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The Accuracy of Dolphin Software in Predicting Soft Tissue Changes after Orthognathic Surgery

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Abstract

Aim: The purpose of the present study was to evaluate the accuracy of Dolphin Imaging version 11.8 software, in predicting soft and hard tissue changes after orthognathic jaw surgery.
Methods: In this retrospective study, pre- and postoperative cephalograms and photographs of 20 patients were scanned and inserted into Dolphin Imaging version 11.8 software and traced by the software. Cephalometric superimposition was performed before and after the operation to determine the extent of changes in each jaw. The software then simulated postoperative images according to the calculated changes for each patient.
Results: The results of this study showed that the upper lip had the highest accuracy in both sagittal and vertical axes. The highest reliability was in the upper lip with 80% error in the sagittal axis and the tip of the nose with 80% error in the vertical axis. The lowest accuracy in our study was related to soft tissue Menton which had the least reliability with an error frequency of 35% and 45% in the sagittal and vertical axis, respectively.
Conclusion: Based on the method used and the findings obtained by digital measurements, it can be concluded that the Dolphin Imaging version 11.8 software can be used to reliably predict hard tissue as well as soft tissue, especially in the upper lip area.

Keywords: Dolphin software, Orthognathic surgery, Soft tissue, Prediction.

1. Background

The patient's understanding of potential outcomes of maxillofacial surgery is the key to successful treatment (1). It is difficult, if not impossible, for patients to visualize facial changes after orthognathic surgery without the help of imaging tools (2). Hence, predicting post-surgical changes is an essential component in planning orthognathic treatment that includes hard tissue and soft tissue components (3). While hard tissue movement certainly affects the face profile result, it is actually the soft tissue response that determines the rate of change in the face and profile appearance (3). Traditionally, orthognathic surgical treatment was predicted based on cephalometric radiographic analysis and surgical replication on plaster models mounted on an adjustable articulator (4). Currently, technological advances in this field have led to the development of computer-aided video prediction systems for projecting orthognathic surgical treatment. Using the patient's photographic images simulate treatment suggestions and offer the patient a more realistic and understandable picture.

Computerized prediction of orthognathic surgical results using video imaging was first performed by Sarver et al. in 1988 (5). There is currently a wide range of cephalometric computer systems for predicting orthognathic surgery. Dolphin imaging software (Dolphin Imaging Solutions, Chatsworth, CA) is one of the popular orthognathic surgery prediction software currently available. Dolphin imaging software was first introduced in 1994 at the Second Conference on Computers in Orthodontics at the ninth Brazilian

SPO Orthodontic Congress. This high-tech computer program works with cutting-edge graphic software (6). The software provides an alternative method for cephalometric tracing without the use of conventional cephalometric radiography, and thus facilitates the way for 3D cephalometry. The software can perform more than 120 different linear and angular cephalometric analyses that are widely used in orthodontics and surgery (7).

In 2004, a comparative study was conducted by Smith et al. to investigate five orthognathic surgical simulation programs. Out of about 100 patients, 10 were selected by two experienced maxillofacial surgeons considering the inclusion criteria. Three groups including eight orthodontists, nine maxillofacial surgeons, and nine non-professionals reviewed and rated the simulation images produced by each software in a two-way comparison. In addition, they scored on a 6-point scale for each simulation relative to actual results. Dentofacial Planner software (79%) was selected as the best simulator, followed by Dolphin version 8 and Quick Ceph imaging software with 5% difference. However, Dolphin software allowed for better correction of position and contour of soft tissue, and, overall, the Dolphin software performed better in long face patients (8).

