ORIGINAL ARTICLE CE AJO-DO

# Profile line accuracy in cephalometric radiographs

**Marie-Laure Arn,[a] Jasmina Opacic,[a] Georgios Kanavakis,[b,c] Demetrios Halazonetis,[c] and Nikolaos Gkantidis[a]**
*Bern and Basel, Switzerland, and Athens, Greece*

**Introduction:** This study investigates the accuracy of facial soft-tissue profile lines in lateral cephalometric radiographs by comparing them to true profile lines derived from 3-dimensional photographs. **Methods:** This prospective methodological study was performed on preexisting records of 100 orthodontic patients. The true profiles were obtained by defining the true midsagittal plane through best-fit approximation of mirrored 3-dimensional surface models. Two curves were drawn on each profile image, and landmarks and sliding semilandmarks were placed on them. This resulted in 2 profile landmark configurations per patient, which were superimposed using Procrustes superimposition. The Procrustes distances between corresponding landmarks were used as a metric to assess the accuracy of the cephalometric profile line, as compared with the true reference. **Results:** On average, there were small statistically significant differences between the cephalometric and the actual profile lines (100,000 permutations; $P = 0.031$; median interlandmark distance, 0.84 mm). However, when assessing individual patients, the cephalometric profile line deviated significantly from the true profile, with 40% of the distances between corresponding landmarks being >1 mm and 10% being >2 mm. There were no differences between the sexes or between younger and older patients (aged 8.0-12.5 vs 12.5-55.0 years). However, there were small differences between 2 x-ray devices (median, 0.18 mm; $P < 0.001$), which often exceeded 1 mm at the soft-tissue nasion area, probably because of the cephalostat. **Conclusions:** On average, the lateral cephalometric radiographs might provide an adequate representation of the facial profile, but when individual patients are considered, there is often a clinically significant error. Thus, lateral cephalograms should be used with caution to evaluate the facial soft-tissue profile. (Am J Orthod Dentofacial Orthop 2025;168:75-87)

Since its introduction in 1931 by Broadbent,[1] the lateral cephalometric radiograph has been widely used for diagnosis and treatment planning, but also for growth assessment and evaluation of treatment results.[2,3] It allows assessment of the different parts of the craniofacial skeleton, the teeth, and the facial soft tissues, as well as their interrelationships.[2]

Lateral cephalograms are 2-dimensional (2D) radiological representations of 3-dimensional (3D) structures. Therefore, they have certain well-known limitations, such as image magnification, distortion, and superimposition of bilateral anatomic structures.[4,5] Landmark identification and measurement errors are additional problems.[6,7] These limitations can lead to erroneous assessment and potentially affect diagnosis and key decisions in treatment planning.

The importance of facial soft-tissue morphology has been emphasized in orthodontics,[8-10] as well as in other disciplines, including anthropology[11,12] and craniofacial surgery.[13] The soft-tissue surface defines the directly

[a]Department of Orthodontics and Dentofacial Orthopedics, University of Bern, Bern, Switzerland.
[b]Department of Pediatric Oral Health and Orthodontics, University Center for Dental Medicine, University of Basel, Basel, Switzerland.
[c]Department of Orthodontics, School of Dentistry, National and Kapodistrian University of Athens, Athens, Greece
Demetrios Halazonetis owns stock in dHAL Software, the company that markets Viewbox 4. Demetrios Halazonetis was not involved in data generation and analysis; thus, he could not affect the study outcomes. All other authors have completed and submitted the ICMJE Form for Disclosure of Potential Conflicts of Interest, and none were reported.
This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.
The study protocol has been approved by the Swiss Ethics Committee of the Canton of Bern (protocol No. 2019-01815; approved on December 17, 2019). All procedures were performed in compliance with relevant laws and institutional guidelines. Written informed consent was obtained from all subjects and/or their legal guardians, allowing the use of their data for research purposes.
All relevant data are within the manuscript. The datasets generated and/or analyzed during the current study will be available on request. Owing to the sensitive nature of the surface models used in this study, participants were assured raw data would remain confidential and would not be shared.
Address correspondence to: Nikolaos Gkantidis, Department of Orthodontics and Dentofacial Orthopedics, University of Bern, Freiburgstrasse 7, Bern, Switzerland; e-mail, nikolaos.gkantidis@unibe.ch or nikosgant@yahoo.gr.
Submitted, February 2024; revised and accepted, February 2025.
0889-5406

https://doi.org/10.1016/j.ajodo.2025.02.009

perceivable image during human interactions, and its appearance is related to several important life outcomes, such as mental health, the ability to make friends, having a successful marriage, or reaching higher-ranking positions in professional life.[12,14,15] Therefore, it is not surprising that improvement in facial appearance is a major reason to seek treatment[16] and is related to patient satisfaction.[9,10]

The soft-tissue facial profile is important in diagnosis and treatment planning,[8,17,18] impacting such decisions as to perform orthognathic surgery[13] or orthodontic treatment with tooth extractions.[19] Currently, there are 3D imaging modalities that offer a realistic, real-size, and distortion-free representation of the facial soft-tissue profile that is also unaffected by the orientation of the original object during image acquisition.[20-23] However, the lateral cephalogram, despite its several limitations, remains a standard diagnostic tool for several disciplines. Previous studies compared conventional lateral cephalograms to lateral cephalograms derived from cone-beam computed tomography scans and identified significant variations in soft-tissue surface assessments.[24,25] Similar findings were obtained from comparisons of lateral cephalometric radiographs to actual measurements on a phantom.[26] These studies assessed linear and angular measurements between soft-tissue landmarks. However, the accuracy of the entire facial profile line derived from a lateral cephalogram has apparently not yet been evaluated.

This study aimed to assess the facial soft-tissue profile line accuracy on 2D lateral cephalometric radiographs as compared with the true profile line derived from 3D photographs.[23] For this, we used preexisting lateral cephalograms and 3D facial photographs of actual patients to trace the corresponding profile lines and applied geometric morphometric methods on the tracings. The null hypothesis of the study was that there is no clinically significant difference between the patient's true soft-tissue profile line and the profile line depicted in lateral cephalometric radiographs.

## MATERIAL AND METHODS

The study protocol has been approved by the Swiss Ethics Committee of the Canton of Bern (protocol No. 2019-01815; approved on December 17, 2019). All procedures were performed in compliance with relevant laws and institutional guidelines. Written informed consent was obtained from all subjects and their legal guardians, allowing the use of their data for research purposes.

This prospective methodological study was performed on preexisting records of 100 orthodontic patients retrieved from the archives of the Department of Orthodontics and Dentofacial Orthopedics, University of Bern. Lateral cephalometric radiographs and 3D photographs comprise standard records for diagnosis and treatment planning. One author (J.O.) searched for patients fulfilling the eligibility criteria, and the last author (N.G.) controlled all selected patients to confirm eligibility. A consecutive selection was performed, applying a backward search strategy to control for selection bias. All records were taken between February 2011 and September 2019.

Inclusion criteria were (1) subjects aged 8-60 years; (2) available sets of pretreatment or posttreatment lateral cephalometric radiographs and 3D photographs taken at the same session, in rest position (closed or open lips) and with the teeth in maximum intercuspation (slight contact); and (3) 3D photographs generated by postgraduate students being enrolled for at least 6 months in the postgraduate program.

Exclusion criteria were (1) patients with mobility or mental disorders reported in the medical history, as well as congenital malformations, systemic diseases, or syndromes that could affect growth or facial morphology; (2) large facial asymmetries detected through visual inspection by 2 authors (J.O., M.L.A.) that could imply underlying pathologies. In case of disagreement, a joint decision was taken with the last author (N.G.); (3) distorted soft tissues because of facial expressions or muscle tension detected through visual inspection by 2 authors (J.O., M.L.A.). Disagreements were resolved after consulting the last author (N.G.); (4) subjects with facial hair longer than a few millimeters or any hair interfering with the profile line or subjects wearing glasses during image acquisition; (5) inadequate quality images with notable distortions detected through visual inspection by 2 authors (J.O., M.L.A.). In case of disagreement, a joint decision was taken with the last author (N.G.); and (6) denied informed consent.

