Accuracy of computer-aided prediction in soft tissue changes after orthodontic treatment

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Introduction: An accurate prediction in the soft tissue changes is of great importance for orthodontic treatment planning. Previous studies on the accuracy of the Dolphin visual treatment objective (VTO) in predicting treatment results were mainly focused on orthognathic treatment. The accuracy of Dolphin VTO prediction for orthodontic treatment is, however, poorly understood. The aim of this study was to evaluate the accuracy of Dolphin VTO prediction in soft tissue changes after orthodontic treatment by comparing the changes between predicted and actual values. **Methods:** A total of 157 patients were screened for eligibility, and 34 young adult patients (8 males, 26 females; mean age 24.8 ± 3.9 years) were finally included in the study based on the inclusion and exclusion criteria. The landmarks and parameters of the Holdaway soft tissue analysis were used for the cephalometric analyses. The cephalometric tracings of the actual treatment result and the Dolphin predicted treatment outcome were superimposed to calculate the prediction errors. Paired *t* test was used to compare the statistical differences between the predicted and actual treatment outcomes of the parameters used in the Holdaway soft tissue analysis. **Results:** There were significant differences between the predicted and actual values in parameters of the Holdaway soft tissue analysis ($P < 0.05$). The prediction of the landmarks in the lips region (ie, subnasale, soft tissue A-point, upper lip, lower lip, and soft tissue B-point) was inclined to be overestimated horizontally and underestimated vertically, whereas the prediction of the landmarks belonging to the chin region (ie, soft tissue pogonion, soft tissue gnathion, and soft tissue menton) was inclined to be underestimated horizontally and overestimated vertically. The most accurate prediction was found in the soft tissue A-point, whereas the least accurate one was found in the soft tissue in the chin region. The prediction was relatively more accurate in the vertical direction than in the horizontal direction. **Conclusions:** The Dolphin VTO prediction in soft tissue changes after the orthodontic treatment in patients with bimaxillary protrusion is the most accurate for the soft tissue A-point and the least accurate for the soft tissue chin region. (Am J Orthod Dentofacial Orthop 2019;156:823-31)

Improvement in facial esthetics is the most common motivation for seeking orthodontic treatment,[1,2] especially in patients with an orofacial deformity such as bimaxillary protrusion.[3] The main objectives of orthodontic treatment for bimaxillary protrusion are to improve facial appearance and soft tissue profile, which usually involves the extraction of premolars and retraction of the incisors and lips.[4-7]

To visually stimulate and predict the orthodontic treatment outcomes, computerized profile and photograph prediction systems, such as Dolphin Imaging, Dentofacial Planner Plus, Orthoplan, Quick Ceph Image,

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and Vistadent, are increasingly used during clinical consultation, treatment planning, and decision making.[8] For example, the Dolphin Imaging system, which is commonly used for the management of patients' photographs and videos, cephalometric measurement and analysis, and visual treatment objective (VTO),[9,10] can simulate the whole process of treatment by vivid, simple, and self-evident 3-dimensional animations. It has significantly enhanced the effectiveness and efficiency of doctor-patient communication.[11]

The accuracy of computer-aided VTO prediction in soft tissue changes after orthodontic treatment using Dolphin Imaging software is still under debate.[12] Some studies have reported that it predicted better in the tip of the nose, chin, and submandibular areas.[13] A number of other studies have compared the actual treatment outcome with the software-generated predictions and found clinically significant differences in all measurements.[14,15] These previous studies on the accuracy of Dolphin VTO prediction in soft tissue changes were mainly focused on orthognathic treatment with or without orthodontic treatment. The accuracy of Dolphin VTO prediction for orthodontic treatment is, however, poorly understood.

The aim of this study was to evaluate the accuracy of Dolphin VTO prediction in soft tissue changes after orthodontic treatment by comparing the changes between predicted and actual values.

