

Accuracy of Computer-Assisted Soft Tissue Profile Prediction in Patients Undergoing Fixed Orthodontic Treatment: A Retrospective Study

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Abstract

Background: Accurate prediction of post-treatment facial aesthetics is a key component of modern orthodontic diagnosis, planning, and patient communication. While digital Visual Treatment Objectives (VTO) are widely utilized, the precision of prediction software remains a subject of ongoing debate.

Objectives: to evaluate the accuracy of computer software in predicting soft tissue profile changes in patients undergoing fixed orthodontic treatment.

Methods: This retrospective study included 18 participants (9 males, 9 females) aged 18 to 35 years who underwent fixed orthodontic treatment. Pre- and post-treatment lateral cephalograms and standardized photos in the Natural Head Position (NHP) were obtained. AudaxCeph (v6.6.12) was used to perform cephalometric analysis and generate VTO simulations guided by actual post-treatment skeletal and dental parameters. Digital simulated post-treatment profiles were superimposed onto actual post-treatment photographs using Adobe Photoshop to measure vertical and horizontal landmark discrepancies. Data were analyzed using Kolmogorov-Smirnov, Shapiro-Wilk, paired t-tests, and Wilcoxon signed-rank tests.

Results: No statistically significant differences were observed between simulated and actual profiles for vertical parameters: superior lip height (Sup. L-H: simulated 56.57 ± 8.26 mm vs. final 54.86 ± 4.32 mm; $p = 0.253$), inferior lip height (Inf. L-H: simulated 73.27 ± 7.06 mm vs. final 72.39 ± 6.89 mm; $p = 0.066$), and vertical chin position (Menton, Men-H: simulated 106.09 ± 8.59 mm vs. final 106.37 ± 9.02 mm; $p = 0.313$). Similarly, horizontal skeletal landmarks showed no significant discrepancies: A-V ($p = 0.531$), B-V ($p = 0.915$), and Pog-V ($p = 0.627$). However, statistically significant horizontal discrepancies were detected in the lip regions: superior lip distance to the vertical line (Sup. L-V: simulated 21.92 ± 5.15 mm vs. final 23.67 ± 5.08 mm; $p = 0.031$) and inferior lip distance to the vertical line (Inf. L-V: simulated 21.80 ± 5.28 mm vs. final 20.75 ± 6.33 mm; $p = 0.045$).

Conclusion: AudaxCeph software demonstrated acceptable accuracy in predicting vertical landmarks and skeletal horizontal structures. However, it exhibited significant limitations in predicting the horizontal positions of both the upper and lower lips, suggesting that clinicians should interpret VTO predictions in the perioral region with caution.

Keywords: soft tissue, profile, software, and prediction.

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was obtained from all patients for the use of their clinical data and photographs.

Sample Selection: A total sample of 18 participants (9 males, 9 females; age range: 18–35 years) was selected from the archives of the Orthodontic Department. A sample size calculation performed using G*Power software (version 3.1.9.4) indicated that a minimum sample of 14 participants was sufficient to detect a large effect size ($f = 0.8216$) with 80% actual power and a significance level of 0.05.

Inclusion Criteria:

The inclusion criteria for this study comprised patients who underwent fixed orthodontic treatment utilizing the preadjusted edgewise technique. Eligible participants were required to present with a skeletal Class I relationship, paired with a dental Class I, II, or III malocclusion prior to the intervention. Furthermore, candidates must have achieved a final Class I occlusion post-treatment, characterized by normal overjet and overbite (measuring 2 to 4 mm) and the complete absence of spacing or crowding. Finally, the availability of comprehensive diagnostic and therapeutic records was mandatory, encompassing detailed medical and dental histories, dental casts, panoramic and cephalometric radiographs, and clinical photographs obtained both before and after orthodontic treatment.

Exclusion Criteria:

Conversely, patients were excluded from the study if they presented with missing teeth or significant Bolton discrepancies exceeding 3 mm. Additional exclusion criteria included the presence of craniofacial syndromes, severe skeletal abnormalities, or a history of previously failed orthodontic treatment. Patients who had undergone cosmetic or reconstructive facial surgery during their orthodontic treatment, or within one year prior to its initiation, were also excluded. Lastly, individuals utilizing medications known to potentially reduce soft tissue volume.