A stratified sample selection process was applied to the available data to obtain half of the patients when aged 8-12.5 years and the other half when aged 12.5-60 years. Sex was also stratified to obtain an equal distribution of females and males in both age groups.

A power analysis could not be performed to determine the sample size because of the lack of previous studies on this subject. Furthermore, in geometric morphometric studies, the sample size cannot be determined by straightforward application of mathematical formulas.[27,28] We populated our sample with 100 patient datasets, which was considered adequate to detect significant differences and avoid selection bias.[28]

The 3D photographs were taken by the postgraduate orthodontic residents in a standardized manner, according to the clinic's protocol. They were obtained in the same white room, specially designed for this purpose, using a 3dMDface System and the 3dMD Software (3dMD Inc, Atlanta, Ga). The patients were seated on a turning chair with the knees bent at approximately 90°, the back in an upright position, and the head facing straight at the camera, which was positioned at eye level, at a standardized distance of 1.2 m. They were asked to have their eyes open, their teeth in slight contact, and their muscles relaxed. The background light was removed according to the manufacturer's instructions. The camera was calibrated every morning before the acquisition of the first image of the day and when an error message was received.

The lateral cephalometric radiographs were digital radiographs taken in the radiology department of the dental school, University of Bern, using 2 radiographic devices. The cephalograms taken between March 2011 and October 2015 were obtained with machine 1 (Oralix 9200; Gendex, Milan, Italy), whereas the cephalograms taken between October 2015 and September 2019 were obtained with machine 2 (ProMax 2D S3; Planmeca, Helsinki, Finland). During image acquisition, the patients were standing, the head was positioned with the Frankfort horizontal plane parallel to the floor, and the profile aspect was perpendicular to the x-ray source. They were asked to have the teeth in contact, and the muscles relaxed.

All acquired images (3D photographs [TSB file type] and cephalograms [JPG]) were imported into Viewbox 4 software (version 4.1.0.11, 64bit; dHAL Software, Kifissia, Greece) for further processing. After relevant training, an experienced operator (M.L.A.) with 6 years of exclusive clinical work in orthodontics performed all processing.

The first step of the process was to crop the 3D photographs as follows: the hair, the ears, and the throat were deleted to retain only the face. The ears are usually considered parts of the face, but because of the low quality of their depiction in the 3D photographs (often incomplete), we decided to remove them as well.

The true midsagittal plane of the cropped 3D photographs (ie, the "true profile") was defined according to the recently published method by Gkantidis et al.[23] Briefly, the method requires the mirroring of the 3D photograph and then the best-fit approximation of the original to its corresponding mirrored model through the software's iterative closest point algorithm.[29] The software constructs the midsagittal plane by calculating the middle of all lines connecting the corresponding identical vertices located at the contralateral sides of the 2 models. It has been proved that all such midpoints lie on a single plane.[23] After orienting the true midsagittal plane parallel to the computer screen, a 2D image was exported as a JPG file. In this image, the projection of the most protruding points on the midsagittal plane provided the true profile definition (Fig 1).

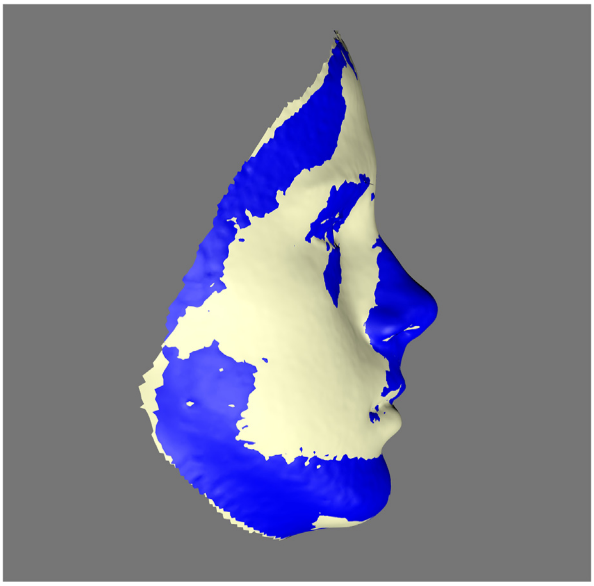


**Fig 1.** Superimposed original (*blue*) and mirrored (light *yellow*) 3D facial photographs, with the midsagittal plane (*gray*) parallel to the computer screen.

The next step was drawing the profile lines on the cephalometric radiographs and the true profiles (Fig 2). For this, landmarks and sliding semilandmarks were placed on 2 prespecified curves. The upper profile curve extended from the trichion to the upper stomion and consisted of 18 sliding semilandmarks and 2 fixed landmarks (upper stomion and upper lip vermilion border). The lower profile curve extended from the lower stomion to the beginning of the throat and consisted of 14 sliding semilandmarks and 2 fixed landmarks (lower stomion and lower lip vermilion border) (Fig 3). After placing the fixed landmarks, the 2 curves were individually adapted to the facial soft-tissue profiles depicted on the cephalometric radiographs and to the 3D-derived true profile images. To minimize detection bias, the profile lines were drawn first on the 100 true profile images and, in a second phase, at least 2 weeks apart, on the lateral cephalometric radiographs, in random order. The entire process was initiated from scratch for each profile line digitization. The original images were freely magnified by the operator and, if needed, image filters were applied on the cephalometric radiographs, primarily to enhance contrast.

Before superimposing respective profile outlines, a sliding process was followed to achieve maximum

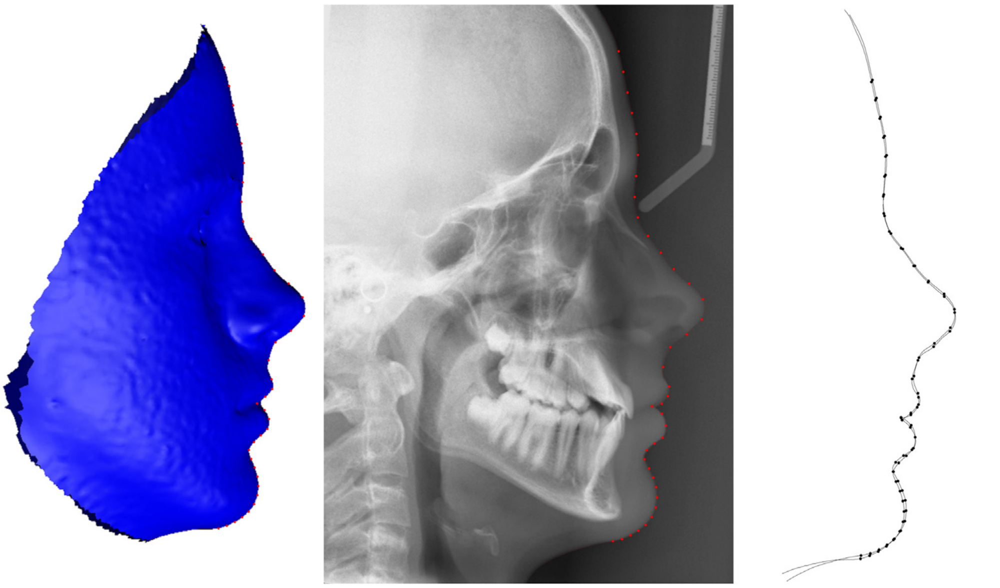


**Fig 2.** Example of 2 profile lines from the same patient, 1 draw on the true profile derived from the 3D photograph (*left*), 1 draw on the lateral cephalometric radiograph (*middle*; machine 2), and after Procrustes best-fit superimposition (*right*).

homology in the position of semilandmarks along their profile curves. Therefore, an average profile was created using all profile outlines in the study sample. This average was used as a reference for the sliding of all semilandmarks. Three cycles of sliding and reprojecting were performed, and after each cycle, a new average profile was created to serve as a reference for the new cycle. At the end of this iterative process, there was no meaningful change in the relative position of the semilandmarks on their curves, and the bending energy between shape configurations was minimized. The final sample of shape configurations was then used for all following analyses.

