

To Evaluate the Accuracy of Computer-Aided Prediction of the Soft Tissue Changes in Mandibular Advancement Cases – An in Vitro Study

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Abstract: *Objective:* This study aimed to assess the accuracy of predicting change in the soft tissue post-mandibular advancement using Dolphin Imaging software by comparing the predicted changes with the actual outcomes. *Materials And Methods:* The study was conducted on patients with good-quality cephalometric radiographs before and after the mandibular advancement treatment of patients aged 10-25 years, with skeletal class II malocclusion, no history of trauma, and TMJ Disorders. *Results:* The analytical comparison of the Holdaway predicted and actual parameters revealed significant differences in two aspects of the Holdaway parameters: the H angle and the Inferior sulcus to H-line. A notably higher predicted value was seen in the predicted H angle, while a lower value was seen in the Inferior sulcus to H-line. ($p \leq 0.05$) There was a non-significant difference in all the actual and predicted landmarks' linear parameters in the vertical(dy) as well as horizontal (dx), except for Lower lip, ST Pg, and ST Me, where the actual values were significantly greater than the predicted values. *Conclusion:* The prediction accuracy of changes in the soft tissue in mandibular advancement using dolphin imaging software may be significantly different for two parameters from the actual treatment result, which are the H angle and the Inferior sulcus to H line. The prediction accuracy in the horizontal plane was least significant in the chin region and precise in the soft tissue point A, with more accurate prediction seen in the vertical than that compared to the horizontal plane.

Keywords: Soft tissue changes, Mandibular advancement, Computer aided prediction.

INTRODUCTION

Beauty lies in the eye of the beholder still, the desire for enhanced facial aesthetics is the prime motivating factor for people to seek orthodontic treatment.¹ Enhancing the soft tissue profile is influenced by several factors and the connection between dental movement and soft tissue changes is intricate, depending on the relationship of soft tissues in all three spatial planes.²

In recent years, the field of orthodontics has experienced a significant transformation, largely driven by advancements in digital technology, including the Virtual Treatment Objectives (VTO) which represents a paradigm shift, enabling more precise, efficient, and predictable treatment planning.

Computerized systems for predicting and visualizing orthodontic treatment outcomes, such as Dolphin Imaging, Dentofacial Planner Plus, Vistadent, Orthoplan, and Quick Ceph Image, help evaluate potential treatment results through profile and photographic simulations.

Today, orthodontists aim to impact not just dental alignment and positioning but also take a more holistic approach, addressing both dental and facial aesthetics. Shifting focus on soft tissue, the importance of facial soft

tissues in orthodontics has grown significantly.^{3,4} In modern orthodontic treatment planning, soft tissue outcomes have become a critical aspect, to the point where many leading orthodontists view less-than-ideal soft tissue results as treatment failures.⁵

Class II Division 1 cases could be due to the forwardly placed maxilla, backwardly placed mandible, or a combination of both. In most of the class II cases seen, there is retrusion of the mandible. In these patients, mandibular advancement may be performed to improve facial aesthetics.⁶

Various treatment options are available for managing Class II malocclusions, including the use of removable or fixed functional appliances, extra-oral or intra-oral distalizing devices, tooth extractions, and orthodontic-surgical interventions, particularly when there are significant skeletal discrepancies.⁷

The reliability of computer-assisted predictions regarding changes in profile after braces treatment is still a subject of discussion for Dolphin Imaging Software.⁸ Some research indicates higher prediction accuracy for specific facial areas such as the chin, submandibular regions, and tip of the nose.⁹ However, few studies have revealed notable discrepancies in all measurements.

Previous investigations into the Dolphin VTO predictions accuracy for changes in the soft tissue have mostly concentrated on orthognathic treatments, whether or not orthodontics are performed and the prediction accuracy of VTO in the Dolphin software for orthodontic procedures remains insufficiently explored. This article aims to assess the precision of soft tissue change predictions in mandibular advancement, using Dolphin Imaging software, by comparing predicted changes with actual outcomes.

AIMS AND OBJECTIVES:

AIM:

The objective of this study was to assess the accuracy of predicting change in the soft tissue post-mandibular advancement using Dolphin Imaging software by comparing the predicted changes with the actual outcomes.

OBJECTIVES:

1. The study aims to compare the changes in soft tissue predicted by Dolphin Imaging software with the actual post-advancement changes observed in patients.
2. To estimate the prediction accuracy of Dolphin Imaging software.

MATERIALS AND METHODS:

The study was conducted in the Department of Orthodontics and Dentofacial Orthopaedics, D.Y. Patil University, School of Dentistry, Navi Mumbai

INCLUSION CRITERIA:

1. Good quality cephalometric radiographs before and after the mandibular advancement treatment of patients aged 10-25 years.
2. Records of patients with
 - Skeletal class II malocclusion.
 - no history of trauma.
 - no history of TMJ Disorders.

EXCLUSION CRITERIA:

1. Patients with a history of Craniofacial trauma, syndrome, or deformities (eg, cleft lip and palate);
2. Patients with a history of previous maxillofacial surgery; and
3. Patients with a history of temporo-mandibular disorders.

SAMPLE SIZE AND STUDY DESIGN:

The research was structured as a Retrospective observational investigation. Patients from a single institute were assessed for credibility. Following the application of inclusion and exclusion criteria, thirty young adult participants (15 males and 15 females) were selected to account for potential dropouts during the study. The study received approval from the Ethics Committee of DY Patil School of Dentistry, Navi Mumbai.

METHODOLOGY:

A consistent cephalometer (Carestream 9600) was used to obtain all the cephalometric radiographs with the patient positioned in their natural head posture, teeth in centric occlusion, and lips gently closed. Analysis, X-ray tracing, and VTO prediction were performed using Dolphin Imaging software version 11.95 Premium.

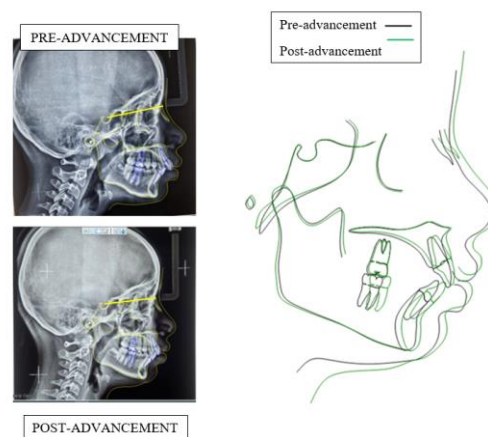


Fig.1 Sample of cephalometric tracing of the patient, superimposing done before and after mandibular advancement.