MATERIAL AND METHODS

The study was designed as a retrospective observational study. A total of 157 patients from the same hospital were screened for eligibility. The determination of sample size was based on a previous study[16] by setting type I error at 0.05 and type II error at 0.20 (80% power). About 12 patients were needed to produce a 2-sided 95% confidence interval with a margin of error of 2 mm. After applying inclusion and exclusion criteria, 34 young adult patients (8 males, 26 females; mean age 24.8 $\pm$ 3.9 years) were included in the study to allow for possible dropout during the study. All eligible participants were informed of the study design and gave their written consent. The study was approved by the Ethics Committee of the State Key Laboratory of Oral Disease, West China School of Stomatology, Sichuan University, China.

Inclusion criteria were (1) nongrowing young adult patients (aged 18-40 years, cervical vertebral maturation stage 5); (2) skeletal Class I, angle Class I bimaxillary dental protrusion malocclusion, and crowding $<$ 4 mm in each arch with normal overjet and overbite; (3) new patients who were going to wear stainless steel brackets with premolars' extraction for reducing lip protrusion; (4) cephalometric radiographs before and after orthodontic treatment were both of good quality; and (5) willingness to participate in the study and signing an informed consent. Exclusion criteria were (1) craniofacial trauma, syndrome, or deformities (eg, cleft lip and palate); (2) previous maxillofacial surgery; and (3) temporomandibular disorders.

All cephalometric radiographs were taken using the same cephalometer (Veraviewepocs; Morita, Kyoto, Japan), in the patient's natural head position, with the teeth in centric occlusion and the lips lightly closed. Dolphin Imaging software version 11.9.07.23 (Patterson Dental, Los Angeles, Calif) was used for cephalometric tracing, analysis, and VTO prediction.

The pre- and posttreatment cephalometric radiographs of each participant were imported, traced, and superimposed using the Frankfort plane as the reference plane (Fig 1). The actual changes of the maxillary and mandibular incisors before and after the treatment (Fig 1), including the horizontal and vertical displacement distances (mm) and angulation changes (°), were calculated and subsequently input into the Dolphin treatment simulation software module (Fig 2, left image) to generate a VTO-predicted treatment outcome (Fig 2, right image). The values of soft tissue changes (the Holdaway analysis parameters; Table I; Fig 3) of the actual posttreatment and the VTO-predicted treatment outcomes were automatically recorded using the Dolphin measurement function as previously described.[17]

The cephalometric tracing of the VTO-predicted profile (Fig 2, blue lines) was superimposed with the actual posttreatment cephalometric tracing (Fig 1, red lines) to generate the cephalometric superimposition showing the difference between the actual changes and the VTO-predicted results (Fig 4).

Both intraoperator and interoperator reliabilities were tested using intraclass correlation coefficients. Six cephalometric radiographs were randomly selected and retraced by 2 independent dental investigators. Each investigator repeated the measurements after 4 weeks. The inter-rater reliability was excellent (correlation coefficient was 0.99). The intrarater reliability was excellent (correlation coefficients for the 2 investigators were 0.95 and 0.99). The 2 investigators and the statistician were all blinded to the study design.

The differences between the predicted and actual values of the soft tissue changes equaled the predicted values minus the actual values. The positive (negative) sign of the value of the difference revealed an overestimation (underestimation) of the VTO-predicted changes relative to the actual changes, with a more forward-(backward) and upward (downward)-predicted