The 2 landmark configurations representing the 2 profile lines per patient (cephalograms and 3D photographs) were then superimposed using Procrustes superimposition that treats the data independently of their scale, rotation, and position.[30] Each pair of profile lines was superimposed separately. The Procrustes distances between the superimposed corresponding landmarks[31,32] comprised the metric to assess the amount of error of the lateral cephalometric radiographs, using the 3D derived data as the gold standard reference.

The primary outcome of the study was the accuracy of the cephalometric profile line, indicated by the Procrustes distances[31] between superimposed landmark configurations located on the 2 compared profile lines. The clinical interpretation of the results was performed through the calculation of relevant summary measures and the visualization of differences between superimposed group averages.

As secondary outcomes, the effects of age, sex, and type of x-ray device on the cephalometric profile line accuracy were investigated.

### Statistical analysis

Statistical analysis was performed by using SPSS software (version 28.0; IBM, Armonk, NY). Raw data were tested for normality through the Kolmogorov-Smirnov test, and certain variables were not normally distributed. Therefore, nonparametric statistics were applied.

Regarding the primary outcome, statistically significant differences between the profile lines obtained from the 3D images and the 2D conventional images were tested through permutation tests using the Procrustes distances between group means as the test criterion (Viewbox 4 software, 100,000 permutations). Differences in group means were visualized through Procrustes superimposition of constructed average configurations for each tested group. Pairwise differences in individual patients/pairs were assessed through the calculation of Procrustes distances after Procrustes superimposition of corresponding profile lines. Individual data for the entire sample were provided for selected landmarks throughout the profile lines using scatter plots. Summary data regarding linear distances of corresponding landmarks, as well as differences in the

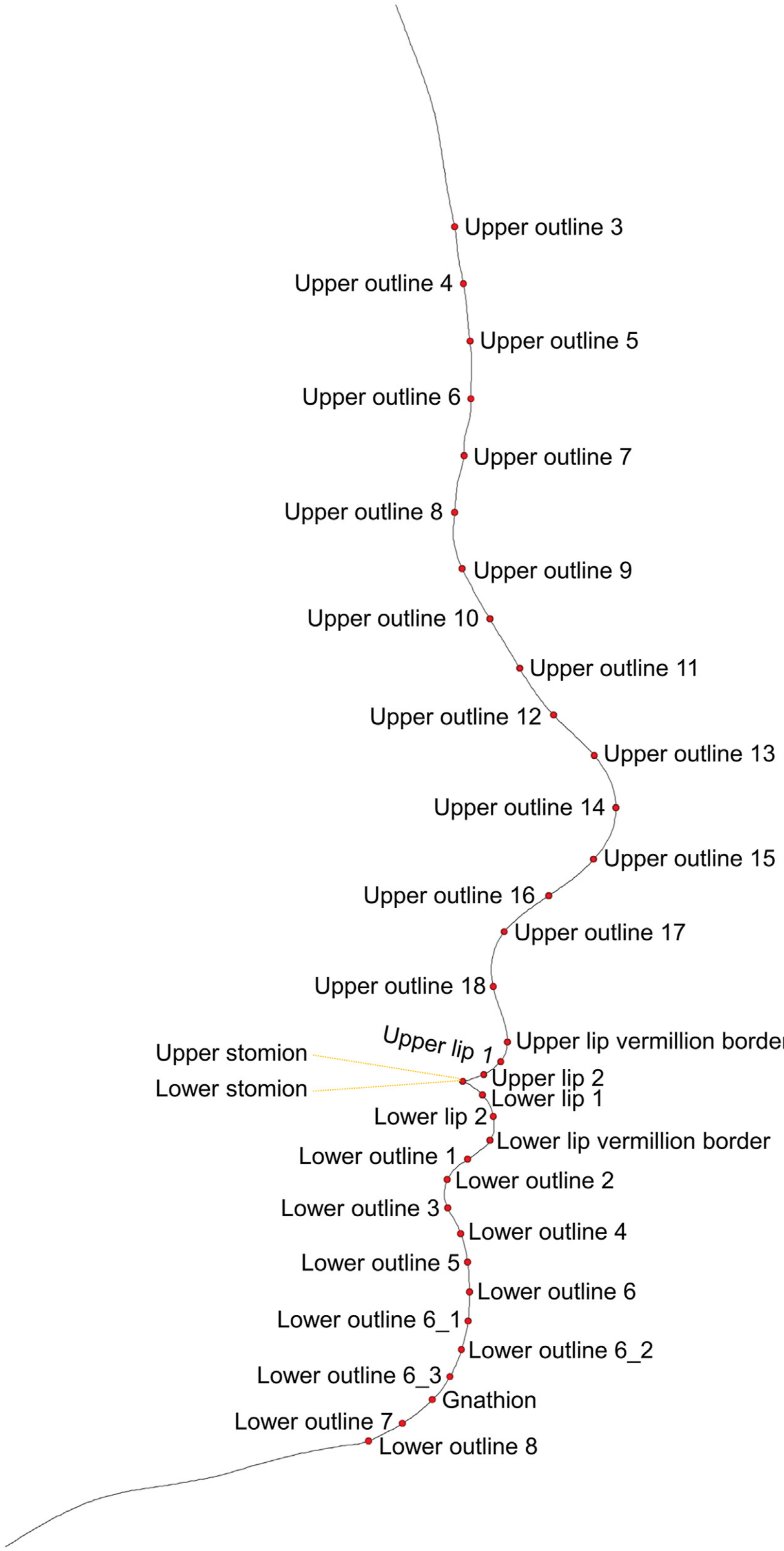



**Fig 3.** Profile line depicting the landmarks and semilandmarks used in the study.

horizontal and vertical levels, were provided using box plots for all landmarks.

The effect of the patient's sex, age, and radiographic machine factors on the primary outcome was assessed through the Mann-Whitney U test.

The level of significance was set at a 2-sided $\alpha = 0.05$, adjusted for multiple pairwise comparisons using a Bonferroni correction.

The intraoperator (M.L.A.) error in landmark identification was assessed by repeated digitization of the 2 profile lines (cephalograms and 3D-derived images) on 30 randomly selected subjects (15 females and 15 males), 2 months after the first digitization. The error of the 2D true profile image generation from the 3D photographs has been assessed elsewhere and was negligible.[23] The mean Procrustes distance between the first and second shape configurations was determined through permutation tests (100,000 permutations) and was minimal, indicating no systematic error ($P = 0.973$). The random error was expressed as the percentage of total variance in shape space that was attributed to the differences between the first and the second digitization.[33] Random error was 12.2%, which was considered acceptable and in the same range as previous similar reports.[34,35]

## RESULTS

Overall, the median age of the 100 participants included in the study was 12.5 years. The sample consisted of 50 females (median age, 16.3; range 8.7-50.5 years), half of which belonged to the young age group (median age, 10.4 years; range 8.7-12.5 years) and half to the older group (median age, 15.3 years; range 12.6-50.5 years) and of 50 males (median age, 12.4 years; range 8.3-55.3 years), half of which belonged to the young age group (median age, 10.8 years; range 8.3-12.3 years) and half to the older (median age, 14.6 years; range 12.6-55.3 years). Nine of the included patient records were posttreatment records (4 females and 5 males), and 91 were pretreatment records (46 females and 45 males). Of the 100 participants, 18 (10 females: 7 young and 3 older; 8 males: 3 young and 5 older) were imaged using 1 x-ray device (machine 1), and the remaining 82 participants (40 females: 18 young and 22 older; 42 males: 22 young and 20 older) were imaged using another (machine 2).