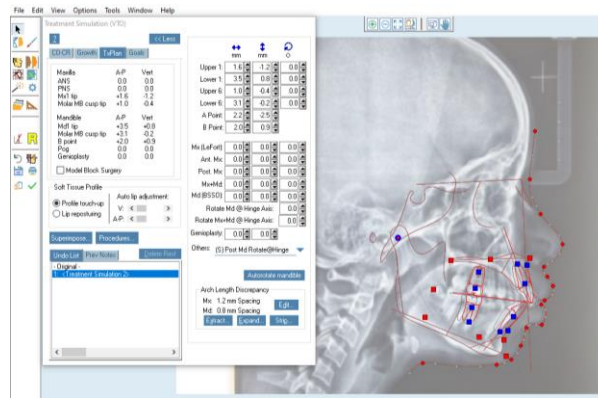


Fig 2. Treatment simulation using the Dolphin VTO displaying the changes in the soft tissue(red line). The definite changes seen pre and post-mandibular advancement, including change seen in the horizontal and vertical direction (in mm), were calculated through superimposition. These values were then added to the treatment simulation table (left) to formulate the predicted VTO outcome(right).

Each participant's pre and post-treatment cephalometric radiographs were taken in, tracing, and superimposition is done with SN as the plane of reference. (Fig.1)

The definite change observed in patients pre and post-mandibular advancement (Fig. 1), together with change in the horizontal and vertical direction (in mm), were evaluated and added to the simulation table (left; Fig. 2) to produce a treatment outcome by VTO(right; Fig.2).

The changes in the soft tissue (as indicated by the soft tissue landmarks in Table 1; Fig. 3 and Holdaway analysis parameters in Table 2; Fig. 4), the real post-mandibular advancement, and treatment results of the VTO were recorded by default utilising the Dolphin calculation tool. The superimposition of the VTO tracing (Fig. 2, red lines) onto the real cephalometric tracing post-mandibular advancement (Fig. 1, green lines), producing a superimposition that displayed the differences in the results (Fig. 5).

All landmarks used in the Holdaway parameters are listed in Table 1, while the specific Holdaway parameters considered are provided in Table 2. The soft tissue changes between the predicted and real values were calculated. Overestimation of the predicted VTO compared to the real change was denoted by a positive sign, while an underestimation was denoted by a negative sign, reflecting a more forward and upward bac or backward and downward predicted displacement in the VTO outcome compared to the actual post-advancement result.

Table 1. Landmarks

LANDMARK	DESCRIPTION
Glabella (G)	The most prominent anterior point on the mid sagittal plane of the forehead.
Soft tissue nasion (N')	The point of greatest concavity in the midline between the forehead and the nose.
Tip of the nose / Pronasale (Pn)	The junction of the inferior margin of the nasal ridge and the columella (the The most prominent or anterior part of the nose).
Subnasale (Sn)	The point where the columella merges with the upper lip in the mid sagittal plane.
ST A	The most concavity point of the upper lip between subnasale and labrale superius.
ST B	The most concavity point of the lower lip between labrale inferius and ST Pg.
Superior Labial Sulcus (Sls)	Point of greatest concavity in the midline of the upper lip between Sn and Ls.
Upper lip / Labrale superioris (Ls)	A point indicating the mucocutaneous border of the upper lip.

Stomium Superius (Sts)	The lowermost point on the vermillion of the upper lip.
Stomium Inferioris (Sti)	The uppermost point on the vermillion of the lower lip.
Lower lip / Labrale inferious (Li)	The median point in the lower margin of the lower membranous lower lip
Inferior labial sulcus (Ils)	Point of greatest concavity in the midline of the lower lip between Li and Pog'.
ST Pg (Pog')	The most anterior point on the chin
ST Me (Me')	The most inferior point on the chin
ST Gn	Midpoint between ST Pg and ST Mn

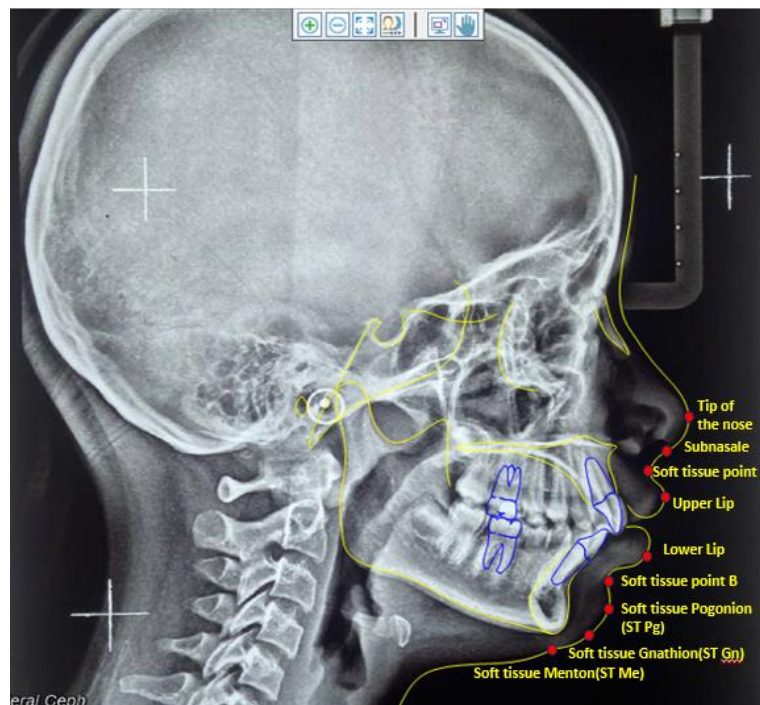


Figure.3 Soft tissue cephalometric Landmarks

Table 2. Holdaway soft tissue analysis

HOLDAWAY PARAMETER	MEANING
Soft tissue chin thickness (mm)	The distance between the hard and soft tissue facial planes at the level of suprapogonion
Skeletal profile convexity (mm)	The dimension between point A and facial line;
H-angle ($^{\circ}$)	The angle formed between the soft tissue facial plane line and the H-line
Lower lip to H-line (mm)	The measurement of the lower lip to the H-line
Nose prominence (mm)	The dimension between the tip of the nose and a perpendicular line drawn to the Frankfort plane from the vermillion
Soft tissue facial angle ($^{\circ}$)	The downward and inner angle formed at a point where the sella-nasion line crosses the soft tissue and a line combining the suprapogonion with the Frankfort horizontal plane

