ORIGINAL ARTICLE

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Three-dimensional cephalometric analysis of the maxilla: Analysis of new landmarks

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Introduction: Clinical evaluation of the midface including the paranasal and upper lip regions is highly subjective and complex. Traditional and 3-dimensional cephalometrics were not developed with the clinical appearance of these midfacial areas in mind and are therefore inappropriate surrogates for the clinical appearance of the midface, making them unsuitable as aids in diagnosing dentofacial deformities. The aim of this study was to evaluate traditional as well as newly defined landmarks and measurements and their correlation with clinical appearance of the midface. **Methods:** Fifty-two subjects who underwent full-field cone-beam computed tomography were recruited for this study. A single examiner assessed each subject's midfacial region (paranasal and upper lip), and a second examiner obtained traditional and newly defined cephalometric measurements for each subject. Both examiners were blinded to each other's data throughout the study. Statistical analysis was performed to assess the correlations of the traditional and novel cephalometric measurements with clinical midfacial findings. The impact of the soft tissue thickness in the paranasal region was also analyzed. The performance of any classification derived from statistically significant variables was analyzed with the use of micro-F scores and area under the receiver operating characteristic curve (AUC). **Results:** Both traditional (SNA) and newly defined measurements (SN_{ANS}, SN_{PR}, SN_{NP}, SN_h) had no statistically significant correlation with clinical paranasal diagnosis. However, in the absence of upper lip procumbency or protrusion, SN_{NP} and SN_h had statistically significant correlations with clinical paranasal diagnosis ($P = 0.047$ and $P = 0.003$, respectively). For upper lip analysis, both traditional (SNA) and newly defined measurements (SN_{CEJ}) had strong correlations with clinical upper lip diagnosis ($P < 0.001$). All statistically significant cephalometric variables had good intra- and interobserver reliability (correlation coefficients $\geq$0.972 and $\geq$ 0.968, respectively) except SNA, which had a low interobserver reliability (correlation coefficient 0.739). Fitted models for paranasal and upper lip analyses showed low micro-F scores, indicating low precision and recall. However, AUC values of 0.7019 and 0.6362 for the paranasal and upper lip analysis, respectively, suggest improved performance of the model when properly trained with a larger sample size. **Conclusions:** Newly defined measurements SN_h and SN_{NP} correlated with clinical paranasal diagnosis only in the absence of upper lip procumbency and protrusion. SNA and SN_{CEJ} were strongly correlated with clinical upper lip diagnosis. However, fitted models based on this study sample yielded low micro-F scores, making the fitted models currently unsuitable for anything besides correlation with clinical findings. A larger sample size will be necessary to further clarify the potential roles of these measurements, especially given the reasonable AUC values. The findings of this study demonstrate the highly subjective and relative nature of midfacial diagnosis and the importance of clinical judgment despite the potential utility of some traditional and new measurements. (Am J Orthod Dentofacial Orthop 2019;156:337-44)

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Dentofacial deformities can cause disharmony of the facial form as well as malocclusion and resultant functional deficit. Although treatment objectives vary depending on each patient's wishes, improving facial esthetics is a goal that clinicians commonly strive for.[1] Facial esthetics is an inherently subjective quality that may vary according to psychosocial and cultural contexts.[2-4] Attempts have been made to use quantitative analysis methods via cephalometrics to assess facial esthetics (in particular the profile) based on population norms in managing dentofacial deformities.[5-11] However, there is no criterion standard in the diagnosis of facial esthetics, and a combination of subjective clinical assessment and cephalometric analysis remains the typical method in treatment planning.[12,13]

When assessing facial esthetics and soft tissue changes, the midface presents a greater challenge owing to its complex structure: variable soft tissue thickness, presence of multiple structures, such as the orbit, nose, and upper lip (each with variable anatomy), and the impact of the nasolabial musculature and its dynamics. In contrast, the form and position of the mandible and its overlying soft tissues is thought to be more simple and predictable, allowing satisfactory soft tissue esthetics in this region with skeletal correction of most mandibular deformities.[14-16] As such, a heavier emphasis is placed on clinical experience when determining the "optimal" sagittal position of the maxilla when planning orthognathic surgery. While excellent outcomes are often achieved with such methods, planning may be difficult and even daunting for some novice and intermediate practitioners. Also, deformities that are in the esthetic "gray area" make it difficult for even experienced practitioners to plan the appropriate position of the maxilla in orthognathic surgery. This underscores the value of an "objective" measure in assessing dentofacial deformities to complement the clinical examination regardless of practitioner experience.