There were no statistically significant differences between sexes as well as between age groups in the linear distances of corresponding landmarks located on the 2 superimposed profile lines ($P > 0.05$; level of significance: $P < 0.001$). Comparable results were observed when assessing variations in landmarks at the horizontal and vertical levels ($P > 0.01$; level of significance: $P < 0.001$). Statistically significant differences were detected between the 2 x-ray devices in 4 out of 108 variables, and these primarily considered the nasal bridge/soft-tissue nasion area in the horizontal direction (x-axis) ($P < 0.001$ [Mann-Whitney U test]; X upper outline 7, X upper outline 8, X upper outline 9, and upper outline 14; Supplementary Fig 1). Overall, the median error of machine 1 was 0.69 mm (interquartile range [IQR], 0.67; range 0.00-6.07), and the median error of machine 2 was 0.87 mm (IQR, 0.84; range 0.01-5.54), indicating a small statistically significant difference ($P < 0.001$ [Mann-Whitney U test]). The observed differences can be attributed to the use of an anterior head support of the cephalostat that interfered less with the midsagittal plane in machine 1 in contrast to machine 2 (Supplementary Fig 2). On the basis of these findings, the sample was considered homogenous and was pooled and no further subgroup analysis was performed.

The null hypothesis of no clinically significant difference between the patient's true profile line and the profile line depicted in lateral cephalometric radiographs was rejected. The overall difference between the 2 profile lines is illustrated through a Procrustes best-fit superimposition of the average profile landmark configurations generated from the 2 types of records (Fig 4). Overall, the median Euclidean distance between the 2 profile line landmarks was 0.84 mm (IQR, 0.83; range 0.00-6.07), which might be considered small, although statistically significant (100,000 permutations, $P = 0.031$). However, when individual patients were considered, there were differences between corresponding points ranging 1-5 mm, which are considered clinically significant. In the entire sample, the Euclidean distances between corresponding landmarks of the 2 profile lines that were $>1$ mm comprised 39.8% of all measurements, whereas in 9.8% of all measurements, the differences were $>2$ mm.

The magnitude and direction of the average differences between the true and the cephalometric profile lines are depicted in Figure 5. The linear differences of each corresponding landmark of the 2 profile lines, after Procrustes best-fit superimposition per individual patient, are presented in Figure 6. On average, the forehead area showed relatively small error with differences in most patients being smaller than 1 mm. There was a tendency for the lateral cephalograms to display the forehead in a more protruded position. The transition between the forehead and the nose (nasal bridge or soft-tissue nasion area) showed bigger differences, often exceeding 1 mm, and almost always toward the dorsal side. This is probably because of the pressure exerted on the soft tissues by the nasion holder used in machine 2 (Supplementary Figs 1 and 2, *A* and *B*). The upper part

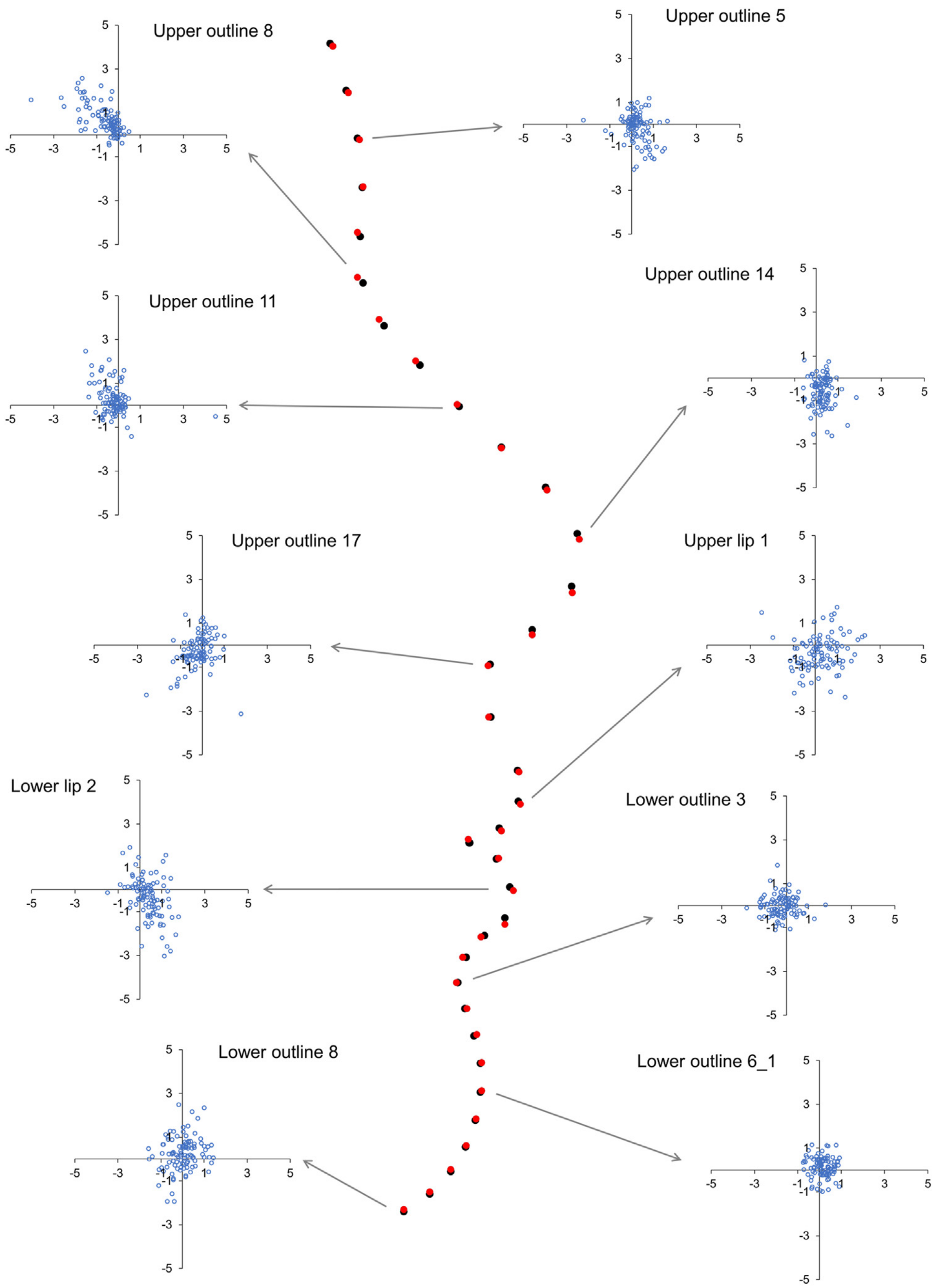



**Fig 4.** The average landmark configuration derived from the 3D photographs is depicted through *black* dots, and the average landmark configuration derived from the lateral cephalometric radiographs is depicted in *red* dots. The *gray* arrows indicate selected points evenly distributed over the entire profile line, in which the differences between the 2 Procrustes-fit approximated landmark configurations of each patient are shown through xy scatter dot plots. The axes show the real magnitude and direction of differences in millimeters.

of the nose presented minor inaccuracies. The tip of the nose and the lower part of the nose just below the tip showed larger inaccuracies toward a more protruded position, sometimes exceeding 1 mm. Differences in the opposite direction, usually <1 mm, were detected in the subnasal area (philtrum) of the upper lip. The