Soft tissue subnasale to H-line (mm)	The measurement from subnasale to the H-line
Upper lip sulcus depth (mm)	The measurement between the upper lip sulcus and a perpendicular line drawn from the vermillion to the Frankfort plane
Lower lip sulcus depth (mm)	The measurement at the point of greatest convexity between the vermillion border of the lower lip and the H-line
Upper lip thickness (mm) (upper lip strain)	The dimension between the vermillion point and the labial surface of the maxillary incisor
Basic upper lip thickness (mm)	The dimension measured approximately 3 mm below Point A and the drape of the upper lip
H-line (mm)	Tangent drawn from the tip of the chin to the upper lip

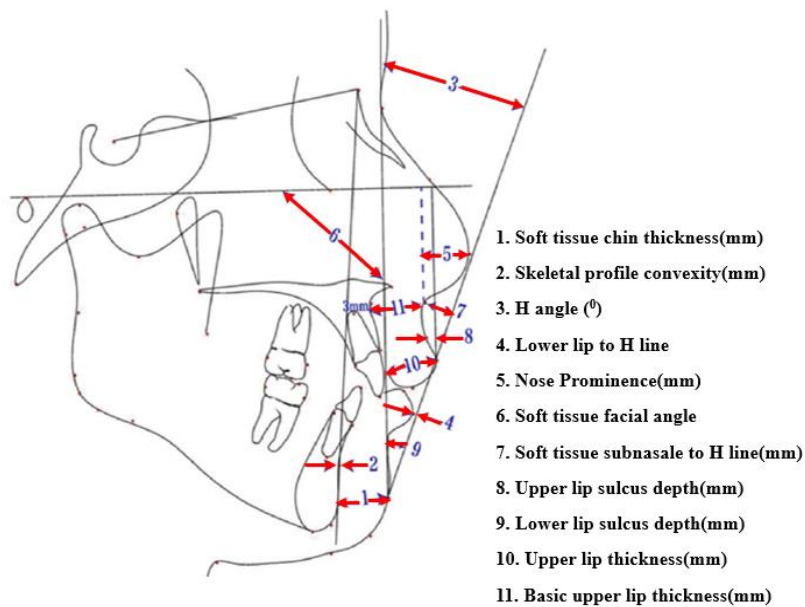


Fig.4. Holdaway soft tissue parameters

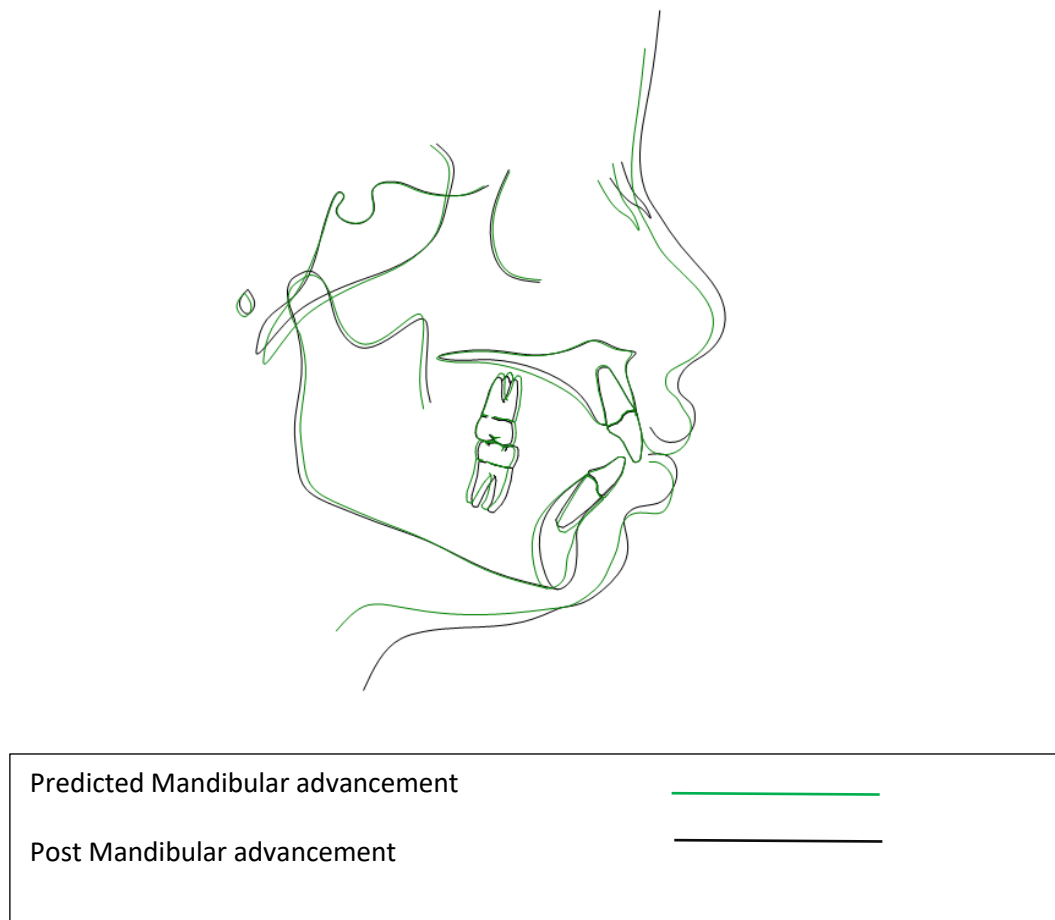


Fig.5 Cephalometric superimposition of the actual changes after mandibular advancement (Black line) and the VTO-predicted changes (Green line) for calculating the predication errors.

STATISTICAL ANALYSIS:

Statistical analysis was performed by entering the collected data into an IBM SPSS statistics version 26 .To describe the mean, and the standard deviation(SD), descriptive statistics were utilized. Analytical statistics was done using paired t-test and p less than or equal to 0.05.

RESULTS

The analytical comparison of the Holdaway predicted and actual parameters (Table 5) revealed significant differences in two aspects of the Holdaway parameters: the H angle and the Inferior sulcus to H-line. A notably higher predicted value was seen in the predicted H angle, while a lower value was seen in the Inferior sulcus to H-line.