Data collection: All lateral cephalometric radiographs selected were captured using a single unit (Planmeca ProMax 2D, Finland) under a standardized protocol. Patients were positioned in a standardized Natural Head Position (NHP) using the mirror method with the Frankfort Horizontal (FH) plane parallel to the floor. Standardized lateral profile photographs selected were taken with a Nikon D7500 DSLR camera equipped with an AF-S VR Micro-Nikkor 105mm macro lens, a ring flash, and Visico rectangular soft boxes, ensuring consistent camera-to-subject distance and head positioning.

Procedure:

1. **Data Entry & Radiograph Calibration:** Patient records were uploaded into AudaxCeph (v6.6.12.4731). Radiographs were calibrated to establish a precise scale (mm) using a known reference ruler.
2. **Cephalometric Landmark Identification:** A total of 33 landmarks (21 hard-tissue, 12 soft-tissue)

1. Introduction:

Aesthetic concerns are the main reason why orthodontic patients seek treatment. among the objectives of orthodontic therapy are stability, good oral function, and enhancement of the dentofacial appearance.⁽¹⁾

A good treatment strategy should balance these objectives.⁽²⁾ it can be challenging to decide whether tooth extraction is essential. the choice is made based on the degree of crowding and the condition of the soft tissue. in many cases, the decision is straight-forward and the choice of treatment plan, with versus without extraction, is obvious.⁽³⁾

Patients may not be satisfied with their therapy due to negative aesthetic effects of both extraction and non-extraction.^(4,5) Soft tissue prediction has progressed since the early 1970s from the use of acetate tracing paper to computer-based line drawings to more modern technologies in the 1990s where computers could alter patient photographs in an attempt to predict outcomes.⁽⁶⁻¹⁰⁾

Simulation and prediction help in treatment planning, patient care, and informed consent process by increasing patients' understanding⁽¹⁾. in the past, lateral cephalograms were the basis for treatment predictions.⁽¹¹⁾

Currently, software programmes that use 2- or 3-dimensional approaches are used to predict how patients will look after treatment. for this purpose, a number of software programmes are available, including Dentofacial planner, Maxilim, and Dolphin. although the majority of these programmes tend to underestimate changes in the chin region, they are nonetheless effective for clinical applications.⁽¹²⁾ Audax Ceph is one of software that can be used for prediction of the treatment outcome also.

Despite great advances in this field, actual results frequently differ from simulated ones due to individual variations in how soft tissues react to bone and dental alterations.⁽¹²⁾ These programmes also exhibit certain soft tissue simulation errors. The purpose of the study was to assess the accuracy of computer software in predicting profile changes in patients undergoing fixed orthodontic treatment.

2. Materials and Methods

Study Design and Ethical Considerations: This retrospective study was approved by the Ethics Committee of the Faculty of Dental Medicine, Al-Azhar University, Assiut Branch (Protocol No: AUAREC202300005-03). Written informed consent

forehead contour and the canthus-tragus plane. True horizontal and vertical reference lines were constructed originating from the center of the pupil. Linear measurements were taken using the digital ruler tool in AudaxCeph to quantify discrepancies. These parameters included: superior lip height (Sup.L-H), inferior lip height (Inf.L-H), menton height (Men-H), and horizontal distances from the vertical reference line to the superior lip (Sup.L-V), inferior lip (Inf.L-V), point A (A-V), point B (B-V), and pogonion (Pog-V).

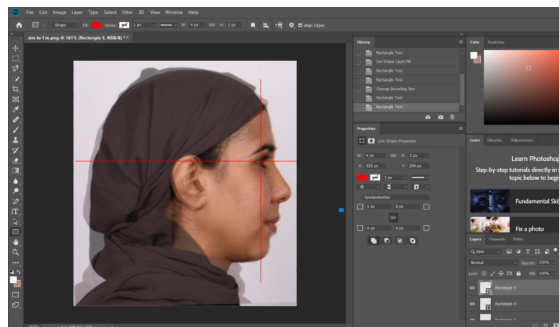


Figure (3): Superimposition of actual vs. simulated profiles using Adobe Photoshop.