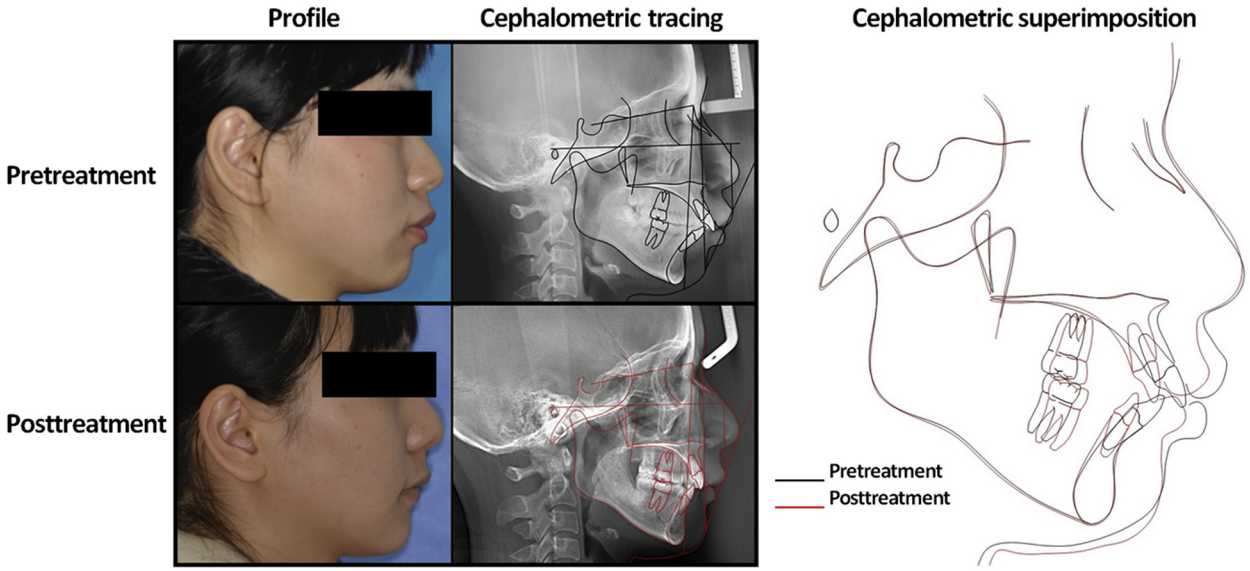

Fig 1. Example of a patient's profile, cephalometric tracing, and superimposition before and after orthodontic treatment.