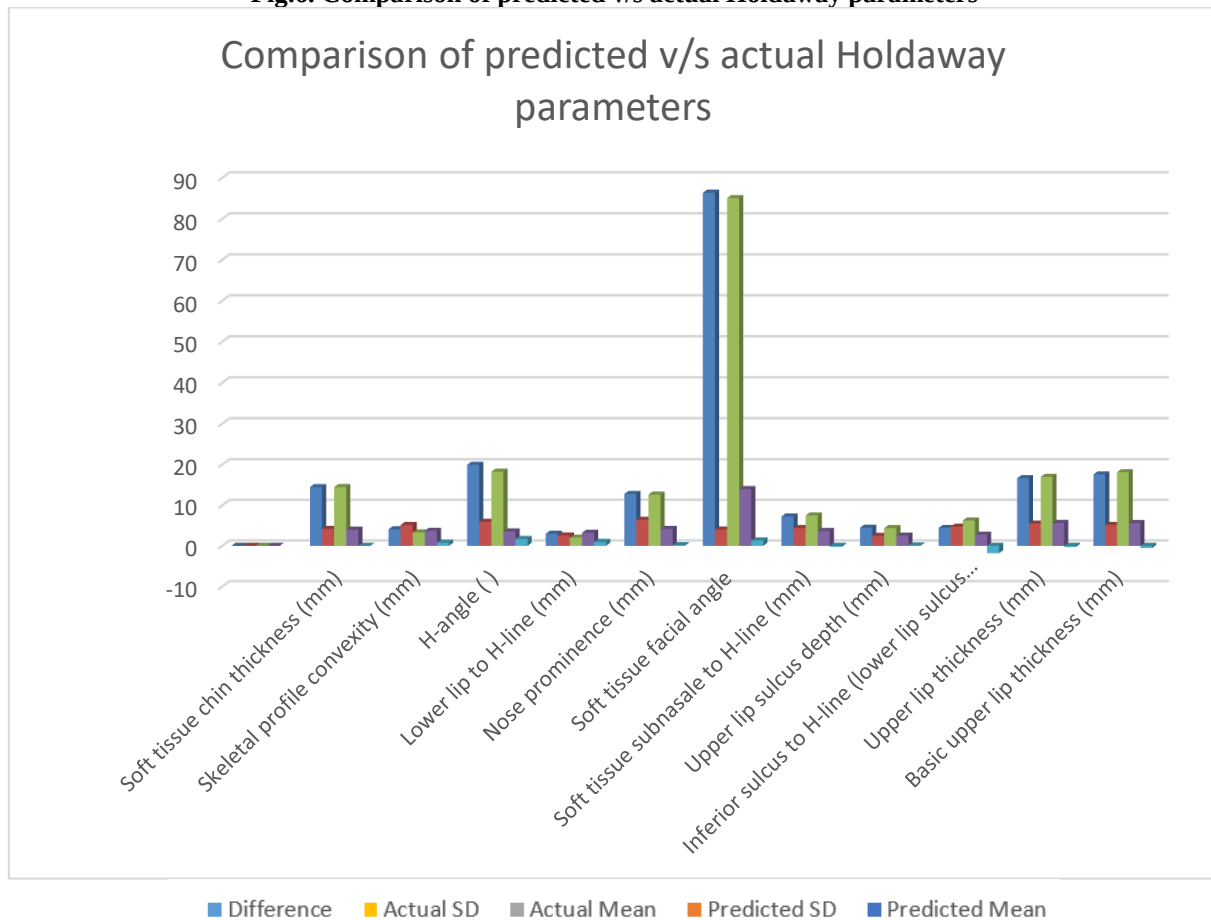
Table 3. Comparison of predicted v/s actual Holdaway parameters

Variable	Predicted		Actual		Difference	p-value
	Mean	SD	Mean	SD		
Soft tissue chin thickness (mm)	14.45	4.15	14.46	3.99	-0.01	0.974
Skeletal profile convexity (mm)	4.08	5.14	3.31	3.69	0.77	0.429
H-angle (°)	19.93	5.90	18.24	3.55	1.69	0.030*
Lower lip to H-line (mm)	2.98	2.55	2.02	3.21	0.96	0.203
Nose prominence (mm)	12.76	6.40	12.61	4.17	0.15	0.861
Soft tissue facial angle(°)	86.34	4.00	85.02	13.97	1.32	0.583
Soft tissue subnasale to H-line (mm)	7.23	4.36	7.48	3.65	-0.25	0.792
Upper lip sulcus depth (mm)	4.45	2.45	4.36	2.52	0.09	0.867
Inferior sulcus to H-line (lower lip sulcus depth) (mm)	4.40	4.71	6.22	2.73	-1.82	0.007*

Upper lip thickness (mm)	16.66	5.47	16.97	5.64	-0.31	0.510
Basic upper lip thickness (mm)	17.57	5.14	18.11	5.61	-0.54	0.188