In another study in 2005, Power et al. compared accuracy and repeatability of predictions of the Dolphin version 8 software with the manual technique as well as actual results after orthognathic surgery in 26 patients who had undergone preoperative orthodontic preparation. Lateral cephalograms were evaluated by manual tracing and indirect digitization by the Dolphin version 8 software. It was demonstrated that manual tracing is more reliable for SNA, SNB, SNmx, MXmd points, and Dolphin digital tracing is more reliable for LImd and UImx points (9). Afterwards, Osvaldo et al. in 2009 compared soft tissue simulation using the software Dentofacial Planner Plus and Dolphin Imaging version 9.0 in 10 patients with class III malocclusion and concave face who were candidates for double jaw surgery. The results showed that the Dolphin software had better prediction in the nasal tip, chin, and submandibular points and the Dentofacial software had better prediction in the nasolabial angle, upper lip, and lower lip (2). Akhoundi et al. (2012) conducted a comparative study on the accuracy of predicting soft tissue changes after orthognathic surgery using the Dolphin version 10 software and manual tracing. The study included 40 patients (35 females and 5 males). In the manual method, both preoperative and postoperative cephalometry were traced on acetate paper and manual prediction on preoperative cephalometry was based on the amount of surgical movements. Then manual prediction was compared with postoperative cephalometry. The findings of this study were as follows: Prediction of the Dolphin software for the nasal tip had the least error and the highest accuracy. The lowest accuracy was related to the subnasal and upper lip in the vertical axis and subnasal and pogonion (Pog) in the horizontal axis (10). Later in 2016, a retrospective study was performed by Peterman et al. on 14 patients with class III malocclusion to determine the accuracy of the Dolphin version 11 software. Preoperative and postoperative cephalometric radiographs were obtained and superimposed over each other to obtain the actual amount of real movement of the two jaws based on the cranial base. Finally, the findings of this study showed that the Dolphin software can be useful in explaining the surgical procedure and in communicating with the patients and helping them make decisions and avoid unrealistic expectations. However, it is not an accurate tool for planning treatment and predicting surgical movements (11). The purpose of this study was to evaluate the accuracy of the Dolphin version 11.8 software in predicting soft tissue changes after orthognathic surgery.

2. Methods

Patient sample

This retrospective study was performed on 20 patients with a mean age of 23 years (18 to 35 years) including 13 females and 7 males. This research was approved by the ethical committee of the Mashhad University of Medical Sciences (IR.MUMS.sd.REC.1394.291). The type of malocclusion and surgery were determined for each subject (Table 1). All of these patients had started orthodontic treatment before surgery, and medical records including cephalometric radiographs and intraoral, face, mandible, maxilla photographs of these patients were of good quality and complete. None of these patients had a history of trauma, head and neck surgery, or congenital craniofacial anomalies. Cephalometries before and after orthognathic surgery were scanned using the Umax scanner Powerlook 2100XL and inserted into Dolphin version 11.8 software. Then cephalometries were traced by the software before and after surgery (Fig. 1, 2).

Table 1. Description of the type of malocclusion and surgical plan

Malocclusion Surgical plan	Class II	Class III	Sum
Two jaws	3	9	12
One jaw	1	7	8
Genioplasty	3	4	7

