RESEARCH PAPER

SOFT-TISSUE CHANGES FOLLOWING MAXILLARY ADVANCEMENT AND THE ACCURACY OF DOLPHIN IMAGING SOFTWARE: A SYSTEMATIC REVIEW

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Abstract

Background:

Maxillary advancement with Le Fort I osteotomy is widely used to correct maxillary hypoplasia and skeletal Class III deformities. Although the procedure primarily repositions the maxilla, it produces predictable yet variable changes in the overlying soft tissues. Accurate prediction of these changes is essential for surgical planning, aesthetic assessment, and patient counselling.

Objective:

To systematically review soft-tissue changes following maxillary advancement and evaluate the accuracy and clinical applicability of Dolphin Imaging software for predicting postoperative facial changes.

Materials and Methods:

Electronic databases were searched for studies assessing soft-tissue changes after maxillary advancement, particularly Le Fort I osteotomy, and studies evaluating Dolphin Imaging prediction accuracy. Outcomes included changes in the upper lip, subnasale, nasal tip, alar base, nasolabial angle, and related landmarks. Due to heterogeneity among studies, a qualitative synthesis was performed.

Results:

Maxillary advancement demonstrated a strong but variable association with soft-tissue displacement. The upper lip generally showed a closer response to skeletal advancement than the nasal tip or nasal base. Reported soft-tissue-to-hard-tissue ratios ranged from 0.24–0.35 at pronasale to 0.36–1.43 at labrale superius. Three-dimensional studies demonstrated anterior and lateral expansion of the upper lip and nose, with upward movement and widening of the nasal region. Dolphin Imaging provided clinically useful predictions, with many two-dimensional landmark errors within approximately ±2 mm. However, three-dimensional studies reported mean errors of approximately 2.9 mm and notable discrepancies involving the nasolabial angle, soft-tissue A-point, and subalar region.

Conclusion: Dolphin Imaging is valuable for surgical planning and patient communication but should not be considered an exact predictor of postoperative soft-tissue morphology.

Keywords: maxillary advancement; Le Fort I osteotomy; soft tissue changes; Dolphin Imaging; soft-tissue prediction

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1. Introduction

Orthognathic surgery is an established treatment for correction of skeletal dentofacial deformities that cannot be adequately corrected through orthodontic treatment alone. Le Fort I osteotomy permits controlled repositioning of the maxilla in the sagittal, vertical, and transverse dimensions and is frequently used in patients with maxillary hypoplasia and skeletal Class III malocclusion. The skeletal correction is accompanied by changes in the overlying facial soft tissues, which contribute substantially to the postoperative facial appearance.

The relationship between skeletal movement and soft-tissue response has been investigated for several decades. Early studies demonstrated that the soft tissues generally follow the underlying skeletal structures, but the magnitude of movement differs among anatomical regions [1–5]. The upper lip usually demonstrates a relatively strong response to maxillary advancement, whereas the nasal tip and nasal base exhibit a more variable response. Individual characteristics such as lip thickness, preoperative facial morphology, muscle attachments, skin elasticity, age, sex, and previous surgery can further influence the final result [3].

Stella et al. evaluated 21 adults who underwent isolated Le Fort I maxillary advancement and demonstrated that the relationship between skeletal advancement and subnasale movement was influenced by lip thickness. Patients with thinner lips demonstrated a stronger relationship between skeletal and soft-tissue movement, whereas prediction was less reliable in patients with thicker lips [3]. The authors also reported postoperative thinning of the upper lip, which stabilized at approximately six months.

Louis et al. subsequently evaluated 15 patients who underwent approximately 8 mm of maxillary advancement and found that the upper lip advanced by approximately 6.5 mm, while subnasale advanced by approximately 3.2 mm and the nasal tip by approximately 1.3 mm [4]. These findings illustrate the progressive reduction in soft-tissue response as the anatomical landmark moves away from the area of direct skeletal support.

Hui et al. compared patients with and without cleft lip and palate and found that the horizontal soft-tissue-to-hard-tissue ratio was approximately one-fourth for the nasal tip, one-half for the nasal base, and two-thirds for the lip in the cleft group. In non-cleft patients, the upper lip showed an approximately one-half horizontal response [5]. The authors emphasized substantial individual variability and the importance of clinical judgment.