Paired t test; * indicates a significant difference at $p \leq 0.05$

Fig.6. Comparison of predicted v/s actual Holdaway parameters



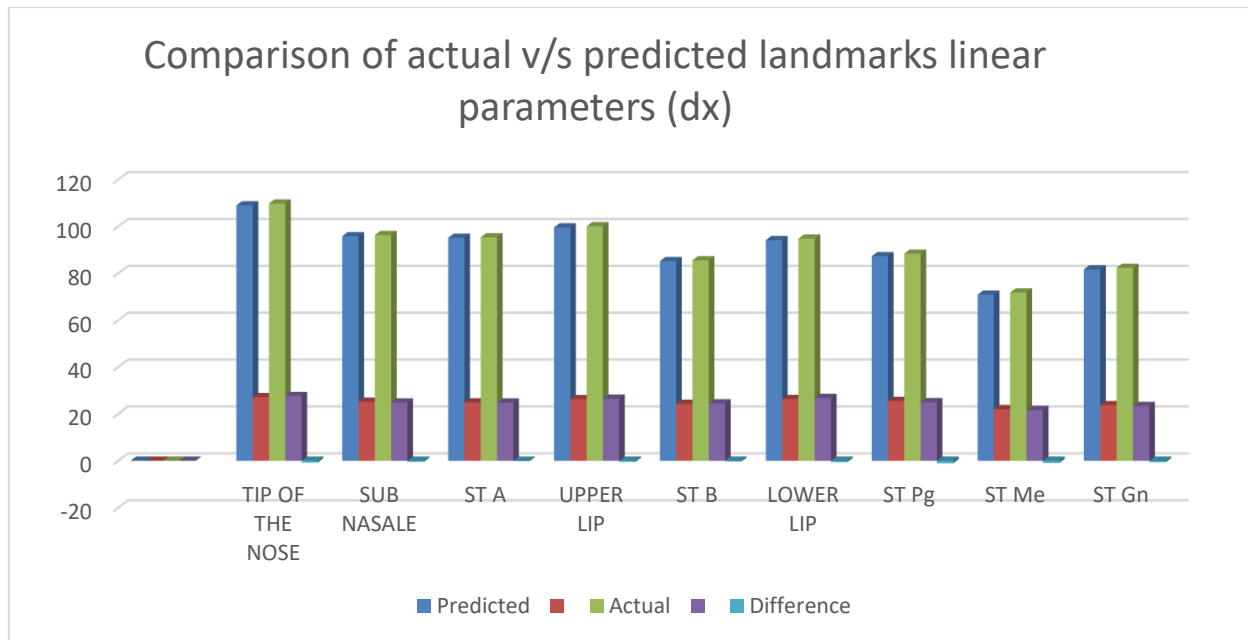
A positive difference indicated an overestimation of the VTO-predicted changes compared to the real changes, while a negative difference signified an underestimation.

Table. 4 Comparison of actual v/s predicted landmarks linear parameters (dx)

Variable	Predicted		Actual		Difference	p-value
	Mean	SD	Mean	SD		
TIP OF THE NOSE	108.98	27.14	109.75	27.60	-0.77	0.072
SUB NASALE	95.80	25.16	96.30	24.84	-0.50	0.130
ST A	95.11	24.86	95.30	24.80	-0.19	0.193
UPPER LIP	99.55	26.26	100.02	26.44	-0.47	0.100
ST B	85.15	24.26	85.51	24.46	-0.35	0.147
LOWER LIP	94.11	26.33	94.75	26.76	-0.64	0.020*
ST Pg	87.25	25.46	88.35	24.95	-1.10	0.002*
ST Me	70.81	21.98	71.76	21.62	-0.95	0.038*
ST Gn	81.61	23.68	82.26	23.32	-0.65	0.090

Paired t test

Fig.7. Comparison of actual v/s predicted landmarks linear parameters (dx)



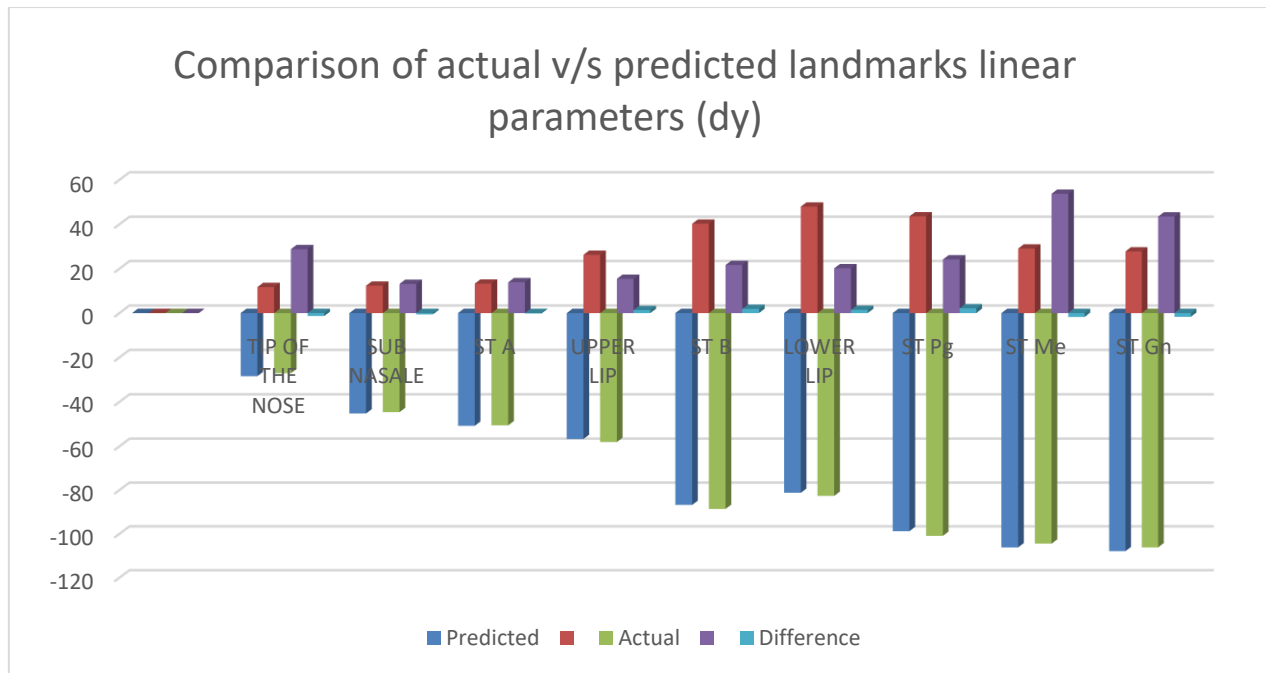
This table compares the actual and predicted landmarks' linear parameters (dx). There was a non-significant difference in all the actual and predicted landmarks linear parameters (dx) except for Lower lip, ST Pg, and ST Me, where the actual values were significantly greater than the predicted values.

Table.5 Comparison of actual v/s predicted landmarks linear parameters (dy)

Variable	Predicted		Actual		Difference	p-value
	Mean	SD	Mean	SD		
TIP OF THE NOSE	-28.43	11.69	-27.11	28.76	-1.32	0.762
SUB NASALE	-45.22	12.32	-44.62	13.10	-0.60	0.206
ST A	-50.78	13.25	-50.60	13.87	-0.19	0.682
UPPER LIP	-56.76	26.23	-58.11	15.40	1.35	0.730
ST B	-86.79	40.23	-88.64	21.61	1.85	0.789
LOWER LIP	-81.23	47.95	-82.64	20.16	1.41	0.832
ST Pg	-98.78	43.57	-100.91	24.16	2.13	0.745
ST Me	-106.20	29.05	-104.45	53.70	-1.75	0.811
ST Gn	-107.90	27.76	-106.18	43.47	-1.72	0.791

Paired t test

Fig.8. Comparison of actual v/s predicted landmarks linear parameters (dy)



This table compares the actual and predicted landmarks linear parameters (dy). There was a non-significant difference in all the actual and predicted landmarks linear parameters (dy).