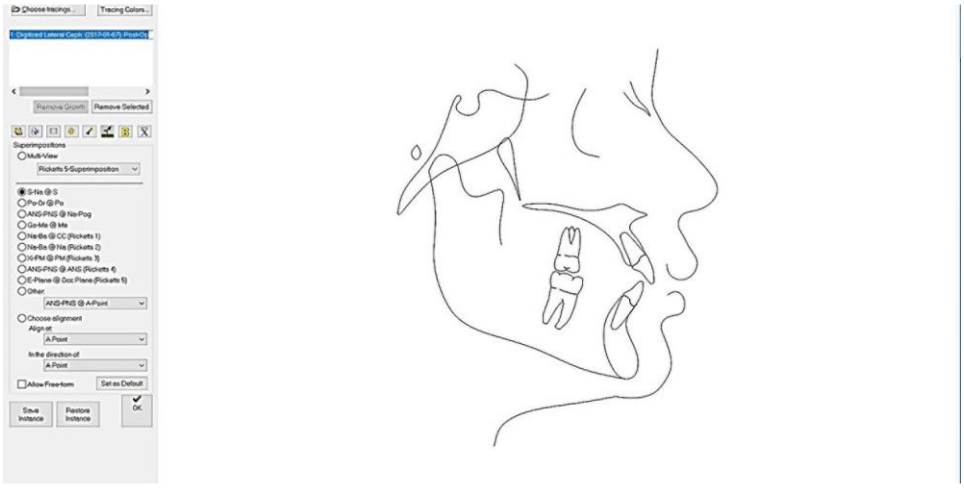

Figure 1. Cephalometric tracing before and after operation by software

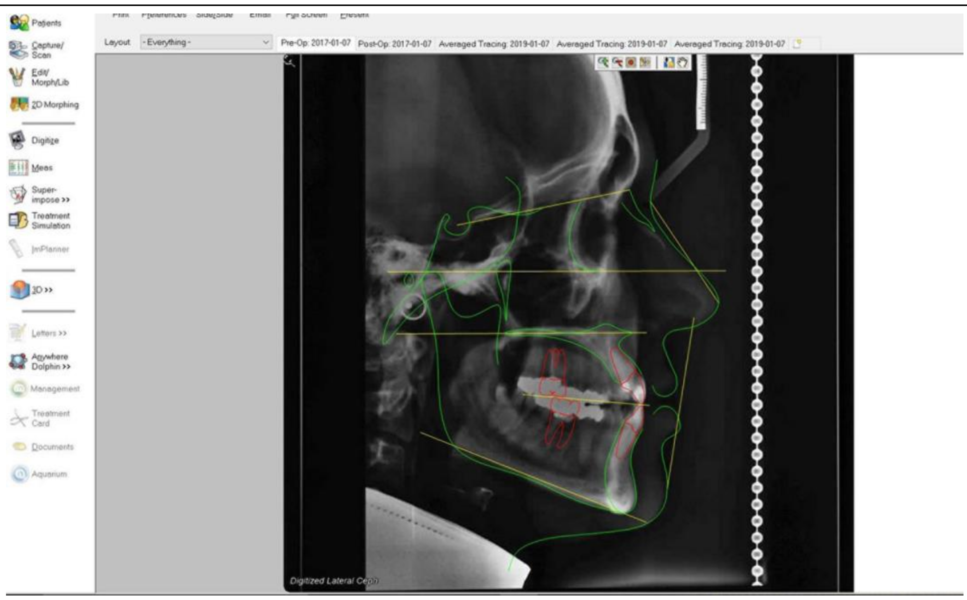

Figure 2. Cephalometric tracing before and after operation by software

Method of prediction

The number of surgical movements was obtained by cephalometric superimposition before and after surgery for each patient (Fig. 3). Point A movements represented maxillary changes and point B movements represented mandibular changes and Pog represented chin changes. Then the extent of these vertical and horizontal changes of each jaw and chin was inserted into the treatment simulation tab. The software produced postoperative simulation according to the data (Fig. 4).

Next, the simulated image and actual postoperative cephalogram were superimposed on each other, on the SN line with a focus on S and the difference in landmarks S, A, B, ANS, PNS, Pog, Gnathion, Menton (Me), Gonion (Go), and Articular (Ar). The condylion, subnasal (Sn), nasal tip (P), upper lip (Ls), and lower lip (Li) were measured in millimeters (Fig. 5).