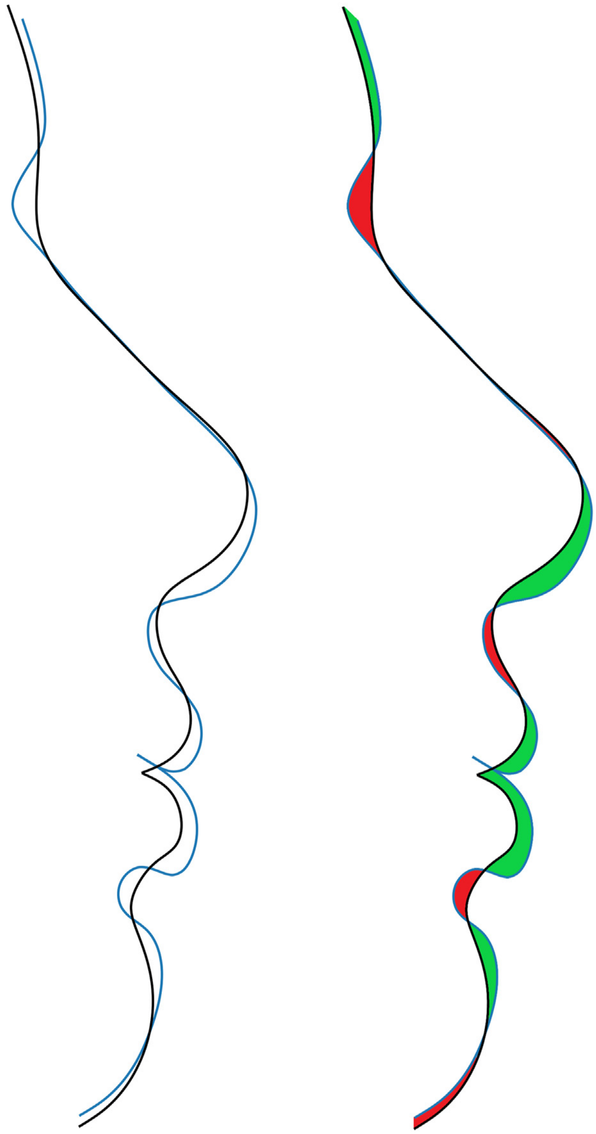


**Fig 5.** Best-fit superimposition of the average profile lines, with their spatial differences magnified by 5. The average profile line derived from the 3D photographs is depicted through the *black* line, and the average profile line derived from the lateral cephalometric radiographs is depicted through the *blue* line after multiplying their differences by 5. In the *right* image, the color between the 2 profile lines highlights their differences (actual difference ×5), with *red* indicating the posterior and *green* anterior position of the actual profile structures in the lateral cephalogram (reference: 3D photograph derived *black* line).

vermilion of the upper and the lower lips showed increased errors and high variability toward a more forward position. The labiomental fold and the chin area were depicted well in the cephalometric radiographs, with differences in most patients varying within 1 mm. The labiomental fold appeared in a slightly posterior position on the cephalometric radiographs, whereas the upper part of the chin was depicted more anteriorly and the lower more posteriorly.

A more detailed assessment of the direction of error in each landmark at the horizontal and vertical levels is provided in Figure 6. Overall, the horizontal differences tended to be approximately 22% smaller than the vertical differences. For most of the points at both levels, the differences were limited to 1 mm. However, at the horizontal and vertical levels, 16.1% and 23.9% of the individual assessments, respectively, presented values >1 mm.

## DISCUSSION

The results of this study showed a relatively good average representation of the facial profile on the lateral cephalometric radiographs when a large group of subjects is considered. The median difference between the cephalometric facial soft-tissue profile to the true reference was statistically significant but of small magnitude (median interlandmark distance, 0.84 mm). However, it was evident that in various individual patients and for certain landmarks, the cephalometric profile line deviated significantly from the true profile, with 40% of the distances between corresponding landmarks being >1 mm and 10% being >2 mm. In specific patients, the errors even reached 5 mm. Such differences can be considered clinically significant and question the use of lateral cephalometry for accurate facial soft-tissue profile assessment. Thus, when relatively large groups of patients are tested in the context of clinical studies, the soft-tissue profile assessment on cephalometric radiographs can be considered reliable. However, for individual patients, it is not certain that the profile depicted on a lateral cephalogram is reliable and should affect treatment decisions. For example, Figure 7, *A* and *B*, shows 2 patients with different amounts of error. In routine clinical practice, distinguishing whether the cephalometric radiograph of an individual patient falls into the first or the second category is challenging.

The primary sources of error in cephalometric radiographs stem from their 2D nature, which involves reducing a 3D object to 2 dimensions.[36,37] A significant source of error is related to head positioning during image acquisition. Noncentered head positions or rotations relative to the beam-film/receptor system can cause distortions.[6] Structures on the midsagittal plane, including the profile, are primarily affected by head orientation errors around the anteroposterior and vertical axes. These