Table.6 The absolute and relative error for Holdaway parameters

Holdaway	Absolute error	Relative error
Soft tissue chin thickness (mm)	-0.01	0.01
Skeletal profile convexity (mm)	0.77	-1.24
H-angle (°)	1.69	0.09
Lower lip to H-line (mm)	0.96	0.16
Nose prominence (mm)	0.15	0.01
Soft tissue facial angle (°)	1.32	0.15
Soft tissue subnasale to H-line (mm)	-0.25	0.10
Upper lip sulcus depth (mm)	0.09	0.19
Inferior sulcus to H-line (lower lip sulcus depth) (mm)	-1.82	-0.40
Upper lip thickness (mm)	-0.31	-0.01
Basic upper lip thickness (mm)	-0.54	-0.02

Fig.9. The absolute and relative error for Holdaway parameters

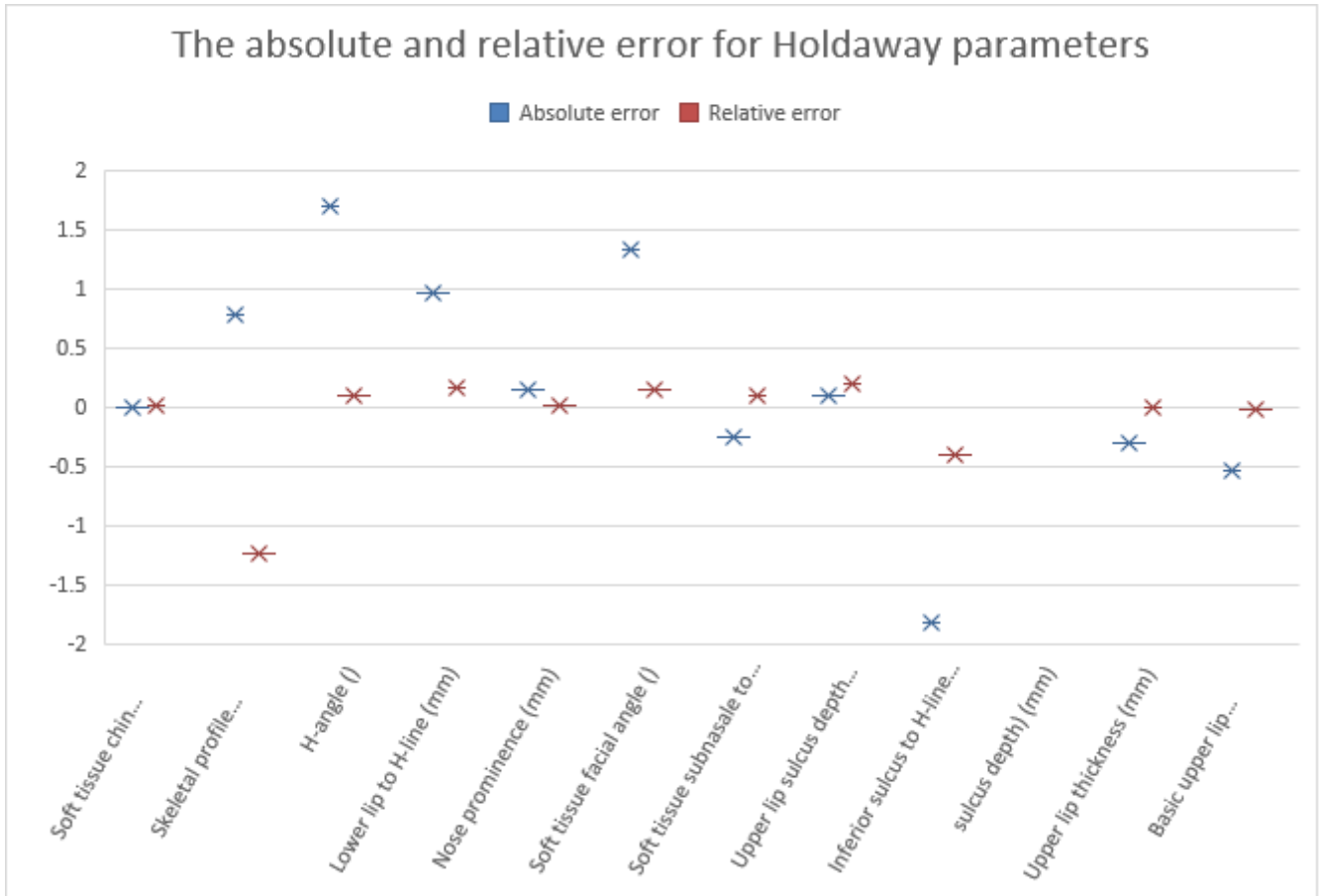


Table 7. The absolute and relative error for predicted landmarks (dx)

TS landmarks	Absolute error	Relative error
TIP OF THE NOSE	-0.77	0.007
SUB NASALE	-0.50	0.005
ST A	-0.19	0.002
UPPER LIP	-0.47	0.005
ST B	-0.35	0.004
LOWER LIP	-0.64	0.007
ST Pg	-1.10	0.012
ST Me	-0.95	0.013
ST Gn	-0.65	0.008

Table 8. The absolute and relative error for predicted landmarks (dy)

TS landmarks	Absolute error	Relative error
TIP OF THE NOSE	-1.32	-0.049
SUB NASALE	-0.60	-0.013
ST A	-0.19	-0.004
UPPER LIP	1.35	0.023
ST B	1.85	0.021
LOWER LIP	1.41	0.017
ST Pg	2.13	0.021
ST Me	-1.75	-0.017
ST Gn	-1.72	-0.016

Fig.10. The absolute and relative error for predicted landmarks (dx)