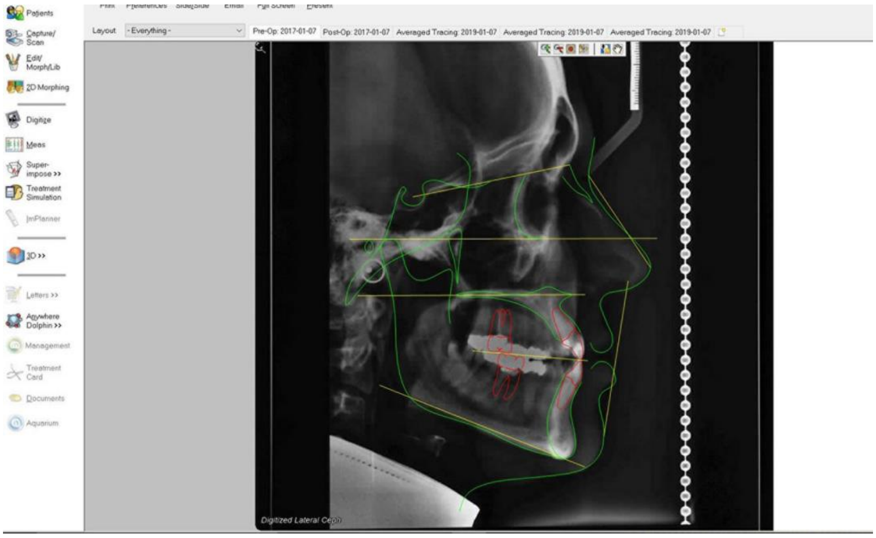

Figure 3. Cephalometric tracing superimposition before and after surgery for each patient

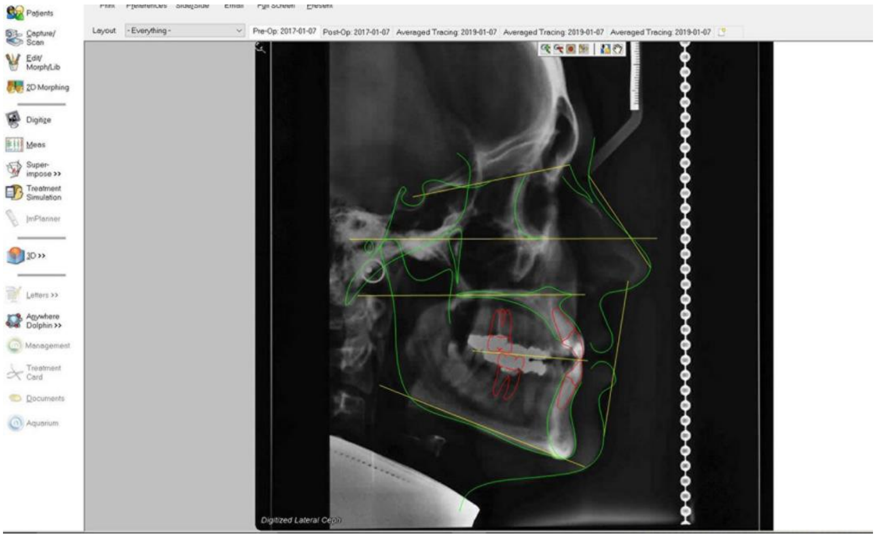

Figure 4. Post-operative simulation by software

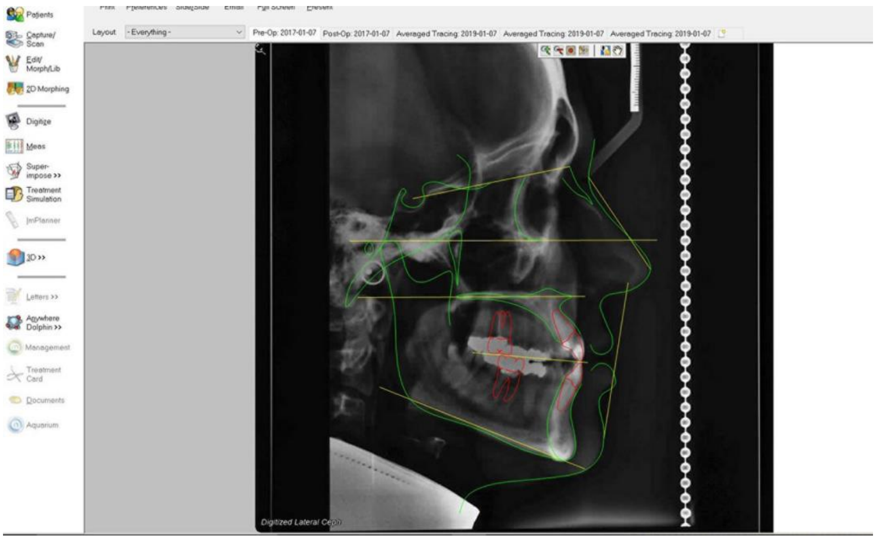

Figure 5. Post-operative simulation and postoperative actual tracing superimposition by software

Reference lines included the FH, SN, E line, H line, occlusal, palatal, and mandibular planes.