Statistical Analysis: Statistical analysis was conducted using SPSS version 20. Normality was tested using Kolmogorov-Smirnov and Shapiro-Wilk tests. Parametric measurements were compared using paired t-tests, while non-parametric measurements (Sup.L-H) were analyzed using the Wilcoxon signed-rank test. The level of significance was set at $p \leq 0.05$.

3. Results:

The results revealed that while the software is a powerful tool, it exhibited specific predictive patterns: It predicted a decrease in prominence for the upper lips, point A, and point B. In contrast, the lower lip was predicted to be more prominent. Both the lower lip and the Menton point were projected to be in a more inferior (lower) position. Statistical analysis confirmed significant differences between the actual and simulated images regarding the distances from the lips to the vertical reference line. Table (1)

Table (1): mean of simulated, final and mean differences of all measurements.

Measurement	Final Mean ± SD	Simulated Mean ± SD	Mean Difference ± SD	P value	Significance
Sup. L-H	54.8 6 ± 4.32	56.57 ± 8.26	1.708 ± 6.13	0.253	NS
Inf. L-H	72.3 9 ± 6.89	73.27 ± 7.06	-0.882 ± 2.26	0.066	NS

were localized manually on pre- and post-treatment radiographs.

3. Photographic-Radiographic Superimposition: Pre-treatment lateral profile photographs were linked and matched with the pre-treatment lateral cephalometric soft-tissue shadow.



Figure (1): superimposition of the pre-treatment lateral profile photograph onto the pre-treatment lateral cephalometric radiograph.

4. VTO Generation and Simulation: Skeletal and dental movements were simulated based on actual post-treatment cephalometric measurements (e.g., SNA, SNB, U1-Apog, L1-Apog). The AudaxCeph VTO algorithm generated a simulated post-treatment profile.



Figure (2): VTO simulation illustrating the dental movement and repositioning within the pre-treatment lateral cephalogram.

5. Discrepancy Analysis: Using Adobe Photoshop (v20.0.5), actual post-treatment photographs were superimposed onto the simulated profiles. Optimal alignment was achieved using the

radiographic records were used to minimize measurement error and enhance reproducibility. By focusing on Audax Ceph software, this study provides clinically relevant data regarding the reliability of commonly used orthodontic prediction tools.

The present study addresses these concerns by comparing simulated post-treatment images with actual post-treatment photographs using standardized reference lines and measurement techniques. This approach allows for an objective assessment of prediction accuracy and helps identify specific regions where prediction errors are most pronounced.^(18, 19)

Studies assessing Audax Ceph software have demonstrated reliable cephalometric measurements and reproducibility; however, limitations in soft tissue prediction accuracy have also been reported. The software tends to provide generalized predictions that may not accurately represent individual variations in lip thickness, strain, or facial muscle tone.^(17, 20)

The findings of the present study are consistent with previous literature, indicating that Audax Ceph software provide useful approximations of post-treatment soft tissue changes but may demonstrate varying degrees of accuracy across different facial regions. Areas such as the lips showed greater prediction discrepancies compared to relatively stable regions like the chin.

The accuracy of lip position prediction differed among studies, in some studies, prediction for the upper lip position was better than that for the lower lip, and in other studies, lower lip position prediction was better. For instance, a previous study using Dolphin software reported that upper lip position more accurately than it did for lower lip position. In the non-extraction group, both the horizontal and vertical simulated positions of the upper lip were like the positions in the real picture. In the extraction group, the simulated pictures predicted a more protruded upper lip, but the difference between the simulated and real position was less than 1 mm.⁽²¹⁾

Several studies have reported variable accuracy of computer-assisted soft tissue prediction software, particularly in regions such as the lips and chin. Using Dolphin Imaging software, Sarver and Ackerman⁽¹⁶⁾ demonstrated that while overall facial profile simulations were clinically useful, prediction errors were more pronounced in the perioral region due to variability in lip posture and muscle activity. Similarly, Konstantonis et al.⁽²²⁾ found that Dolphin predictions were more reliable for the chin and nasal areas than for the upper and lower lips.