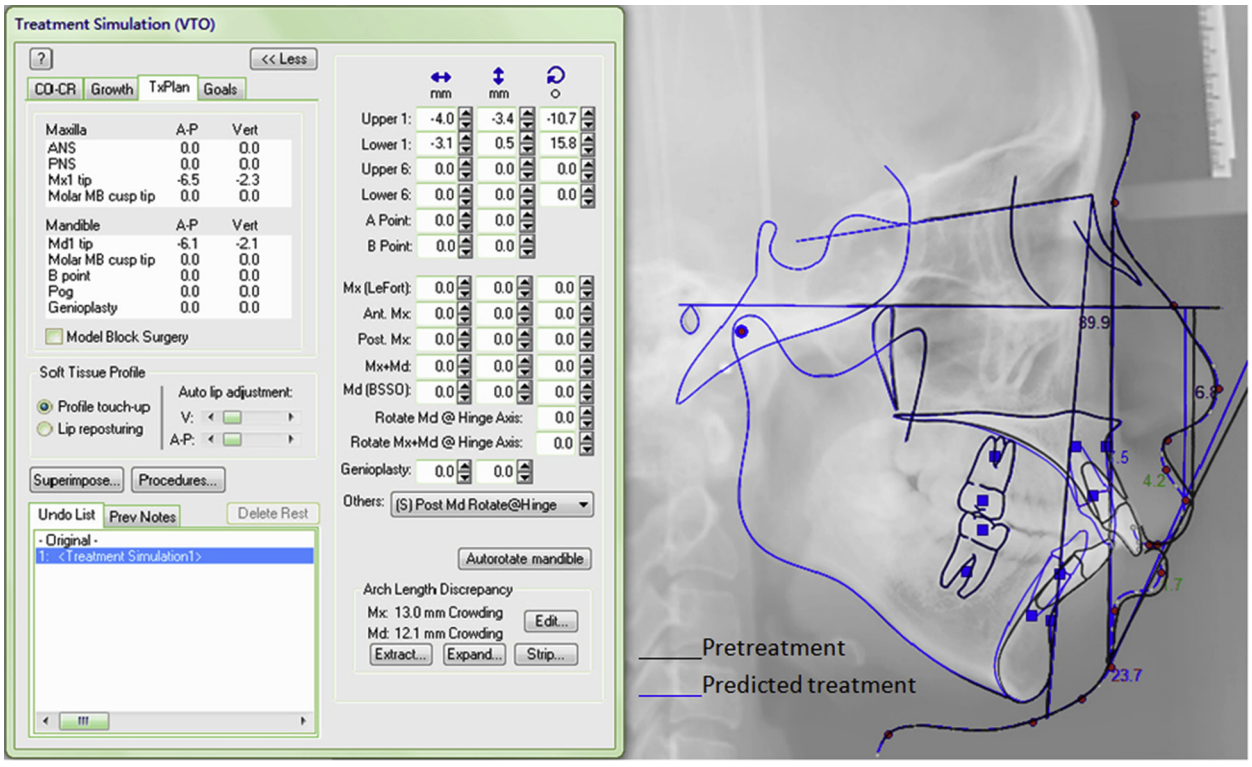

Fig 2. Dolphin VTO treatment simulation showing the predicted soft tissue changes (*blue line*). The actual changes of the maxillary and mandibular incisors before and after the treatment, including the horizontal and vertical displacement distances (mm) and angulation changes (°), were calculated from the cephalometric superimposition before and after the treatment, and subsequently input into the Dolphin treatment simulation module (*left image*) to generate a VTO-predicted outcome (*right image*).

Table I. Cephalometric landmarks and soft tissue analysis used in this study

Item	*Meaning*
Landmarks	
Tip of the nose	The junction of the inferior margin of the nasal ridge and the columella (the furthest point from the plane of the face)
Subnasale	The point where the columella merges with the upper lip
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
Upper lip	The border between skin and mucosa of the upper lip
Lower lip	The median point in the lower margin of the lower membranous lip
ST Pg	The most anterior point on the chin
ST Mn	The most inferior point on the chin
ST Gn	Midpoint between ST Pg and ST Mn
Holdaway soft tissue analysis	
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 (°)	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 (°)	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)	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

displacement of the predicted outcome relative to the actual posttreatment outcome.

The exact error of the prediction in each landmark (Table I) equaled the discrepancy between the predicted position of each landmark relative to its actual posttreatment position. The positive (negative) sign of the exact error revealed the direction of the VTO-predicted position of each landmark relative to its actual treatment displacement; for example, a positive (negative) sign of the prediction error meant a more forward (backward) and upward (downward) VTO-predicted position relative to the actual posttreatment displacement.

The absolute error of prediction (ie, the absolute value of the exact error) revealed the magnitude of error in the prediction of each landmark position after treatment using Dolphin VTO treatment simulation.

Because 2 mm was generally considered as the threshold of clinical significance in the literature,[18,19] the prediction error margins were divided into 3 levels based on the absolute error, including perfect accuracy (<0.5 mm), good accuracy (<1 mm), and moderate accuracy (<2 mm).[16] The percentage of each level of prediction in the landmarks was subsequently calculated.

Statistical analysis

Data were analyzed using SPSS statistical software (version 21; IBM, Armonk, NY). Paired t test was used to compare the statistical differences between the predicted and actual treatment outcomes of the parameters used in the Holdaway soft tissue analysis. One-sample t test was used for landmarks analysis. P values of <0.05 were considered statistically significant.