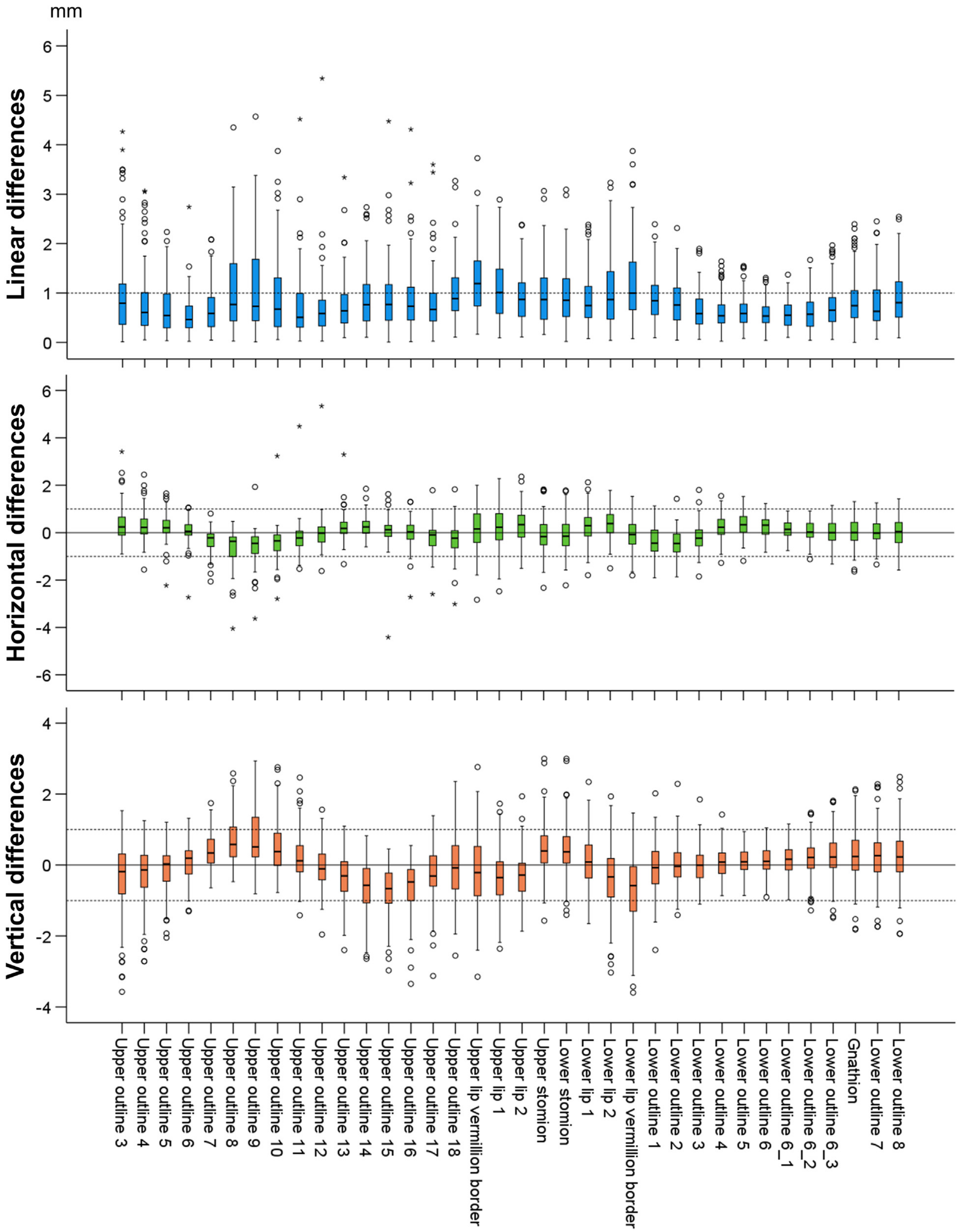



**Fig 6.** Box plots showing the linear (*top*), horizontal (*middle*), and vertical (*bottom*) differences (millimeters) of each corresponding landmark of the 2 profile lines (3D photograph and cephalogram derived)


**Fig 7.** **A**, A patient in which the amount of error of the lateral cephalogram's profile line is small, indicated by the good fit of the cephalometric profile line to the 3D photograph profile line (true reference); **B,** A patient in which the amount of error of the lateral cephalogram's profile line is large, indicated by the reduced fit of the cephalometric profile line to the 3D photograph profile line (true reference).

errors are apparent even when patients are carefully positioned for research purposes.[38] Previous studies focused on skeletal structures, but errors in the soft-tissue profile line can be significant. This is due to the increased distance from the center of the object, which amplifies the impact of head orientation errors, as well as the radiolucency of the thin soft-tissue structures depicted.

The craniofacial area is highly important for human life, both in terms of functionality and esthetic appearance.[12,34] Facial morphology has a key role in this[34] and comprises a primary reason for patients to seek orthodontic or surgical treatment.[9,10] Proper assessment of facial morphology is an integral part of craniofacial diagnosis that can affect treatment decisions.[17,18,39] Consequently, accurate imaging tools should be used

after Procrustes best-fit superimposition per individual patient. The upper limit of the *line* represents the maximum value, the lower limit of the *line* represents the minimum value, the *box* represents the IQR, and the horizontal *line* represents the median value. Outliers are shown as *circles,* whereas extreme outliers are shown as *asterisks*. The *dashes* indicate the level of 1 mm.

in research and clinical practice for the assessment of facial morphology. Because of the potentially high errors of the lateral cephalogram in the representation of individual facial profiles, alternative imaging modalities could be considered in daily practice.

Apart from correct diagnosis and documentation, accurate patient representations are essential for monitoring changes over time.[3] However, even consecutive craniofacial images obtained within a short period and under the same settings can differ because of imaging technique or subject-related factors.[38] To address these limitations, 3D imaging techniques have been introduced.[20,22] Contrary to 2D imaging, 3D technology provides realistic, real-size, and distortion-free representations of structures unaffected by object orientation. This applies to both 3D radiographs and 3D photographs.[40-42] Although 3D radiographs involve radiation exposure, higher costs, and processing challenges,[20,43] 3D photographs are risk-free, quickly acquired, easily archived, versatile in postprocessing, and relatively low-cost.[21,22]

Comparing the results of this study with the limited existing literature is challenging, given the substantial differences in methods and outcomes across previous studies. We identified 2 studies that compared conventional cephalometric measurements to lateral cephalograms synthesized from cone-beam computed tomography scans.[24,25] The first study assessed only 3 linear soft-tissue profile measurements and did not find a statistically significant difference. However, 32%-48% of the measurements deviated by >2 mm.[25] The second study assessed only 2 linear soft-tissue profile measurements and identified a statistically significant average difference of 1.0 and 1.8 mm.[24] This information is quite limited compared with this assessment, but all findings point in the same direction. Finally, we identified a study that assessed 9 linear and 6 angular soft-tissue profile measurements in lateral cephalometric radiographs and compared them to direct measurements performed on a radiographic phantom head.[26] The study identified relatively small, although statistically significant, differences; however, the extrapolation of the experimental findings to actual clinical conditions is questionable.

This study design has several strengths. At first, the study applied novel, highly reliable 3D superimposition methods on 3D stereophotogrammetry models of 100 orthodontic patients to generate the true profile line.[23] The outcome was compared with the cephalometric profile of the same patients using geometric morphometric methods that are superior shape analysis methods than conventional cephalometrics.[44,45] The 3D clinical records were generated by postgraduate students with at least 6 months of active participation in the full-time program to minimize errors resulting from limited experience. These are standard pretreatment and posttreatment records in our department, and thus, the postgraduate students are familiar with them. The lateral cephalograms were obtained from the radiology department of our school, representing actual clinical conditions. The cephalometric radiographs were acquired in a standing position, whereas the 3D photographs were in a sitting position. Except for this, all other settings were the same. However, minimal differences in head posture or soft-tissue tension between the 2 acquisitions cannot be excluded. Previous studies have shown negligible differences in facial soft-tissue surfaces between standing and sitting positions, which were further reduced at the midsagittal plane.[46] Even differences between natural head position and supine head position were primarily located at the submandibular tissues,[47] of which were excluded from the present assessment. In terms of analysis, differences in head posture did not affect the outcomes because, with the use of geometric morphometrics and Procrustes superimposition, differences in size, position, and orientation between the superimposed curves are eliminated to study solely shape differences.[30-32] Two radiographic machines were evaluated to enhance the applicability of the findings. Significant inaccuracies, often exceeding 1 mm, were detected for machine 2 in the presence of a cephalostat with a nasion holder at the neighboring areas. Commonly used linear and angular cephalometric measurements defined through the soft-tissue nasion point, such as facial height or the soft-tissue ANB angle,[11] could be significantly affected by such inaccuracies. The accuracy of the 3D photographs has been well documented in the literature.[48-50] Finally, the intraoperator error of the profile line digitization process was small.

The main limitations of the study derive from its retrospective nature. The main sources of bias in retrospective studies are selection and detection bias. To reduce selection bias, all patients who fulfilled the inclusion criteria were included in the study. Profile line differences are hard to detect through visual inspection during sample selection. Thus, relevant bias is not expected. To control for detection bias, the digitization of a cephalometric radiograph was performed at least 2 weeks apart from the corresponding 3D-derived profile image. The superimposition process and the measurements were fully automated, excluding any source of bias. Although the groups were balanced for age and sex, and the absence of related effects can be considered robust, the comparisons between machines may have been underpowered, potentially leading to an underestimation of the observed differences. Because of the lower quality of the 3D photographs in the throat area (reduced access to the camera sensors), the landmark configurations that were tested in the study extended from the middle of the forehead to Menton. Thus, errors in adjacent areas were not assessed.

## CONCLUSIONS

On average, the lateral cephalometric radiographs might provide an adequate representation of the facial soft-tissue profile, but when individual patients are considered, there is often a clinically significant error. Thus, lateral cephalograms should be used with caution to evaluate the facial profile and should be complemented with other assessments in treatment decisions for individual patients. In the absence of 3D radiographs, whose acquisition requires adequate justification, direct clinical assessment or the use of 3D photographs provides a reliable supplement for cephalometric profile line assessments. This is especially recommended for instances in which profile line analysis is crucial for clinical decision-making. Moreover, 2D photographs can also be used as a supplement to cephalometric analysis, but they might be subjected to comparable errors, primarily because of head orientation issues. When accurate facial profile documentation is needed, such as for clinical research outcome assessment, 3D photographs should be the preferred option.