Software performance was evaluated on the basis of accuracy and reliability. The mean differences measured in each landmark was considered as the predicted error (i.e., the lower the prediction error, the greater the accuracy of the software in prediction).

Absolute magnitude of the software prediction error was determined in three ranges of less than 1 mm, between 1 and 2 mm, greater than 2 mm, and prediction error distribution was determined in these three ranges. The greater the distribution of prediction error in the range of <1 mm, the greater the reliability of the software. Errors related to digitization of images and method errors were investigated by retracing and re-digitizing of five patients at random after two weeks.

Statistical analysis

The sample size calculated 20 cases based on the Dolphin software error range, which was reported in a previous study (11), and produces a two-sided 95% confidence interval with a margin of error of 2 mm when the estimated standard deviation is 3.000. The measurement of assumed errors were $\alpha=0.05$, and $\beta=0.8$ for sample size calculation.

The data were entered into the SPSS software (version 23.0, Chicago, IL), and subsequently analyzed. The mean, standard deviation, and 95% confidence interval for the difference measured at each landmark were calculated.

3. Results

To interpret the results in the tables, it should be noted that the plus (+) sign means that the predicted points are more anterior (in the sagittal axis) and higher (in the vertical axis) than the real points, and the minus (–) sign indicates that the predicted points are more posterior (in the sagittal axis) and lower (in the vertical axis) than the real points (Fig. 6). For superimposing tracing, point S was selected as the reference for adaptation.

Checking points in the sagittal and vertical planes.

Hard tissue

When comparing the landmarks specified in the computer-predicted image with actual surgical profile changes in the sagittal plane, the mean differences between the two groups were 1 mm and <1 mm in 8 out of 11 hard tissue measurements (points A, B, N, Gn, ANS, PNS, Pog, and Me) (Table 2). The most accurate was at point ME and the highest difference was in Go. In general, predictions tended to estimate the hard tissue more anterior.

In the vertical plane, mean changes in the vertical plane between the two groups was <1 mm in 9 out of 11 hard-tissue landmarks (points B, N, ANS, PNS, Pog, Gn, Me, Ar, and Co) (Table 2). In general, the differences recorded on the vertical plane were smaller than those found on the sagittal plane. The highest difference was observed in point A with a mean of 1.36 mm. The most accurate software prediction was at the PNS point (0.1 mm).