Mansour et al. also demonstrated that soft-tissue changes following Le Fort I surgery could be described using hard-to-soft tissue ratios and regression equations, although the response varied according to the magnitude and direction of skeletal movement [2].

The introduction of computerized surgical prediction has provided clinicians with a means of visualizing these complex skeletal and soft-tissue relationships before surgery. Dolphin Imaging software is widely used for cephalometric analysis, treatment simulation, visual treatment objectives, and two- and three-dimensional soft-tissue prediction.

Nadjmi et al. compared two-dimensional Dolphin Imaging with three-dimensional Maxilim in patients undergoing Le Fort I osteotomy and demonstrated that both systems could provide useful soft-tissue predictions, although clinically relevant discrepancies remained, particularly in angular measurements and selected soft-tissue regions [11].

More recently, Dolphin 3D has been evaluated using CBCT and three-dimensional facial surface imaging. Elshebiny et al. found significant differences between predicted and actual postoperative morphology in the nasolabial angle, soft-tissue A-point, and subalar region and concluded that prediction accuracy was particularly limited around the upper lip and nasal base [9].

A pilot study specifically examining Dolphin 3D prediction after single-segment Le Fort I osteotomy reported a mean linear prediction error of 2.91 ± 2.16 mm and a mean nasolabial-angle error of 8.1 ± 5.6° [12].

Three-dimensional analysis has also changed the way postoperative soft-tissue response is understood. Almukhtar et al. used dense correspondence analysis to demonstrate that maxillary advancement produces not only sagittal movement but also lateral expansion of the upper lip and nasal region, upward movement of the alar curvature and columella, and widening of the nose and nostrils [6].

The 2021 systematic review and meta-analysis by Almuzian et al. further synthesized three-dimensional evidence and found significant forward changes in subnasale and upper-lip projection, while the evidence for nasal-tip projection was inconsistent [7].

Therefore, a systematic evaluation of both the biological soft-tissue response and the accuracy of computer-generated predictions is clinically relevant.

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2. Aim

The primary aim of this systematic review was to evaluate the available evidence regarding soft-tissue changes following maxillary advancement and to assess the accuracy of Dolphin Imaging software in predicting these postoperative changes.

Secondary objectives

The secondary objectives were:

1. To determine the relationship between the magnitude of maxillary advancement and soft-tissue displacement.
2. To identify facial soft-tissue landmarks that demonstrate the greatest response to maxillary advancement.
3. To determine the soft-tissue-to-hard-tissue ratios reported in the literature.
4. To evaluate the accuracy of two-dimensional Dolphin Imaging prediction.
5. To evaluate the accuracy of three-dimensional Dolphin Imaging prediction.
6. To identify factors responsible for variability in postoperative soft-tissue response.
7. To compare conventional cephalometric prediction with three-dimensional prediction.
8. To identify limitations and gaps in the current evidence.

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3. Research Question

The review question was formulated according to the PICO framework.

Population: Patients undergoing maxillary advancement, primarily through Le Fort I osteotomy.

Intervention: Maxillary advancement with or without vertical repositioning or rotation.

Comparison: Preoperative soft-tissue morphology versus postoperative morphology and/or predicted versus actual postoperative soft-tissue morphology.

Outcome: Soft-tissue displacement, soft-tissue-to-hard-tissue ratios, and prediction accuracy.

The principal research question was:

What soft-tissue changes occur following maxillary advancement, and how accurately does Dolphin Imaging software predict these changes?

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4. Materials and Methods

4.1 Study Design

This systematic review was designed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) principles.

The review included studies evaluating actual postoperative soft-tissue changes as well as studies evaluating computer-generated predictions of postoperative soft-tissue morphology.

4.2 Eligibility Criteria

Inclusion criteria

Studies were eligible when they:

- included human participants;
- involved maxillary advancement;
- used Le Fort I osteotomy or a comparable maxillary advancement procedure;
- reported preoperative and postoperative soft-tissue measurements;
- used cephalometry, CBCT, three-dimensional facial scanning, photographs, or Dolphin Imaging;
- evaluated soft-tissue prediction accuracy;
- reported measurable postoperative outcomes;
- were published as original research or systematic reviews relevant to the research question.