Traditional cephalometric analyses are most commonly used as an adjunct to clinical examination in the management of dentofacial deformities. However, the overwhelming majority of the original cephalometric analysis systems did not have facial form in mind and in fact were not meant for evaluation of facial esthetics.[9,17-19] More recently, 3-dimensional (3D) cephalometric systems have been developed with widespread use of cone-beam computed tomography (CBCT); however, these are only extensions of the traditional cephalometric analyses using similar or identical landmarks[20-24] and therefore do not correlate with clinical appearance of the midface.

The purpose of the present study was to investigate both traditional and several newly defined midfacial landmarks and measurements with the use of 3D cephalometrics and determine how they correlate with the clinical examination. The authors aimed to establish a more reliable adjunct in diagnosing and managing dentofacial deformities of the maxilla.

MATERIAL AND METHODS

This study was approved by the Institutional Review Board of the University of Illinois at Chicago (protocol number 2017-0536).

Patients aged 12-64 years, presenting to the Oral and Maxillofacial Surgery clinic at the University of Illinois at Chicago who were treatment planned to undergo a full-field CBCT for their planned visit were recruited after fully disclosing details of the study. Written informed consents (and assent with parental permission for minors) were obtained. Exclusion criteria included presence of syndromes affecting the craniofacial structures, history of facial fractures or surgery, presence of facial swelling or soft tissue abnormality (eg, recent facial surgery or trauma), and presence of cognitive impairment or lack of decisional capacity. Consecutive selection of subjects was limited only by the availability of the examiner (M.D.H.) in the clinic.

Clinical examination of the midface was performed by a single oral and maxillofacial surgeon examiner (M.D.H.) in the following fashion, with the subject's head oriented with the clinical Frankfort horizontal plane (FHP) and pupils parallel to the floor: (1) paranasal region from profile and three-quarter profile view; (2) upper lip from profile and three-quarter profile view; and (3) thickness of paranasal soft tissues. Subjects determined to have a short face with overclosure of the mandible were instructed to slightly open the jaw until the lower lip was out of contact with the upper lip. This was to eliminate the effect of the lower lip on the upper lip form. All clinical examination findings were recorded in a categoric fashion. For paranasal projection, subjects were categorized as "normal," "moderately deficient," or "severely deficient." For upper lip, subjects were categorized as "moderately deficient," "severely deficient," "normal," "moderately protrusive/procumbent," or "severely protrusive/procumbent."

Using imaging analysis software (Tx Studio; Imaging Sciences International, Hatfield, Pa), a second examiner—a chief oral and maxillofacial surgery resident—blinded to the clinical examination (M.R.M.) oriented the CBCT with the FHP parallel to the horizontal axis and with the medial canthi aligned in the frontal plane. New and traditional landmarks were identified by toggling between different windows and slices. These landmarks are summarized and illustrated in Table 1 and Figures 1-3, respectively. The same measurements were made again in 2 weeks to analyze intraobserver reliability. Using blinded data, a senior orthodontic resident examiner not related to the study made the

Table I. Description of midfacial landmarks used

Landmark	*Description*
CEJ	Facial aspect of the cementoenamel junction of the maxillary right incisor
NP	Anterior aspect of the nasopalatine canal (as in Delaire et al[25])
PR	Most lateral portion of the right piriform rim on frontal view
Point h	Point on the right maxilla directly below the soft tissue alar base on axial view

same measurements twice with a 2-week washout period in between. These measurements were used to examine inter- and intraobserver reliability of the traditional and newly defined landmarks.

The clinical examination data and cephalometric measurement data were stored separately in secure spreadsheets (Excel; Microsoft Corp, Redmond, Wash) and were later deidentified and merged for statistical analysis.

Statistical analysis

A multinomial logistic regression with cumulative link was used to analyze the correlation between cephalometric and clinical variables. To determine the effect of soft tissue thickness (which may clinically camouflage a retrognathic maxilla), soft tissue thickness was analyzed as a covariate. All statistical analysis was performed with the use of SAS (SAS Institute, Cary, NC).

In addition to soft tissue thickness, the presence of upper lip protrusion/procumbency was controlled for by performing a multinomial logistic regression with cumulative link after excluding subjects with clinically protrusive or procumbent upper lips. This was to account for the relative nature of the anteroposterior projection in the midface. For example, a "normal" paranasal projection could be perceived as deficient in the setting of significant upper lip protrusion or procumbency. Statistical analysis was performed by an analyst who was not involved with data collection (S.H.).

Correlation coefficients were calculated for intra- and interobserver reliability of statistically significant variables. The performance of any classification derived from statistically significant variables was analyzed with the use of micro-F scores, which measures a generalization of sensitivity and specificity for multiclass classifications (instead of binary). Area under the receiver operating characteristic curve (AUC) was also used to measure the performance of classifications. Leave-one-out cross-validation was performed when calculating the micro-F scores and AUC values, allowing testing of the multinomial linear regression model.