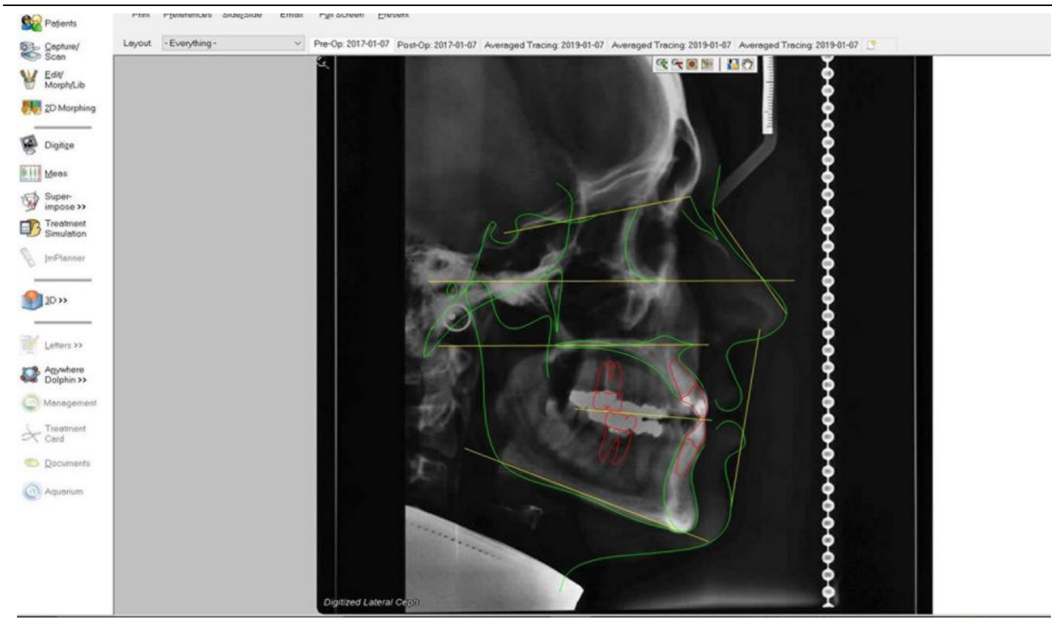

Figure 6. Comparison of measured change of points relative to the sagittal and vertical axis

Table 2. Mean and standard deviation of differences between the measurement of the actual points of hard tissue and predicted points by the software

Hard tissue points	Sagittal axis mean±SD	Vertical axis mean±SD
A	0.9± 2.09	1.3±1.83
B	0.7±1.53	0.8±2.14
N	-0. 4±1.55	-0.4±1.5
ANS	1±1.89	-0.4±2.04
PNS	0.2±1.69	0.1±1.73
Pog	0.2±1.91	-0.1±3.2
Gn	-0.5±1.98	0.1±2.96
Me	0.1±1.75	0.5±2.80
Go	2±1.96	1.1±2.42
Ar	1.4±1.19	0.9±0.95
Co	1.4±1.72	-0.2±1.56

Soft tissue

Also, in the sagittal axis, the mean was 2 and less than 2 mm in 4 out of 5 soft tissue measurements (SN, P (nose tip), upper lip, and lower lip) (Table 3). The highest accuracy was in the upper lip and the highest difference was in the Me point. In the vertical axis, 3 of 5 soft tissue landmarks (Sn, lower lip, and upper lip) had a mean difference of less than 1 mm, which was better than the differences recorded in the sagittal axis (Table 3). The highest accuracy was in the upper lip. The highest difference was in the tip of the nose with a mean of 1.5 mm and generally tended to overestimate the impact of hard and soft tissue more than the actual amount. Distribution of predicted error (the difference between the computer-predicted image and actual results of surgery) in the vertical and sagittal planes is shown in Tables 4 and 5. Data are divided into three groups (less than 1 mm, between 1 and 2 mm, and more than 2 mm). Reliability was attributed to <2 mm changes.

Table 3. Mean and standard deviation of the differences between the measurement of the actual points of soft tissue and predicted points by the software

Soft tissue points	Sagittal axis mean±SD	Vertical axis mean±SD
Sn	-2±2.42	0.9±1.79
P	-1.08±2.63	1.5±3.7
Lower lip	-1.28±2.04	0.6±2.67
Upper lip	-1.02±3.7	0.4±3.76
Men´	-2.2±7.3	1±4.08

Data distribution in the sagittal axis offers a wide range of SD with significant dipole expansion, especially in the Me region, and the difference is more than 2 mm in 65% of cases. The most reliable hard tissue region in software prediction was Ar with <1 mm difference in 75% of cases and <2 mm

Table 4. Distribution of predicted error of hard tissue

Soft tissue points	Sagittal axis Distribution of differences			Vertical axis Distribution of differences		
	X < 1	1 - 2	X > 2	X < 1	1 - 2	X > 2
A	45%	25%	30%	60%	20%	20%
B	35%	55%	10%	25%	45%	30%
N	40%	30%	30%	75%	20%	5%
ANS	40%	20%	40%	35%	50%	15%
PNS	65%	25%	10%	35%	50%	15%
Pog	20%	65%	15%	30%	30%	40%
Gn	40%	30%	30%	50%	5%	45%
Me	25%	45%	30%	30%	15%	55%
Go	40%	30%	30%	30%	30%	40%
Ar	75%	5%	20%	65%	35%	0%
Co	60%	25%	15%	45%	40%	15%

in 80% of cases, and the most reliable point in soft tissue was the upper lip with 50% error distribution in <1 mm and 80% in <2 mm.