RESULTS

There were statistically significant differences between the predicted values and the actual values in 5 parameters of the Holdaway soft tissue analysis (Table II), including the H-angle (difference between the predicted and actual values $= 1.34 \pm 0.51$ mm, $P < 0.05$), lower lip sulcus depth (-0.97 ± 0.33 mm, $P < 0.05$), lower lip to H-line (1.69 ± 0.30 mm, $P < 0.05$), upper lip sulcus

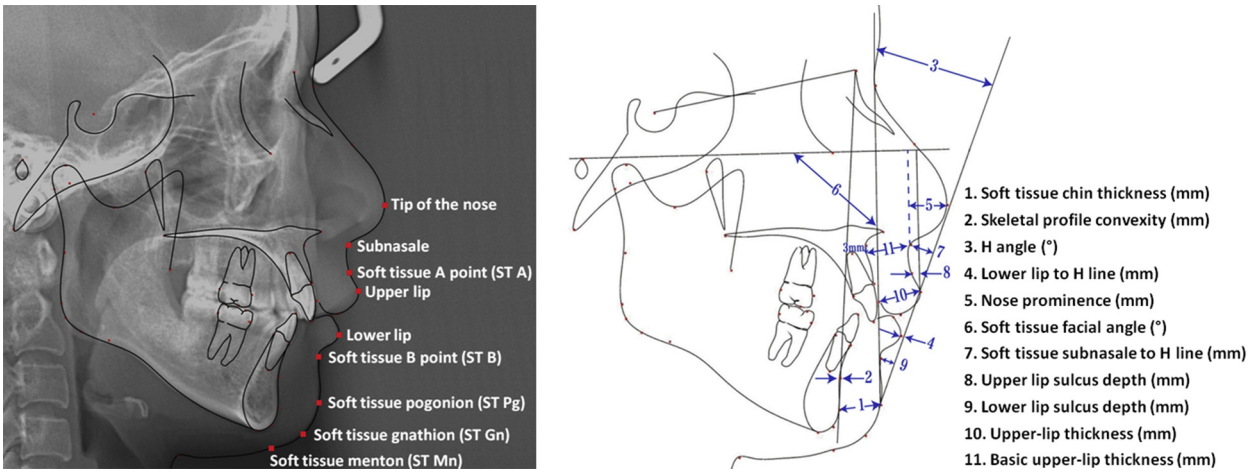

Fig 3. Cephalometric landmarks (*left image*) and Holdaway soft tissue analysis parameters (*right image*) used in the study.

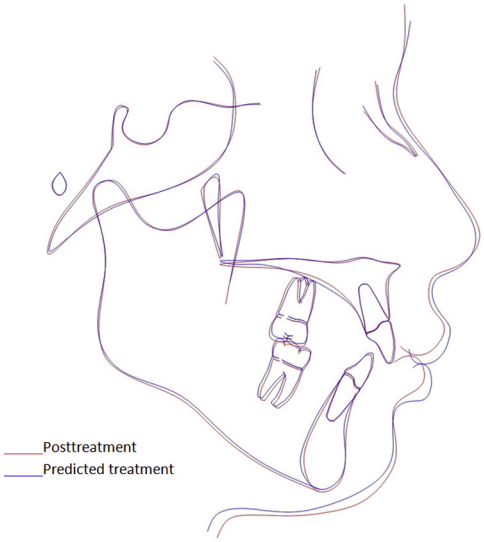

Fig 4. Cephalometric superimposition of the actual changes after treatment (*red line*) and the VTO-predicted changes (*blue line*) for calculating the predication errors.

depth (0.60 ± 0.17 mm, $P < 0.05$), and nasal prominence(−1.01 ± 0.32 mm, $P < 0.05$). The positive (negative) sign of the value of the difference revealed an overestimation (underestimation) of the VTO-predicted changes relative to the actual changes.

Tables III and IV summarize the exact and absolute errors of prediction in the horizontal and vertical planes. The prediction of the landmarks in the region of the lips (ie, subnasale, soft tissue A-point [ST A], upper lip, lower lip, and soft tissue B-point [ST B]) was inclined to be overestimated horizontally and underestimated vertically (ie, more forward and downward relative to their actual posttreatment positions), whereas the prediction of the landmarks belonging to the chin region (ie, soft tissue pogonion [ST Pg], soft tissue gnathion [ST Gn], and soft tissue menton [ST Mn]) was inclined to be underestimated horizontally and overestimated vertically (ie, more backward and upward relative to their actual posttreatment positions) (Tables III and IV; Fig 4).