## AUTHOR CREDIT STATEMENT

Marie-Laure Arn contributed to formal analysis, data curation, visualization, and original draft preparation; Jasmina Opacic contributed to formal analysis, data curation, visualization, and manuscript review and editing; Georgios Kanavakis contributed to formal analysis and manuscript review and editing; Demetrios Halazonetis contributed to conceptualization, software, manuscript review and editing, visualization, and supervision. Nikolaos Gkantidis contributed to conceptualization, methodology, validation, formal analysis, data curation, original draft preparation, manuscript review and editing, visualization, supervision, and project administration.

## SUPPLEMENTARY DATA

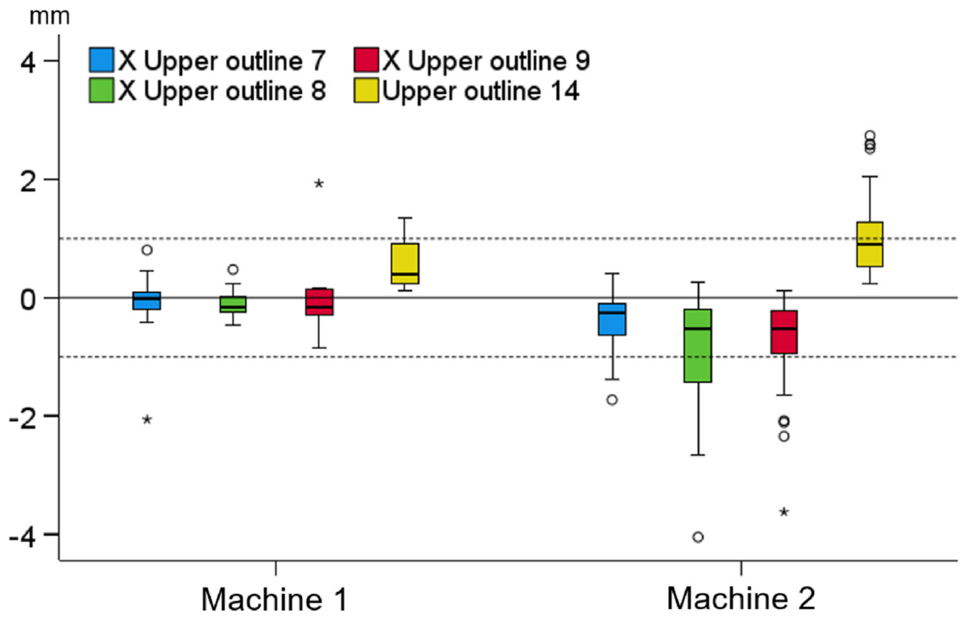
Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.ajodo.2025.02.009.

## REFERENCES

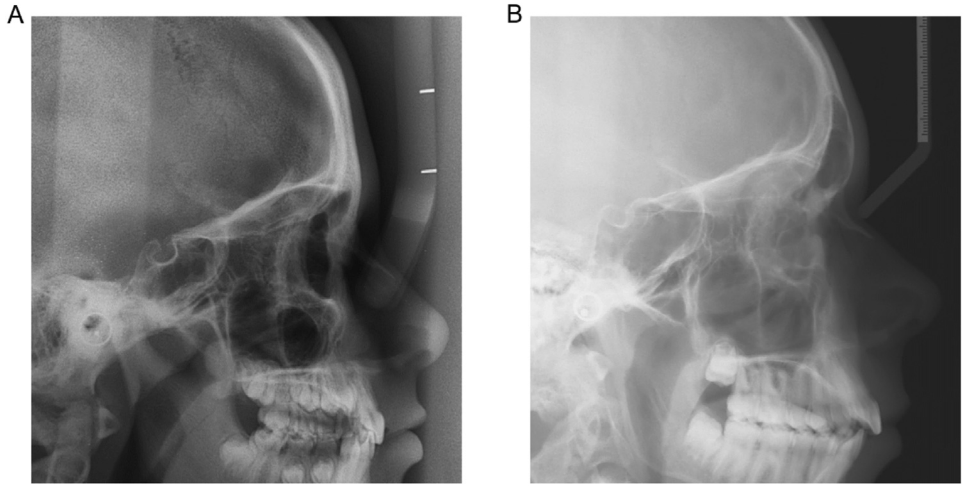

1. Broadbent BH. A new X-ray technique and its application to orthodontia. Angle Orthod 1931;1:45-66.
2. Nielsen IL. Cephalometric morphological analysis: what information does it give you? Int Orthod 2011;9:316-24.
3. Graf CC, Dritsas K, Ghamri M, Gkantidis N. Reliability of cephalometric superimposition for the assessment of craniofacial changes: a systematic review. Eur J Orthod 2022;44:477-90.
4. Ahlqvist J, Eliasson S, Welander U. The cephalometric projection. Part II. Principles of image distortion in cephalography. Dentomaxillofac Radiol 1983;12:101-8.
5. Halazonetis DJ. From 2-dimensional cephalograms to 3-dimensional computed tomography scans. Am J Orthod Dentofacial Orthop 2005;127:627-37.
6. Ahlqvist J, Eliasson S, Welander U. The effect of projection errors on cephalometric length measurements. Eur J Orthod 1986;8:141-8.
7. Major PW, Johnson DE, Hesse KL, Glover KE. Landmark identification error in posterior anterior cephalometrics. Angle Orthod 1994;64:447-54.
8. Bergman RT. Cephalometric soft tissue facial analysis. Am J Orthod Dentofacial Orthop 1999;116:373-89.
9. Pachêco-Pereira C, Abreu LG, Dick BD, De Luca Canto G, Paiva SM, Flores-Mir C. Patient satisfaction after orthodontic treatment combined with orthognathic surgery: a systematic review. Angle Orthod 2016;86:495-508.
10. Pachêco-Pereira C, Pereira JR, Dick BD, Perez A, Flores-Mir C. Factors associated with patient and parent satisfaction after orthodontic treatment: a systematic review. Am J Orthod Dentofacial Orthop 2015;148:652-9.
11. Farkas LG. Anthropometry of the head and face. 2nd ed. New York: Raven press; 1994.
12. Little AC, Jones BC, DeBruine LM. Facial attractiveness: evolutionary based research. Philos Trans R Soc Lond B Biol Sci 2011;366:1638-59.
13. Psomiadis S, Gkantidis N, Sifakakis I, Iatrou I. Perceived effects of orthognathic surgery versus orthodontic camouflage treatment of convex facial profile patients. J Clin Med 2023;13:91.
14. Cremona M, Bister D, Sheriff M, Abela S. Quality-of-life improvement, psychosocial benefits, and patient satisfaction of patients undergoing orthognathic surgery: a summary of systematic reviews. Eur J Orthod 2022;44:603-13.
15. Dayan S, Rivkin A, Sykes JM, Teller CF, Weinkle SH, Shumate GT, et al. Aesthetic treatment positively impacts social perception: analysis of subjects from the HARMONY study. Aesthetic Surg J 2019;39:1380-9.
16. Zhang M-J, Sang Y-H, Tang Z-H. Psychological impact and perceptions of orthodontic treatment of adult patients with different motivations. Am J Orthod Dentofacial Orthop 2023;164:e64-71.
17. Tsiouli K, Topouzelis N, Papadopoulos MA, Gkantidis N. Perceived facial changes of class II division 1 patients with convex profiles after functional orthopedic treatment followed by fixed orthodontic appliances. Am J Orthod Dentofacial Orthop 2017;152:80-91.
18. Zouloumi ME, Tsiouli K, Psomiadis S, Kolokitha OE, Topouzelis N, Gkantidis N. Facial esthetic outcome of functional followed by fixed orthodontic treatment of class II division 1 patients. Prog Orthod 2019;20:42.
19. Konstantonis D. The impact of extraction vs nonextraction treatment on soft tissue changes in class I borderline malocclusions. Angle Orthod 2012;82:209-17.
20. Mai DDP, Stucki S, Gkantidis N. Assessment of methods used for 3-dimensional superimposition of craniofacial skeletal structures: a systematic review. PeerJ 2020;8:e9263.
21. Häner ST, Kanavakis G, Matthey F, Gkantidis N. Valid 3D surface superimposition references to assess facial changes during growth. Sci Rep 2021;11:16456.