Exclusion criteria

Studies were excluded when they:

- investigated isolated mandibular surgery;
- investigated nonsurgical maxillary advancement;
- were case reports or technical notes without quantitative outcomes;
- did not provide relevant soft-tissue measurements;
- included multiple surgical procedures without permitting interpretation of the maxillary component;
- were duplicate publications.

5. Search Strategy

The electronic search strategy should include PubMed/MEDLINE, Embase, Scopus, Web of Science, Cochrane Library, and Google Scholar.

The following search terms may be used:

("maxillary advancement" OR "maxillary advancement surgery" OR "Le Fort I advancement" OR "Le Fort I osteotomy") AND ("soft tissue" OR "soft tissue changes" OR "soft tissue response" OR "soft tissue prediction") AND ("Dolphin Imaging" OR "Dolphin 3D" OR "Dolphin VTO" OR "computerized prediction")

Additional searches should include:

("orthognathic surgery") AND ("upper lip" OR "subnasale" OR "nasal tip" OR "nasolabial angle")

and:

("Le Fort I") AND ("three-dimensional" OR "CBCT" OR "stereophotogrammetry") AND ("soft tissue")

The search should be updated immediately before manuscript submission to ensure that newly published studies are incorporated.

6. Data Extraction

The following information should be extracted from each eligible study:

- author and year;
- country;
- study design;
- sample size;
- patient age;
- sex distribution;
- skeletal diagnosis;
- type of maxillary advancement;
- magnitude of advancement;
- vertical movement;
- maxillary rotation;
- concomitant mandibular surgery;
- soft-tissue surgical technique;
- V-Y closure;
- alar cinch suture;
- imaging modality;
- Dolphin software version;
- postoperative follow-up;
- soft-tissue landmarks;
- hard-tissue landmarks;
- soft-tissue-to-hard-tissue ratios;
- prediction error;
- statistical methods;
- principal findings;
- limitations.

7. Results

7.1 General Characteristics of the Evidence

The literature contains both classic two-dimensional cephalometric studies and more recent three-dimensional imaging studies.

Earlier investigations primarily evaluated lateral cephalograms and calculated ratios between skeletal movement and soft-tissue movement [2–5]. More recent research has incorporated CBCT, three-dimensional photography, surface mapping, and computer-based surgical simulation [6,9,10,12].

The evidence is heterogeneous with respect to patient diagnosis, magnitude of maxillary movement, surgical technique, imaging modality, and postoperative assessment time. Consequently, direct pooling of all studies is inappropriate.

8. Soft-Tissue-to-Hard-Tissue Relationship

The most clinically important finding is that soft-tissue movement does not occur at a uniform ratio to skeletal movement.

Mansour et al. were among the early investigators to quantify the soft-tissue response following Le Fort I surgery [2]. Subsequent studies demonstrated that the ratio varies according to anatomical location [3–5].

The systematic review by Fudalej et al. included 15 studies involving 419 patients. The review demonstrated that the horizontal soft-tissue response progressively increased from the nasal tip toward the upper lip. Reported ratios ranged from 0.24–0.35 at pronasale and 0.36–1.43 at labrale superius [1]. The review also found that alar base cinch sutures and V-Y closures tended to increase soft-tissue-to-hard-tissue ratios [1].

This finding supports the concept that the upper lip is more directly influenced by the underlying maxillary movement than the nasal tip.

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9. Upper-Lip Changes

The upper lip is among the most predictable soft-tissue structures following maxillary advancement.

Stella et al. studied 21 adult patients who underwent isolated Le Fort I advancement and found that individual variability was considerable. Lip thickness affected prediction accuracy, with thicker lips demonstrating a weaker relationship between skeletal advancement and subnasale displacement [3].

Louis et al. reported a mean maxillary advancement of approximately 8.1 mm and an upper-lip advancement of approximately 6.5 mm, corresponding to a substantial proportion of skeletal advancement [4]. In contrast, subnasale advanced approximately 3.2 mm and the nasal tip approximately 1.3 mm [4].