The absolute error of the prediction revealed the magnitude of the difference between the predicted and actual values. Generally, the absolute errors of prediction in the horizontal plane were statistically greater than those in the vertical plane ($P < 0.05$ for all), except for the landmarks in the upper lip region (ie, ST A and upper lip) (Tables III and IV). The most accurate prediction was found in the ST A with the least absolute errors (1.04 ± 0.17 mm in the horizontal plane and 1.57 ± 0.22 mm in the vertical planes) and highest percentage of absolute error <2 mm (85.29% in the horizontal plane and 61.76% in the vertical plane) compared with those in the other soft tissue landmarks ($P < 0.05$ for all). The most inaccurate prediction was in the soft tissue chin landmarks (ie, ST Pg, ST Mn, and ST Gn) with greater absolute errors and a lower percentage of absolute error <2 mm than those in the other soft tissue landmarks (Tables II and III).

DISCUSSION

An accurate prediction in soft tissue changes is of great importance for orthodontic treatment planning. The present study evaluated the accuracy of the Dolphin VTO in predicting the treatment result of soft tissue

Table II. Statistical comparison of the soft tissue changes between the predicted values and the actual values

Holdaway soft tissue analysis items	*Predicted values, mean ± SEM*	*Actual values, mean ± SEM*	*Difference between the predicted and actual values*	*95% CI of the difference*		*t*	P
				Lower	*Upper*		
Soft tissue chin thickness (mm)	11.75 ± 0.47	12.00 ± 0.39	−0.25 ± 0.44	−1.15	0.64	−0.57	0.57
Skeletal profile convexity (mm)	2.67 ± 0.51	2.54 ± 0.56	0.13 ± 0.57	−1.03	1.28	0.22	0.83
H-angle (°)	20.19 ± 0.89	18.85 ± 0.80	1.34 ± 0.51	0.29	2.38	2.63	0.01
Lower lip to H-line (mm)	2.27 ± 0.30	0.57 ± 0.24	1.69 ± 0.30	1.08	2.31	5.61	<0.01
Nose prominence (mm)	7.37 ± 0.54	8.37 ± 0.42	−1.01 ± 0.32	−1.67	−0.35	−3.12	<0.01
Soft tissue facial angle (°)	91.00 ± 0.68	90.79 ± 0.69	0.20 ± 0.41	−0.63	1.03	0.49	0.63
Soft tissue subnasale to H-line (mm)	9.52 ± 0.54	8.72 ± 0.39	0.80 ± 0.41	−0.04	1.64	1.94	0.06
Upper lip sulcus depth (mm)	3.81 ± 0.18	3.21 ± 0.16	0.60 ± 0.17	0.25	0.94	3.55	<0.01
Inferior sulcus to H-line (lower lip sulcus depth) (mm)	3.10 ± 0.37	4.07 ± 0.21	−0.97 ± 0.33	−1.64	−0.30	−2.96	<0.01
Upper lip thickness (mm)	14.41 ± 0.46	13.72 ± 0.36	0.69 ± 0.37	−0.07	1.45	1.85	0.07
Basic upper lip thickness (mm)	17.29 ± 0.57	17.58 ± 0.58	−0.29 ± 0.66	−1.62	1.05	−0.43	0.67

Note. The difference between the predicted and actual values equals the predicted values minus the actual values.
SEM, standard error of the mean; *CI*, confidence interval.

Table III. The exact and absolute errors of the prediction in soft tissue changes in the horizontal plane