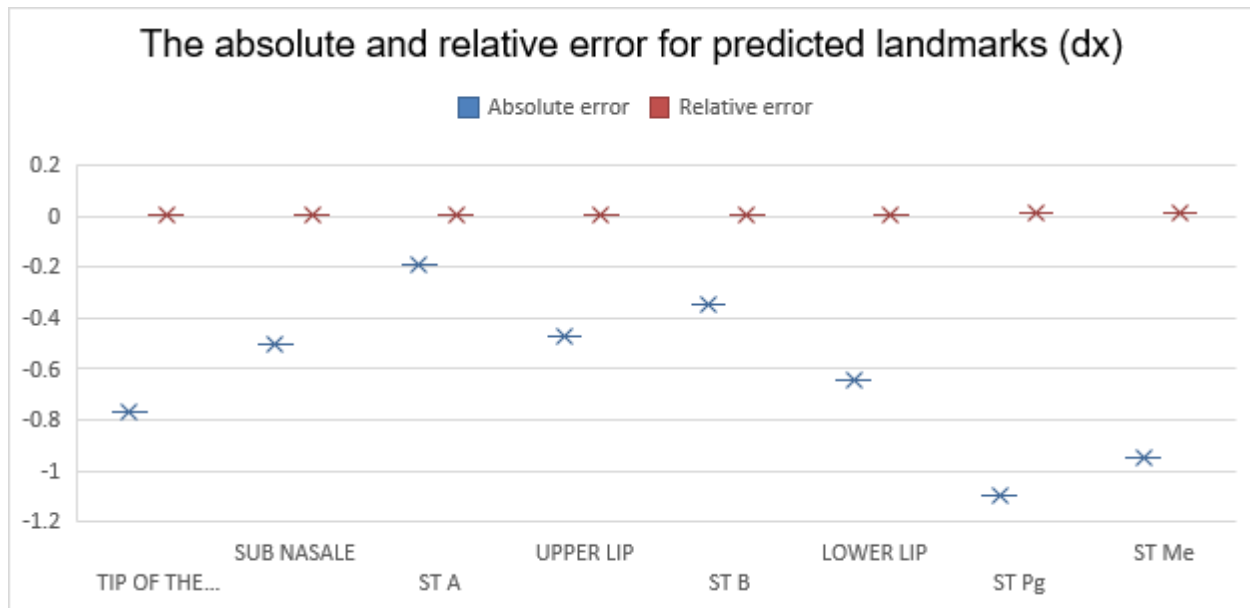
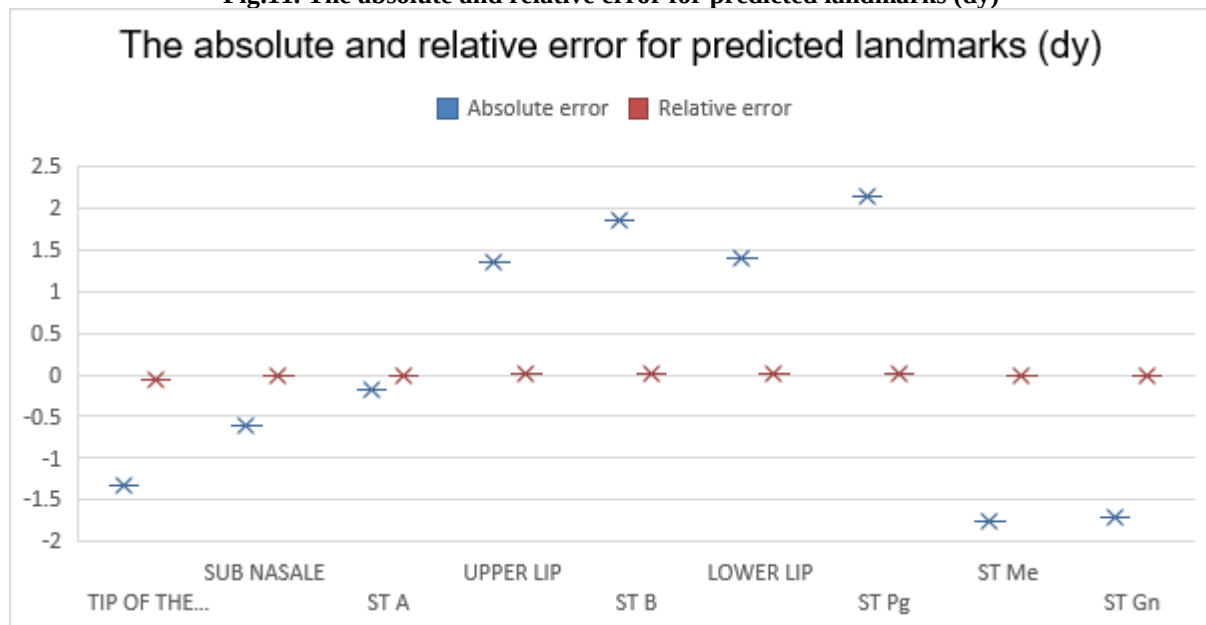


Fig.11. The absolute and relative error for predicted landmarks (dy)



Intra-examiner reliability assessment for Holdaway parameters showed an almost perfect agreement for all the parameters ranging from 0.882 to 0.999.

Intra-examiner reliability assessment for TS landmarks parameters showed a perfect agreement for all the parameters measured in vertical plane (dy) and almost perfect to perfect agreement for horizontal plane (dx) parameters.

Table 9. Intra-examiner reliability for Holdaway parameters

Holdaway	ICC
Soft tissue chin thickness (mm)	0.998
Skeletal profile convexity (mm)	0.966
H-angle (°)	0.970
Lower lip to H-line (mm)	0.980
Nose prominence (mm)	0.993
Soft tissue facial angle (°)	0.983
Soft tissue subnasale to H-line (mm)	0.882
Upper lip sulcus depth (mm)	0.984

Inferior sulcus to H-line (lower lip sulcus depth) (mm)	0.994
Upper lip thickness (mm)	0.999
Basic upper lip thickness (mm)	0.999

Intraclass correlation test

Table 10. Intra-examiner reliability for predicted landmarks (dx & dy)

TS landmarks	dx	Dy
TIP OF THE NOSE	1.000	0.999
SUB NASALE	1.000	1.000
ST A	1.000	1.000
UPPER LIP	1.000	1.000
ST B	1.000	1.000
LOWER LIP	1.000	1.000
ST Pg	1.000	1.000
ST Me	1.000	1.000
ST Gn	1.000	1.000

Intraclass correlation test

DISCUSSION

The current trend in orthodontics is increasingly focused on soft tissue relationships because worsening of the profile is seen if soft tissue relationships are overlooked during diagnosis or if aesthetic goals are not prioritized.⁴ The prediction accuracy of changes in soft tissue is crucial for effective orthodontic treatment planning. While fixed appliances may not significantly alter the skeletal structure, research suggests they help enhance soft tissue harmony and reduce the facial characteristics associated with Class II malocclusions.¹⁰

The current research assessed the VTO prediction accuracy of Dolphin software in determining the soft tissue changes in Class II patients post-mandibular advancement (orthodontic treatment only) with either myofunctional or fixed functional appliances without orthognathic surgery.