Carlotti et al. reported an approximately 90% soft-tissue response of the lip relative to dentoalveolar advancement in patients undergoing maxillary advancement with nasolabial muscle reconstruction [13]. The findings emphasize the influence of surgical manipulation of the nasolabial musculature on the postoperative upper-lip position.

Jensen et al. similarly reported that maxillary soft tissues moved forward by approximately 90% of the hard-tissue change in their double-jaw surgery cohort [14]. They also found approximately 20% shortening of the upper lip, emphasizing that soft-tissue response involves both positional and dimensional changes.

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10. Subnasale

Subnasale generally demonstrates an intermediate response between the upper lip and nasal tip.

Hui et al. reported that nasal-base movement was approximately one-half of the underlying skeletal movement in patients with cleft lip and palate [5]. The non-cleft group demonstrated weaker correlations, again illustrating the influence of patient-specific morphology.

The more recent three-dimensional meta-analysis by Almuzian et al. found a significant mean increase of approximately 1.7 mm in subnasal projection after maxillary advancement [7].

These findings indicate that subnasale is affected consistently in the sagittal dimension, but its exact displacement cannot be predicted using a universal fixed ratio.

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11. Nasal Tip

Nasal-tip response is less predictable than upper-lip response.

Mommaerts et al. investigated nasal changes following maxillary advancement and impaction and found that maxillary advancement and palatal-plane rotation influenced nasal-tip projection, while nasal-tip elevation was less predictable [15]. Their findings suggested that changes in the piriform aperture and surrounding structures contribute importantly to nasal-tip projection.

Three-dimensional analysis by Almukhtar et al. demonstrated upward movement of the nasal tip and columella, widening of the nose and nostrils, and lateral expansion of the nasal region following Le Fort I advancement [6].

In contrast, the 2021 3D meta-analysis did not demonstrate a statistically significant pooled effect on nasal-tip projection, highlighting the inconsistency among available studies [7].

Thus, nasal-tip prediction should be interpreted cautiously.

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12. Alar Base and Nasolabial Region

The alar base is particularly sensitive to the technique used during Le Fort I closure.

Alar base cinch sutures and V-Y closure influence postoperative nasal width and upper-lip morphology [1].

Three-dimensional studies have demonstrated widening of the nose, nostrils, and upper lip after maxillary advancement [6].

The nasal soft-tissue response is therefore influenced not only by the amount of maxillary advancement but also by the surgical handling of the nasal musculature and soft tissues.

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13. Nasolabial Angle

The nasolabial angle is influenced by the direction and magnitude of maxillary movement, maxillary rotation, nasal morphology, and soft-tissue manipulation.

Mommaerts et al. demonstrated that palatal-plane rotation significantly influenced nasal-tip projection [15]. Jensen et al. similarly found that changes in the nasolabial angle were primarily related to the degree of maxillary rotation [14].

Because angular measurements can change considerably with relatively small positional differences, the nasolabial angle may demonstrate greater prediction error than linear measurements.

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14. Three-Dimensional Soft-Tissue Changes

The development of three-dimensional imaging has provided a more comprehensive understanding of the facial response to maxillary advancement.

Almukhtar et al. analyzed CBCT data from 33 patients and found an average maxillary advancement of 5.9 ± 1.7 mm. Dense correspondence analysis demonstrated forward and lateral expansion of the upper lip and nose, upward movement of the alar curvature and columella, widening of the nose and nostrils, and minimal changes in the cheeks [6].

These findings demonstrate that soft-tissue response is three-dimensional and cannot be completely described by traditional lateral cephalometric landmarks.

The systematic review and meta-analysis by Almuzian et al. included four studies and 105 patients. The mean maxillary advancement was 5.58 mm. Significant forward changes were observed in upper-lip projection and subnasal projection, while evidence regarding nasal-tip projection was inconsistent. Upper philtrum width also increased significantly [7].

The authors concluded that evidence for three-dimensional nasolabial changes was relatively weak because of heterogeneity among studies, emphasizing the need for standardized prospective research.

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15. Dolphin Imaging Software

Dolphin Imaging has become an important component of computer-assisted orthodontic and orthognathic treatment planning.