Item	*Exact error, mean ± SEM (mm)*	*Absolute error, mean ± SEM (mm)*	*Acceptable absolute error, %*		
			<0.5 mm	*<1 mm*	*<2 mm*
Tip of the nose	−0.25 ± 0.43	2.02 ± 0.25	11.76	29.41	55.88
Subnasale	0.20 ± 0.47	2.12 ± 0.29	14.71	29.41	52.94
ST A	0.15 ± 0.24	1.04* ± 0.17	29.41	61.76	85.29
Upper lip	0.72 ± 0.33	1.59* ± 0.22	14.71	41.18	73.53
ST B	1.19 ± 0.43	2.21 ± 0.27	14.71	23.53	52.94
Lower lip	2.17 ± 0.42	2.77 ± 0.30	5.88	17.65	38.24
ST Pg	−0.12 ± 0.77	3.68 ± 0.43	5.88	11.76	26.47
ST Mn	−0.77 ± 0.90	4.20 ± 0.53	11.76	14.71	26.47
ST Gn	−0.49 ± 0.84	4.13 ± 0.44	2.94	5.88	17.65
Overall average			12.42	26.14	47.71

Note. The exact error is the predicted values of soft tissue changes minus the actual values of soft tissue changes, reflecting the directional bias of the prediction, that is, a positive (negative) sign of the exact error means a more anterior (posterior) and upward (downward) VTO-predicted position relative to the actual posttreatment displacement. The absolute error is the absolute value of each exact error, reflecting the magnitude of the difference between the predicted and actual values.
SEM, standard error of the mean.
*Indicates the value is less than the clinical significance of 2 mm.

responses to orthodontic treatment in patients with bimaxillary protrusion and found that the prediction in 5 Holdaway parameters (ie, H-angle, lower lip sulcus depth, lower lip to H-line, upper lip sulcus depth, and nasal prominence) was significantly different from the actual changes. The prediction of the landmarks in the lip region was inclined to be overestimated horizontally and underestimated vertically, whereas the prediction of the landmarks in the chin region was inclined to be underestimated horizontally and overestimated

Table IV. The exact and absolute errors of the prediction in soft tissue changes in the vertical plane

			Acceptable absolute error, %		
Item	*Exact error, mean ± SEM (mm)*	*Absolute error, mean ± SEM (mm)*	*<0.5 mm*	*<1 mm*	*<2 mm*
Tip of the nose	−0.59 ± 0.42	1.96* ± 0.27	17.65	26.47	52.94
Subnasale	−0.07 ± 0.41	1.89* ± 0.24	8.82	32.35	64.71
ST A	−0.09 ± 0.35	1.57* ± 0.22	26.47	38.24	61.76
Upper lip	−0.24 ± 0.41	1.80* ± 0.27	20.59	35.29	55.88
ST B	−0.48 ± 0.47	2.11 ± 0.31	23.53	32.35	52.94
Lower lip	−0.50 ± 0.39	1.81* ± 0.24	17.65	32.35	61.76
ST Pg	0.11 ± 0.63	2.93 ± 0.36	17.65	26.47	35.29
ST Mn	0.16 ± 0.46	2.16 ± 0.26	8.82	17.65	58.82
ST Gn	0.30 ± 0.55	2.53 ± 0.33	8.82	26.47	45.95
Overall average			16.67	29.74	54.90

Note. The exact error is the predicted values of soft tissue changes minus the actual values of soft tissue changes, reflecting the directional bias of the prediction, that is, a positive (negative) sign of the exact error means a more anterior (posterior) and upward (downward) VTO-predicted position relative to the actual posttreatment displacement. The absolute error is the absolute value of each exact error, reflecting the magnitude of the difference between the predicted and actual values.
SEM, standard error of the mean.
*Indicates the value is less than the clinical significance of 2 mm.

vertically. The most accurate prediction was found in the ST A, and the most inaccurate prediction was found in the landmarks around the chin area.