Table 5. Distribution of the predicted error of soft tissue

Soft tissue points	Sagittal axis Distribution of differences			Vertical axis Distribution of differences		
	X < 1	1 - 2	X > 2	X < 1	1 - 2	X > 2
Sn	20%	30%	50%	35%	40%	25%
P	20%	30%	50%	40%	40%	20%
Lower lip	35%	40%	25%	20%	30%	50%
Upper lip	50%	30%	20%	35%	30%	35%
Men´	0%	35%	65%	20%	25%	55%

In general, the upper lip showed <2 mm in 80% of cases. In the lower lip area, the prediction error was <2 mm in 75% of cases. Total hard tissue areas in 76% of cases and soft tissue areas in 58% of cases showed < 2 mm error in the sagittal axis. Prediction error distribution in the vertical axis is also shown in Tables 4 and 5. Data distribution was higher in the <2 mm range compared to the sagittal plane. In the vertical plane, the most reliable point of hard tissue in software prediction was N and 75% of the cases of difference were <1 mm and <2 mm in 95% of cases. The most reliable soft tissue point was the tip of the nose (P) with 80% error distribution <2 mm. The lowest reliability was in the Me´ point. Only 25% of prediction errors were less than 1 mm. Overall, the upper lip region showed an error of less than 2 mm in 65% of cases. The lower lip area had <2 mm prediction errors in 50% of cases. Total hard tissue areas in 73% of cases and soft tissue areas in 63% of cases showed <2 mm error in the vertical axis. The position of the lips relative to the E-line and H-line is also predicted more anterior than their actual amount. The predicted error distribution for the upper lip was concentrated at errors <4 mm, while the lower lip had greater error ranges (Tables 6 and 7).

Table 6. Mean and standard deviation of the differences between the measurement of actual points and predicted points by the software

Soft tissue points	Mean±SD
Upper lip to E line	-0.5±2.77
Lower lip to E line	0.9±3.43
Upper lip to H line	0.5±2.05
Lower lip to H line	2±3.42

Table 7. Distribution of the predicted error

Soft tissue points	Distribution of the predicted error		
	X < 2	2 - 4	X > 4
Upper lip to E line	50%	40%	10%
Lower lip to E line	30%	45%	25%
Upper lip to H line	60%	40%	0%
Lower lip to H line	60%	25%	15%

The method error in the linear measurements was 0.1 mm and the difference between the mean measurements was not statistically significant using the t-test.

4. Discussion

Currently, the advancement of computer systems has enabled cephalometric analysis of digital radiographs and the prediction of surgical outcomes. Understanding the accuracy of these computer-generated predictions can help the clinician develop a suitable treatment plan for complex patients requiring surgical treatment, and create more realistic expectations for patients (1). In the present study, the accuracy of the Dolphin software in predicting soft tissue changes after orthognathic surgery in 20 patients who has started orthodontic treatment was investigated. The results of cephalometries before and after surgery with the Dolphin software show that the upper lip had the highest accuracy in both the sagittal and vertical axes. The lowest accuracy was in the Me point on the sagittal and vertical axes.

Numerous studies have been conducted on software systems such as Quick Ceph Image, the Dentofacial Planner, Vistadent, Orthodontic Treatment Planner, and so forth that allow clinicians to manipulate and modify hard and soft tissue profiles and do preoperative image processing to simulate treatment, digitally (5). Our study was conducted on the software Dolphin version 11.8. This software predicts treatment by two separate linear parameters based on the direction of surgery on the x- and y-axis. The results of our study show that software predictions of soft tissue profiles in the vertical axis were more accurate than the sagittal axis. Error frequency of <2 mm was 63% in the vertical axis and 58% in the sagittal axis.