The software allows:

- digital cephalometric analysis;
- two-dimensional surgical simulation;
- visual treatment objectives;
- three-dimensional CBCT-based planning;
- soft-tissue prediction;
- comparison of predicted and postoperative facial profiles.

Its principal advantage is the ability to provide a visual representation of the anticipated postoperative result.

However, prediction accuracy should be distinguished from clinical usefulness. A prediction may be sufficiently accurate for patient communication while still being inadequate for precise numerical prediction of individual soft-tissue landmarks.

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16. Accuracy of Two-Dimensional Dolphin Prediction

Nadjmi et al. evaluated Dolphin version 10 in patients undergoing Le Fort I osteotomy and compared it with Maxilim [11]. Their results demonstrated that computerized prediction can provide useful estimates of postoperative facial morphology, but differences remained in specific regions and angular measurements.

In a study of Class III patients treated with maxillary advancement and mandibular setback, Dolphin VTO demonstrated prediction errors within approximately ±2 mm along the X-axis at most evaluated landmarks. The lower lip demonstrated the greatest inaccuracy [8].

The authors concluded that Dolphin was clinically useful for demonstration and communication but should be used cautiously for precise surgical planning [8].

This distinction is important. A 2-mm prediction error may be acceptable for visualization but may be clinically meaningful when evaluating a specific facial landmark or surgical objective.

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17. Accuracy of Three-Dimensional Dolphin Prediction

Three-dimensional prediction provides theoretically greater anatomical information than two-dimensional prediction but introduces additional sources of error.

In a pilot study of seven patients undergoing single-segment Le Fort I osteotomy, Dolphin 3D demonstrated a mean linear prediction error of 2.91 ± 2.16 mm and a mean nasolabial-angle error of 8.1 ± 5.6° [12].

Elshebiny et al. evaluated 20 patients who underwent bimaxillary surgery using Dolphin 3D version 11.9. Significant differences were found between predicted and actual postoperative measurements in the nasolabial angle, soft-tissue A-point, and subalar region. The authors concluded that prediction accuracy was particularly limited around the upper lip and nasal base [9].

Knoops et al. compared Dolphin with ProPlan CMF and a probabilistic finite-element model. The reported root mean square surface error was approximately 1.8 ± 0.8 mm for Dolphin, compared with approximately 1.2 ± 0.4 mm for ProPlan and 1.3 ± 0.4 mm for the finite-element model [10].

Dolphin uses a landmark-based prediction approach, whereas continuous-deformation models can simulate soft-tissue displacement across the facial surface. This difference may explain some of the limitations observed in three-dimensional prediction. [Table 1]

Table 1. Summary of Key Evidence

18. Factors Affecting Soft-Tissue Prediction

Several factors contribute to variability in soft-tissue response.

18.1 Magnitude of maxillary advancement

The amount of skeletal movement influences the magnitude of soft-tissue displacement, but the relationship is not necessarily linear [2–5].

18.2 Direction of movement

Anterior, vertical, and rotational movements produce different soft-tissue responses. Maxillary rotation can substantially influence the nasolabial angle and nasal projection [14,15].

18.3 Lip thickness

Thicker lips may demonstrate weaker correlations between skeletal and soft-tissue movement [3].

18.4 Surgical technique

V-Y closure and alar cinch sutures can alter upper-lip and nasal morphology [1,14].

18.5 Concomitant mandibular surgery

When maxillary advancement is combined with mandibular setback or advancement, interpretation of lower-lip and chin changes becomes more complicated [8,14].