Previous studies on the accuracy and reliability of the Dolphin VTO in predicting treatment results were mainly performed on the soft and hard tissue responses to orthognathic treatment (with or without orthodontic treatment).[14,16,20-23] It has been found that the Dolphin VTO was acceptably accurate in predicting the changes of hard tissue landmarks of SNA, SNB, and facial angle. In soft tissue changes, most studies have found that the tip of the nose was the most precisely predicted landmark, whereas the subnasale and lips were the least accurately predicted landmarks after orthognathic treatment.[21-23]

However, the accuracy of Dolphin VTO in the prediction of soft tissue changes after orthodontic treatment is still unclear. A number of studies about orthognathic treatment (with or without orthodontic treatment) have reported that the Dolphin VTO did not show a directional bias in the prediction.[20,22] This is in agreement with our finding that the distribution of the underestimation and overestimation were similar (without a pronounced direction bias) in both horizontal and vertical planes. However, some other studies have found that Dolphin VTO predicted different parts of soft tissues with errors leaning to certain directions[16,24]; for example, there was a study showing that the landmarks belonging to the maxilla region (tip of nose, subnasale, ST A and upper lip) were more likely to be underestimated, and the landmarks representing the mandible region (lower lip, ST Pg, ST Mn, and ST Gn) were more likely to be overestimated in the horizontal plane; almost all of the soft tissue landmarks were inferiorly predicted in the vertical plane.[16]

In the present study, the most accurately predicted landmark was the ST A, whereas the most inaccurate prediction was found in the landmarks around the chin area. This is in agreement with the previous studies, which found that the landmarks of ST Pg,[22] ST Mn,[16] and ST Gn[24] had the least predictive accuracy. The reason for the poor accuracy of prediction in the soft tissue chin region is unclear in the literature. It might be due to the unstable trait of the soft tissue thickness in this region, which is strongly associated with the body mass index.

In the study, the Dolphin VTO was generally more accurate in predicting the soft tissue changes in the vertical plane than those in the horizontal plane. The proportions of the errors below 0.5 mm, 1 mm, and 2 mm were consistently higher in the vertical direction than in the horizontal plane. This may be due to the relatively lesser soft tissue movement in the vertical direction than that in the horizontal direction during the actual orthodontic treatment in patients with bimaxillary protrusion. This is consistent with a previous study that suggested that a higher accuracy in the vertical direction was expected because the orthognathic surgery mainly involved sagittal algorithms.[21] However, there are also a number of studies that have reported that the prediction errors in the vertical direction were greater than those in the horizontal direction.[16,23]

The clinically acceptable prediction error (ie, <2 mm)[16] was 47.71% and 54.90% in the horizontal and vertical planes, respectively, in the study. When the

landmarks belonging to the chin region (ie, ST Pg, ST Mn, and ST Gn), which had the least prediction accuracy, were excluded from the statistical analysis, these percentages increased to 59.80% and 58.33%, respectively. These percentages were even higher in the studies using orthognathic surgery cases, which reported that the proportion of the errors <2 mm was 79% (horizontally) and 61% (vertically),[16] and the rate of errors <2 mm was 91% (horizontally) and 68% (vertically) after excluding the ST Mn and ST Gn from the analysis.[23] Further studies are needed to investigate and clarify the potential sources of the prediction errors.

The Dolphin VTO prediction in soft tissue changes is based on a fixed ratio to simulate the changes after treatment; the validity of this ratio, however, is still uncertain according to the literature.[12,25-28] Holdaway believed that the ratio of movement between upper lip and maxillary incisors was 1:1, whereas Ricketts considered the ratio to be 2:3.[25] There is a great variation in the ratio of movement between soft and hard tissues, ranging from 1:1.1 to 1:2.6.[12,25-28] This may be because the soft tissue changes can be influenced by not only hard tissue movement but also many other factors, such as soft tissue thickness and tension, dentofacial morphology, age, sex, ethnicity, and the technology used for measurement.[29-33] A defect of Dolphin prediction is that the software algorithm does not take these factors into consideration during prediction. This software should be used with caution in practice to avoid unrealistic expectations and patient dissatisfaction.

CONCLUSIONS

The Dolphin VTO prediction in soft tissue changes after orthodontic treatment in patients with bimaxillary protrusion may be significantly different from the actual treatment result for some particular parameters. The prediction was relatively more accurate in the vertical direction than in the horizontal direction, with the most accuracy seen in predicting the soft tissue A and the least accuracy in predicting the soft tissue in the chin region.

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