22. Wampfler JJ, Gkantidis N. Superimposition of serial 3-dimensional facial photographs to assess changes over time: a systematic review. Am J Orthod Dentofacial Orthop 2022;161:182-97.e2.
23. Gkantidis N, Opacic J, Kanavakis G, Katsaros C, Halazonetis D. Facial asymmetry and midsagittal plane definition in 3D: a bias-free, automated method. PLoS One 2023;18:e0294528.
24. da Silva MBG, Gois BC, Sant'Anna EF. Evaluation of the reliability of measurements in cephalograms generated from cone beam computed tomography. Dent Press J Orthod 2013;18:53-60.
25. Kumar V, Ludlow J, Soares Cevidanes LH, Mol A. In vivo comparison of conventional and cone beam CT synthesized cephalograms. Angle Orthod 2008;78:873-9.
26. Benson PE, Richmond S. A critical appraisal of measurement of the soft tissue outline using photographs and video. Eur J Orthod 1997;19:397-409.
27. Cardini A, Elton S. Sample size and sampling error in geometric morphometric studies of size and shape. Zoomorphology 2007;126:121-34.
28. Cardini A, Seetah K, Barker G. How many specimens do I need? Sampling error in geometric morphometrics: testing the sensitivity of means and variances in simple randomized selection experiments. Zoomorphology 2015;134:149-63.
29. Besl PJ, Mckay ND. A method for registration of 3-D shapes. IEEE Trans Pattern Anal Mach Intell 1992;14:239-56.
30. Rohlf FJ, Slice D. Extensions of the procrustes method for the optimal superimposition of landmarks. Syst Zool 1990;39:40-59.
31. Bookstein FL. Morphometric tools for landmark data: geometry and biology. Cambridge: Cambridge University Press; 1991.
32. Dryden I, Mardia K, Sons J, Winkler G. Statistical Shape Analysis. Chichester: John Wiley & Sons; 1998. p. 2000.
33. Kanavakis G, Häner ST, Matthey F, Gkantidis N. Voxel-based superimposition of serial craniofacial cone-beam computed tomographies for facial soft-tissue assessment: reproducibility and segmentation effects. Am J Orthod Dentofacial Orthop 2021;159:343-51.e1.
34. Kanavakis G, Halazonetis D, Katsaros C, Gkantidis N. Facial shape affects self-perceived facial attractiveness. PLoS One 2021;16:e0245557.
35. Kanavakis G, Silvola A-S, Halazonetis D, Lähdesmäki R, Pirttiniemi P. Incisor occlusion affects profile shape variation in middle-aged adults. J Clin Med 2021;10:800.
36. Farkas LG, Bryson W, Klotz J. Is photogrammetry of the face reliable? Plast Reconstr Surg 1980;66:346-55.
37. Biwasaka H, Tokuta T, Sasaki Y, Sato K, Takagi T, Tanijiri T, et al. Application of computerised correction method for optical distortion of two-dimensional facial image in superimposition between three-dimensional and two-dimensional facial images. Forensic Sci Int 2010;197:97-104.
38. Houston WJ, Maher RE, McElroy D, Sherriff M. Sources of error in measurements from cephalometric radiographs. Eur J Orthod 1986;8:149-51.
39. Papamanou DA, Gkantidis N, Topouzelis N, Christou P. Appreciation of cleft lip and palate treatment outcome by professionals and laypeople. Eur J Orthod 2012;34:553-60.
40. Aldridge K, Boyadjiev SA, Capone GT, DeLeon VB, Richtsmeier JT. Precision and error of three-dimensional phenotypic measures acquired from 3dMD photogrammetric images. Am J Med Genet A 2005;138A:247-53.
41. Hong C, Choi K, Kachroo Y, Kwon T, Nguyen A, McComb R, et al. Evaluation of the 3dMDface system as a tool for soft tissue analysis. Orthod Craniofac Res 2017;20:119-24.
42. Lisboa C de O, Masterson D, da Motta AFJ, Motta AT. Reliability and reproducibility of three-dimensional cephalometric landmarks using CBCT: a systematic review. J Appl Oral Sci 2015;23:112-9.
43. Gkantidis N, Schauseil M, Pazera P, Zorkun B, Katsaros C, Ludwig B. Evaluation of 3-dimensional superimposition techniques on various skeletal structures of the head using surface models. PLoS One 2015;10:e0118810.
44. Gkantidis N, Halazonetis DJ, Alexandropoulos E, Haralabakis NB. Treatment strategies for patients with hyperdivergent class II division 1 malocclusion: is vertical dimension affected? Am J Orthod Dentofacial Orthop 2011;140:346-55.
45. Halazonetis DJ. Morphometrics for cephalometric diagnosis. Am J Orthod Dentofacial Orthop 2004;125:571-81.
46. Ozsoy U, Sekerci R, Ogut E. Effect of sitting, standing, and supine body positions on facial soft tissue: detailed 3D analysis. Int J Oral Maxillofac Surg 2015;44:1309-16.
47. Hoogeveen RC, Sanderink GCH, Berkhout WER. Effect of head position on cephalometric evaluation of the soft-tissue facial profile. Dentomaxillofac Radiol 2013;42:20120423.
48. Lübbers H-T, Medinger L, Kruse A, Grätz KW, Matthews F. Precision and accuracy of the 3dMD photogrammetric system in craniomaxillofacial application. J Craniofac Surg 2010;21:763-7.
49. Eder M, Brockmann G, Zimmermann A, Papadopoulos MA, Schwenzer-Zimmerer K, Zeilhofer HF, et al. Evaluation of precision and accuracy assessment of different 3-D surface imaging systems for biomedical purposes. J Digit Imaging 2013;26:163-72.
50. Zhao Y-J, Xiong Y-X, Wang Y. Three-dimensional accuracy of facial scan for facial deformities in clinics: a new evaluation method for facial scanner accuracy. PLoS One 2017;12:e0169402.

## SUPPLEMENTARY MATERIALS




**Supplementary Fig 1.** Box plots showing the differences between corresponding landmarks of the 2 profile lines (3D photograph and cephalogram derived), after Procrustes best-fit superimposition, per individual patient and radiographic machine. There were significant differences between radiographic machines in the depicted points (X upper outline 7, $P = 0.0001$; X upper outline 8, $P = 0.0001$; X upper outline 9, $P = 0.0003$; upper outline 14, $P = 0.0008$; Mann-Whitney U test, Bonferroni adjusted significance level: $P < 0.001$). The "X" indicates horizontal differences between the specified points; otherwise, the direct Euclidean distance is assumed. The upper limit of the *line* represents the maximum value, the lower limit of the *line* is the minimum value, the *box* is the IQR, and the horizontal *line* is the median value. Outliers are shown as *circles,* whereas extreme outliers are shown as *asterisks*. The *dashes* indicate the level of 1 mm.



**Supplementary Fig 2.** The anterior head support of the cephalostats was used to obtain lateral cephalometric radiographs with **(A)** machine 1 (Oralix 9200; Gendex, Milan, Italy) and (**B**) machine 2 (ProMax 2D S3; Planmeca, Helsinki, Finland).