Study	Sample	Procedure	Assessment	Principal finding
Mansour et al. [2]	—	Le Fort I	2D cephalometry	Established soft-to-hard tissue ratios
Stella et al. [3]	21	Isolated Le Fort I advancement	2D cephalometry	Lip thickness influenced prediction
Louis et al. [4]	15	Maxillary advancement	2D cephalometry	Upper lip response greater than nasal response
Hui et al. [5]	50	Maxillary osteotomy	2D cephalometry	Different responses in cleft/non-cleft patients
Fudalej et al. [1]	419	Le Fort I	Systematic review	Upper lip showed greater soft-tissue response
Almukhtar et al. [6]	33	Le Fort I advancement	3D CBCT	Demonstrated multidimensional facial changes
Nadjmi et al. [11]	—	Le Fort I	Dolphin/Maxilim	Useful but imperfect prediction
Dolphin VTO study [8]	14	Maxillary advancement + mandibular setback	Dolphin 2D	Approximately ±2 mm at most landmarks
Dolphin 3D pilot [12]	7	Le Fort I	Dolphin 3D	Mean error approximately 2.9 mm
Elshebiny et al. [9]	20	Bimaxillary surgery	Dolphin 3D	Errors particularly around upper lip/nasal base
Almuzian et al. [7]	105	Le Fort I	Systematic review/meta-analysis	Significant upper-lip and subnasal changes
Keldal et al. [17]	25	Bimaxillary surgery	Dolphin/ImageJ	Upper lip followed approximately 83% of skeletal movement

18.6 Postoperative adaptation

Soft-tissue changes continue after surgery. Hack et al. reported that most changes occurred during the first postoperative year, but significant changes could continue over subsequent years [16].

18.7 Imaging methodology

Two-dimensional cephalometry measures a limited number of landmarks, whereas three-dimensional imaging permits assessment of the entire facial surface. Consequently, results obtained from these modalities should not be considered directly interchangeable.

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19. Recent Evidence

A 2025 retrospective cohort study by Keldal et al. evaluated 25 patients with skeletal Class III malocclusion who underwent bimaxillary surgery and used Dolphin Imaging and ImageJ for cephalometric measurements [17]. The mean planned maxillary advancement was 5.48 mm, compared with an actual postoperative advancement of 5.32 mm. Upper-lip advancement was approximately 83% of the skeletal movement, while nasal-tip elevation averaged approximately 1.27 mm [17].

These findings support the general observation that the upper lip follows maxillary advancement substantially more closely than the nasal tip.

Importantly, this recent study also assessed long-term outcomes, with follow-up extending to 1–3 years after treatment. This is valuable because postoperative soft-tissue adaptation may continue beyond the initial postoperative period [17] [Table 2]

Table 2. Soft-Tissue Response According to Anatomical Region

Soft-tissue region	Expected response to maxillary advancement	Predictability
Upper lip	Marked forward displacement	Relatively high
Labiale superius	Forward displacement; possible shortening/thickening changes	High–moderate
Subnasale	Forward and sometimes superior movement	Moderate
Nasal base	Forward and transverse changes	Moderate–low
Alar base	Widening and displacement	Low–moderate
Nasal tip	Projection/elevation changes	Low
Columella	Superior and anterior changes	Moderate–low
Nasolabial angle	Changes according to advancement and rotation	Moderate–low
Lower lip	Secondary changes, especially in bimaxillary surgery	Low
Chin	Primarily affected by mandibular movement	Low for isolated maxillary surgery

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20. Discussion

The present review demonstrates that the soft-tissue response to maxillary advancement is predictable only within certain anatomical and clinical boundaries.

The upper lip generally demonstrates the strongest association with skeletal advancement. The systematic review by Fudalej et al. showed a progressive increase in soft-tissue-to-hard-tissue ratios from the nasal tip toward the upper lip [1].

This observation is supported by classic studies. Stella et al. demonstrated that lip thickness influences the predictability of soft-tissue response [3], while Louis et al. demonstrated that an approximately 8-mm maxillary advancement produced approximately 6.5-mm upper-lip advancement but only approximately 3.2-mm subnasale advancement and 1.3-mm nasal-tip advancement [4].

Therefore, a single universal ratio should not be applied to all facial landmarks.

The nose represents one of the greatest challenges in soft-tissue prediction. Nasal-tip projection and elevation are influenced by maxillary advancement, palatal-plane rotation, piriform aperture morphology, nasal musculature, and surgical technique [6,15].

The 2021 3D meta-analysis provides additional evidence that the upper lip and subnasale show more consistent sagittal changes than the nasal tip [7].

The accuracy of Dolphin Imaging should therefore be interpreted according to the intended purpose. For patient communication and visualization of general facial changes, Dolphin can be highly useful. However, studies evaluating prediction accuracy demonstrate that the software may produce clinically relevant errors at selected landmarks [8–12].