Previous studies evaluating Dolphin Imaging have reported acceptable accuracy in predicting overall profile changes, particularly in the nasal and chin

Men-H	106.37 ± 9.02	106.09 ± 8.59	0.280 ± 1.14	0.3 13	NS
Sup. L-V	23.67 ± 5.08	21.92 ± 5.15	1.756 ± 2.13	0.0 31	S
Inf. L-V	20.75 ± 6.33	21.80 ± 5.28	1.752 ± 2.30	0.0 45	S
A-V	20.97 ± 4.82	20.72 ± 4.76	0.248 ± 1.64	0.5 31	NS
B-V	13.72 ± 6.55	13.68 ± 6.18	0.040 ± 1.59	0.9 15	NS
Pog-V	14.43 ± 7.71	14.25 ± 7.01	0.182 ± 1.56	0.6 27	NS

SD: standard deviation, NS: not significant, S: significant, HS: highly significant

4. Discussion:

Orthodontic treatment aims to optimize occlusion, functional stability, and facial aesthetics, which heavily dictate overall patient satisfaction. Since soft tissue responses to orthodontic tooth movement are complex and do not always predictably follow underlying skeletal changes, accurate prediction tools are essential for realistic treatment planning, patient communication, and obtaining informed consent.^(14, 15)

Advances in computer technology have significantly influenced orthodontic diagnosis and simulation. Early prediction methods using manual tracings and acetate overlays have gradually evolved into digital cephalometric analyses and computer-generated simulations. Modern software programs integrate photographic images with cephalometric data to generate visual predictions of post-treatment facial profiles. These tools offer the advantages of efficiency, reproducibility, and enhanced patient understanding. However, despite continuous technological improvements, the accuracy of these simulations remains a subject of debate.⁽¹⁶⁾

Audax Ceph is considered among the most widely used orthodontic software programs for cephalometric analysis and soft tissue simulation. The software allow integration of lateral cephalograms with profile photographs to generate predicted post-treatment facial profiles. This program is commonly used to simulate orthodontic outcomes, particularly in cases involving extraction decisions, incisor retraction, and profile modification.⁽¹⁷⁾

The retrospective nature of this study allowed for comparison between predicted and actual post-treatment soft tissue profiles without influencing clinical decision-making. Standardized photographic and

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regions, while greater discrepancies were observed in the upper and lower lip areas. These inaccuracies may be attributed to the dynamic nature of lip posture and muscle activity, which are difficult to simulate using static cephalometric images. This result in agree with present study that reported statically significant differences between final and predicted measurements related to lower lip area.⁽²³⁾

Oz et al.⁽²⁴⁾ compared the treatment simulation results of Quick Ceph Studio software (Quick Ceph Systems, San Diego, California, USA) with real final photographs in class II division 2 patients treated by functional appliances. In contrast to results of the present study, they reported that the simulated picture was different from the real one in the vertical position of the upper lip.

Zhang et al.⁽²⁵⁾ evaluated the prediction accuracy of Dolphin software in cases of bimaxillary dentoalveolar protrusion. All of the cases were treated by 4 premolar extractions. The authors stated that in the predicted profiles, the lips were more protruded and more inferior than they were in the real final images. Results of that study regarding the horizontal position of the lower lips were very similar to the results of the present study.

5. Conclusions and Recommendations:

Within the limitations of this study, we conclude that:

1. AudaxCeph software provides acceptable and clinically useful approximations of skeletal horizontal landmarks (Point A, Point B, Pogonion) and vertical facial parameters.
2. Significant predictive errors occur in the horizontal projection of both the upper and lower lips, indicating that computerized perioral VTO simulations should be interpreted with clinical caution.
3. Clinicians should combine software predictions with their professional clinical judgment rather than relying on them as absolute outcomes.
4. Integration of 3D facial modeling and frontal view simulations is strongly recommended in future software updates to enhance patient satisfaction and the informed consent process.

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