Pektas et al., who studied the Dolphin version 10 software, also stated that computer prediction in the sagittal axis was more accurate for all soft-tissue landmarks than the vertical axis, and error frequency of <2 mm was 91% in the sagittal axis and 68% in the vertical axis (12). This is also consistent with Akhoundi et al.(10), who studied the Dolphin version 10 software, and Lu et al. (13), who studied the Dolphin version 8 software. They stated that prediction of soft tissue outcomes in the vertical axis is more accurate than the sagittal axis. The results of our study show that the upper lip has the highest accuracy in both the sagittal and vertical axes. The highest reliability in the sagittal axis is in the upper lip with 80% error frequency and the tip of the nose in the vertical axis with 80% error frequency. This finding is consistent with most previous studies. In a 2016 study by Peterman et al. on the Dolphin version 11.0.3 software, the highest reliability was for point B and the tip of the nose with 100% error frequency of <2 mm (11). Similar to our study, Akhoundi et al. (2012) regarding the Dolphin version 10 software (10) and Pektas et al (2007) regarding the same version of the software reported that the most reliable prediction of soft tissue was related to the tip of the nose (12). This finding was inconsistent with Peterman et al. (11), who used the Dolphin visual treatment objective (VTO) prediction software. In their study, predictions in the sagittal direction were more accurate than in the vertical direction, and prediction error frequency of <2 mm was 79% in the sagittal axis and 61% in the vertical axis, which could be because of the use of the Dolphin VTO software.

In our study, the lowest accuracy and the least reliable with 35% and 45% error frequency of <2 mm (in sagittal and vertical axis, respectively) was for the Me point. Whereas, in a study by Peterman et al. (11), the lower lip with 58% and 14% error frequency of <2 mm (in sagittal and vertical axes, respectively) had the least reliability, which is consistent with Lu (13), Konstiantos (14), Syliangco (15), Sameshima (16), and Kazandjian (17). They all found the lowest accuracy and predictability in the lower lip, due to the effect of the position and angle of the incisors, the thickness and the tonicity of soft tissue, and the underlying muscle connections.

The findings of this study show that soft tissue landmarks in the horizontal axis have a negative value (underestimate) compared to actual tissue progression. There is a tendency to predict soft tissue in the more posterior direction than actual position, and soft tissue landmarks have a positive value (overestimated) in the vertical axis and tendency to predict soft tissue higher than the actual position. Akhoundi et al. (2012) regarding the Dolphin version 10 software showed similar results, suggesting that soft tissue predictions were in the higher and more posterior position than actual postoperative outcomes (10). Gosset et al. (2005), in a study on the Dolphin version 8 software showed that both overestimation and underestimation existed among the tested landmarks (18).

Our results also show that the position of the lips to the E line and H line are overestimated more than their actual value. Lu et al. (13). Studied the Dolphin version 8 software and found that prediction of the distance of the lips to point N-pog and the E line was overestimated, which is consistent with our study. This is also consistent with Upton et al.'s study, who showed that the predicted distance of the lips to the E line was overestimated more than their actual value (19).

Based on the method used in this study and the findings obtained by digital measurements, it can be concluded that the Dolphin Imaging version 11.08 software can be reliable for predicting hard tissue as well as soft tissue, particularly in the upper lip area.

The limitations of this study are due to being a retrospective study, and all the subjects in this study were not operated on by one surgeon and the images were taken by several clinicians. Thus, the post-surgical results may have been affected. It is suggested that a prospective study be conducted using more cases and use the three-dimensional technology to compare the results with two-dimensional photos. The Dolphin version 11.08 should also be re-examined in terms of enlargement and the matching of different radiographic images. Furthermore, mandible autorotation and lip positioning should be revised and improved.

Conclusion

The results of this study show that the upper lip has the highest accuracy in both the sagittal and vertical axes. The highest reliability in the sagittal axis is found in the upper lip and the tip of the nose in the vertical axis. The Me point has the least accuracy and least reliability in our study. In relation to hard tissue, the highest accuracy for the points Me and PNS are in the sagittal and vertical axes, respectively, and the most reliable point is in the Ar, in both axes. Due to the ease of learning and working with the Dolphin Imaging software, this software can be used as an assistant in diagnosis, treatment planning, and clinical trials and research work. It is hoped that the new and modified version of the software will provide more accurate predictions that will lead to better planning for patients.

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Conflict of interests

The authors declare that they have no conflict of interests.

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