planning (20).

For our study, when the orthognathic surgery prediction made by the computer software and the real values after the operation were examined, there was a statistically insignificant difference between the digital prediction and the surgical outcome in maxillary and mandibular dental parameters (U1-NA, L1-NB, interincisal angle, IMPA). It is important to examine the reasons for this difference to explain it. In this study, CBCT recordings of individuals collected an average of 10 months after orthognathic surgery were used. Intermaxillary elastics are frequently employed in the control sessions of patients whose postoperative orthodontic treatment process is ongoing, and because of intermaxillary elastics, even if there was no significant difference, tooth movement might develop at different levels than predicted.

Akhoundi et al. compared the success of the manual method with computer software by examining the prediction of soft-tissue changes after orthognathic surgery on lateral cephalometric radiographs collected from 40 cases. The conclusion presented by their study was that the tip of the nose was the most reliably predictable soft-tissue point. They reported that the least successful soft-tissue areas in the vertical plane were the subnasale and upper lip points, while the least successful areas in the horizontal plane were the subnasale and pogonion points. The researchers found that, although statistically significant, these differences were at clinically reasonable levels and computer software offers consistent predictions in orthognathic surgery planning (21). In another study comparing the prediction of soft-tissue changes using two imaging programs (Dolphin Imaging 10 and Vistadent OC), the predictions were the least accurate for the lower lip region. However, the two software programs were found to be reliable in terms of surgical outcome prediction (22). In our study, there was a difference between digital prediction and surgery outcome in the maxillary and mandibular soft-tissue parameters (upper lip E-plane, lower lip E-plane, and nasolabial angle) although these were statistically insignificant. This difference was higher in the second group in which there was impaction in the maxilla compared to the first group in which there was no impaction. The fact that these mean values did not constitute statistical significance did not mean that the cases with more than 3 mm impaction of the maxilla provided a successful prediction in this regard. When these cases were examined, an error rate other than the statistical average was found. For this reason, it is important to explain why the statistically insignificant differences arose in our study. Our study group consisted of 20 cases, and this relatively low number is one of the limitations of our study.

Although accurate prediction of soft-tissue parameters is one of the most important steps in treatment planning, advancing technological knowledge and methods still do not provide satisfactory and perfect soft-tissue prediction. It is necessary and important to focus on a specific area and evaluate the parameters, followed by not only obtaining two-dimensional prediction results but also three-dimensional prediction results.

Conclusions

In conclusion, in this study, we showed that orthognathic surgery predictions made on lateral cephalometric radiographs obtained from CBCT recordings with computer software are reliable and can be used clinically. It was determined that both computer software packages were successful in terms of two-dimensional orthognathic surgery prediction, and there was no significant difference between them.

Ethical Approval: Ethics committee approval was received for this study from Dicle University, Faculty of Dentistry Ethics Committee in accordance with the World Medical Association Declaration of Helsinki, with the approval number: 2019/02.

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