This study described the soft tissue changes in class II patients on 2 different parameters. First is the Holdaway analysis, followed by the specific soft tissue landmark changes. These soft tissue landmarks are evaluated separately in both the horizontal and the vertical planes. The analytical comparison of the Holdaway-predicted and actual parameters (Table 3) showed significant differences in two components of the Holdaway parameters: the H angle and the Inferior sulcus to H-line. A positive variation indicated an overestimation, and a negative variation indicated an underestimation of the changes predicted by VTO relative to the definite changes. Specifically, the predicted H angle was significantly higher than the real value (indicating overestimation), while the predicted Inferior sulcus to H-line was considerably lower than the actual value (indicating underestimation).

Comparison of the actual and predicted landmarks linear parameters (dx) (table 4) showed that there was a non-significant difference in all the actual and predicted landmarks linear parameters (dx) except for the landmarks of the chin region i.e. Lower lip, ST Pg and ST Me where the actual values were significantly greater than the predicted values. These landmarks predicted were backwardly placed when compared to the actual landmarks post treatment.

Comparison of the actual and predicted landmarks linear parameters (dy) (table 5) showed that there was a non-significant difference in all the actual and predicted landmarks linear parameters (dy).

The absolute error of prediction refers to the difference between the predicted post-advancement value (using Dolphin software) and the actual post-advancement value, expressed as the absolute value of the error. This measurement is in the same units as the original data. In accordance with the literature, where a 2 mm threshold is often considered clinically significant,¹¹ the prediction error was categorized into three tiers based on the absolute error: <0.5 mm for perfect accuracy, <1 mm for good accuracy, and <2 mm for moderate accuracy.¹²

The relative prediction error is the ratio of the absolute error to the true value. This value has no units but can be expressed as a percentage by multiplying it by 100%. The positive or negative value of the relative error indicates the inclination of the predicted position through the VTO in comparison to the actual post-treatment displacement. A positive sign suggests that the predicted position is more forward and upward, while a negative sign indicates that the predicted position is more downward and backward relative to the original post-mandibular advancement displacement.

The predictions for the landmarks in the horizontal line (Table 7) tended to be underestimated in both the lip and chin regions. However, while the difference was not significant in the lip region, it was significant in the chin region. In the vertical plane (Table 8), the predictions were generally overestimated in the lip region and underestimated in the chin region, though the differences were not significant in either region. The most accurate predictions were observed for the ST A and ST B landmarks, while the least accurate predictions were found for the landmarks in the chin area.

Intra-examiner reliability assessment was evaluated for both the Holdaway parameters and the TS Landmarks. Intra-examiner reliability assessment for Holdaway parameters (Table 9) showed an almost perfect agreement for all the parameters ranging from 0.882 to 0.999. Intra-examiner reliability assessment for TS landmarks parameters (Table 10) showed a perfect agreement for all the parameters measured in vertical plane (dy) and almost perfect to perfect agreement for horizontal plane (dx) parameters.

Research performed previously on the reliability and accuracy of Dolphin VTO prediction in treatment sequel has primarily focused on the tissue responses to orthognathic treatment(hard and soft), both with and without orthodontic intervention.

Peterman et al.. observed that the maxillary landmarks were underestimated (negative value) in terms of actual advancement while the mandibular soft tissue landmarks were overestimated (positive value) in terms of the actual retraction of the soft tissue. Among these, the prediction for the lower lip (Li) was the least accurate.¹³

Research has demonstrated that Dolphin in majority of the studies have indicated that the most reliably predicted landmark is tip of the nose, and the least accurate being the subnasale and lips after orthognathic treatment.¹³ Nevertheless, the reliability of Dolphin VTO changes in profile following orthodontic treatment is still not understood.

Zhang et al.. found that predictions in the lip region were generally overestimated horizontally and underestimated vertically. In contrast, predictions in the chin region were usually underestimated horizontally and overestimated vertically. The soft tissue A-point exhibited the most accurate predictions, while the chin region showed the least accuracy. Overall, vertical predictions were more accurate than horizontal ones. These results are consistent with our findings, although the changes in vertical landmark positions were not statistically significant in either the lip or chin regions.¹⁴

Shahla et al.. examined the predisposition of changes in the soft tissue for a Class II skeletal pattern using Dolphin VTO. Out of the three parameters showing statistical significance from Holdaway's analysis in this

study, two Holdaway parameters—inferior sulcus to H-line and H angle- are similar to our study.¹⁵

In line with our study, which identified prediction errors in the chin and lower lip regions, Nakornnoi et al. evaluated three different orthodontic treatments: non-extraction, extraction, and orthognathic surgery, and assessed the accuracy of Digital Imaging software in forecasting soft tissue changes.¹⁶

Our findings were similar to those of the study done by Arif et al., which stated that the prediction accuracy of the dolphin VTO was lesser in the horizontal direction when compared to the vertical.¹⁷

There are fixed ratios designed to simulate post-treatment alterations through which the dolphin VTO software predicts changes. 1:1 ratio for the change between the upper lip and maxillary incisors as recommended by Holdaway, while a 2:3 ratio was suggested by Ricketts. The movement ratios between hard and soft tissues vary widely, from 1:1.1 to 1:2.6.¹⁴ This variation may be due to several factors, including the thickness of soft tissue, sex, ethnicity, tension, age, dentofacial structure, and the methods for measuring. One limitation of the Dolphin VTO software is that its algorithm does not account for these influencing factors. Therefore, it is important to use the software carefully in clinical settings to prevent unrealistic expectations and minimize the risk of patient dissatisfaction.

SUMMARY AND CONCLUSION:

The prediction accuracy of changes in the soft tissue in mandibular advancement using dolphin imaging software may be different significantly for the H angle and Inferior sulcus to H line from the actual treatment result.

The predicted H angle value was significantly greater than the actual H angle value, and the predicted Inferior sulcus to H-line value was notably lower than the actual Inferior sulcus to H-line value.

The prediction accuracy in the horizontal plane was least significant in the chin region and precise in the soft tissue point A, with more accurate prediction seen in the vertical plane than that compared to the horizontal plane.

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