The limitations become more evident in three-dimensional prediction. Dolphin 3D has demonstrated mean prediction errors of approximately 3 mm in some studies, and significant discrepancies have been reported in the upper lip, nasal base, subalar region, and nasolabial angle [9,12].

The difference between actual postoperative change and software prediction should therefore be explicitly recognized in future studies. A study that simply reports postoperative soft-tissue changes answers a different question from a study that compares predicted versus actual outcomes.

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21. Clinical Implications

The findings of this systematic review have several clinical implications.

First, Dolphin Imaging can be used effectively as a visual treatment-planning and patient-communication tool.

Second, clinicians should avoid promising an exact postoperative facial appearance based solely on software simulation.

Third, prediction should be interpreted on a landmark-specific basis. The upper lip and subnasale may demonstrate greater predictability than the nasal tip, alar base, and lower facial soft tissues.

Fourth, surgical variables should be incorporated into interpretation, including:

- magnitude of maxillary advancement;
- vertical repositioning;
- clockwise or counterclockwise rotation;
- alar cinch suture;
- V-Y closure;
- nasal morphology;
- upper-lip thickness;
- concomitant mandibular surgery;
- postoperative interval.

Finally, three-dimensional assessment should increasingly be incorporated into clinical research because the facial soft-tissue response extends beyond the limited landmarks visible on a lateral cephalogram.

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22. Limitations of the Review

The available literature is characterized by considerable methodological heterogeneity.

Differences exist in:

- patient diagnosis;
- age and sex;
- magnitude of advancement;
- direction of maxillary movement;
- isolated versus bimaxillary surgery;
- surgical technique;
- use of alar cinch sutures;
- V-Y closure;
- imaging modality;
- Dolphin software version;
- postoperative follow-up;
- soft-tissue landmarks;
- statistical methodology.

These differences limit direct quantitative comparison.

In addition, many available studies are retrospective and have relatively small samples. The three-dimensional systematic review by Almuzian et al. included only four studies in its meta-analysis, illustrating the limited amount of homogeneous 3D evidence available [7].

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23. Recommendations for Future Research

Future investigations should:

1. Use prospective study designs.

2. Include larger sample sizes.
3. Separate isolated maxillary advancement from bimaxillary surgery.
4. Standardize the magnitude and direction of maxillary movement.
5. Record V-Y closure and alar cinch techniques.
6. Use standardized CBCT and three-dimensional facial scanning protocols.
7. Use a standardized set of soft-tissue landmarks.
8. Report both linear and angular prediction errors.
9. Report clinically acceptable prediction-error thresholds.
10. Evaluate outcomes at standardized postoperative intervals.
11. Include long-term follow-up of at least 12 months.
12. Report patient-specific variables such as lip thickness and preoperative nasal morphology.
13. Compare Dolphin with other current three-dimensional planning systems.
14. Investigate artificial-intelligence and biomechanical prediction models.
15. Distinguish between **actual postoperative soft-tissue change** and **software prediction accuracy**.

24. Conclusion

Maxillary advancement produces significant changes in the facial soft-tissue envelope, particularly in the upper lip, subnasale, nasal base, nasal tip, and nasolabial region. The response is greatest and most predictable near the upper lip and decreases in predictability toward the nasal tip and other anatomically complex regions.

The literature demonstrates substantial variability in soft-tissue-to-hard-tissue ratios. The upper lip may follow a large proportion of maxillary advancement, whereas the nasal tip and nasal base demonstrate smaller and more variable responses [1–5].

Three-dimensional investigations demonstrate that soft-tissue changes occur in multiple dimensions, including sagittal displacement, vertical movement, and transverse expansion [6,7].

Dolphin Imaging is a useful tool for cephalometric analysis, surgical simulation, visualization, and patient communication. However, two-dimensional and three-dimensional prediction studies demonstrate that clinically significant discrepancies may occur, particularly in the upper lip, nasal base, subalar region, lower lip, and nasolabial angle [8–12].

Therefore, Dolphin Imaging should be considered a **predictive aid rather than an exact predictor of postoperative facial morphology**. Accurate clinical interpretation requires consideration of the magnitude and direction of skeletal movement, individual soft-tissue characteristics, surgical technique, and postoperative adaptation.

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