Fig 1. Landmarks PR (*red*) and CEJ (*blue*).

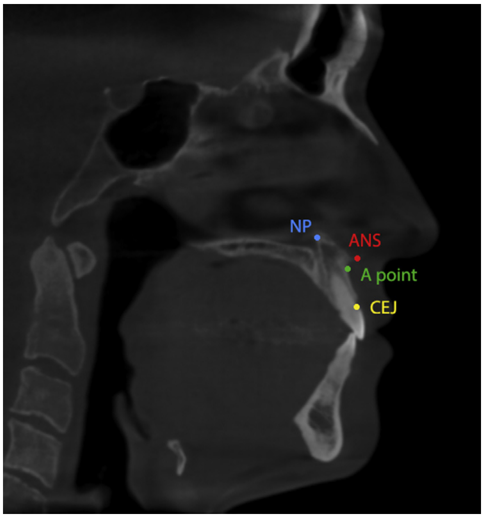

Fig 2. Landmarks NP (*blue*), ANS (*red*), A point (*green*), and CEJ (*yellow*).

RESULTS

A total of 52 subjects were examined, of which 18 were male and 34 were female. Descriptive statistics are summarized in Table II. The logistic regression model for the paranasal analysis was:

$$logit(P[Y \leq j]) = \alpha_j + \beta_1 \times SN_{ANS} + \beta_2 \times SN_{NP} + \beta_3 \times SN_{PR} + \beta_4 \times SN_h$$

where Y represents the categoric variables, and j = 1-3, corresponding to the normal, moderately deficient, and severely deficient categories. The model for the upper lip analyses was

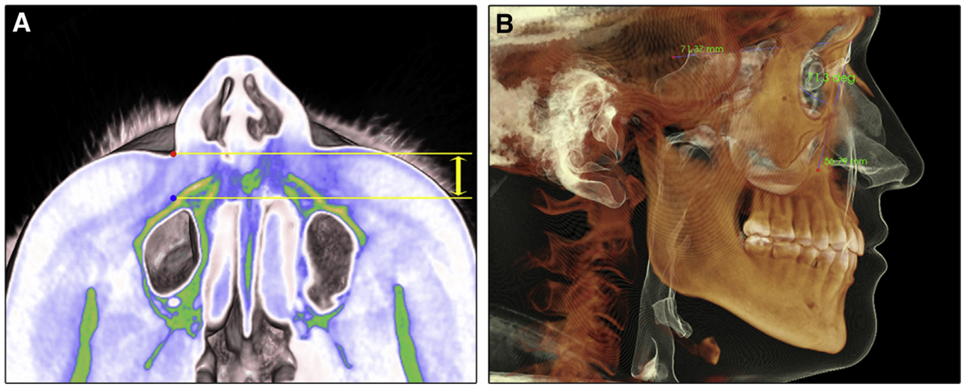

Fig 3. **A,** Point h (*blue dot*) is identified directly posterior to the alar base (*red dot*). The *yellow double-arrow* shows the thickness of the paranasal soft tissues. **B,** SN_h shown in composite hard-soft tissue view.

$$logit(P[Y \leq j]) = \alpha_j + \beta_1 \times SNA$$

$$logit(P[Y \leq j]) = \alpha_j + \beta_1 \times SN_{CEJ}$$

where Y represents the categoric variables, and j = 1-4, corresponding to the moderately deficient, normal, moderately protrusive, and severely protrusive categories.

For the paranasal analysis, all cephalometric variables—SNA, SN_{ANS}, SN_{NP}, SN_{PR}, and SN_h—showed no statistically significant correlation with the clinical projection of the paranasal region. This was unchanged even when controlling for soft tissue thickness ($P = 0.51$). However, when controlling for the presence of upper lip procumbency or protrusion, statistically significant correlations were seen for SN_{NP} ($P = 0.047$) and SN_h ($P = 0.003$). Descriptive statistics for paranasal analysis for subjects without clinically procumbent or protrusive upper lips are summarized in Table III, and a fitted model based on this analysis is presented in Table IV.

For the upper lip analysis, both SNA and SN_{CEJ} showed highly statistically significant correlations with procumbency and protrusion ($P = 0.0007$ and $P < 0.0001$, respectively). Descriptive statistics for upper lip analysis are summarized in Table V, and a fitted model based on this analysis is presented in Table VI.

Intraobserver reliabilities for SNA, SN_{CEJ}, SN_{NP}, and SN_h were 0.992, 0.998, 0.972, and 0.978, respectively. Interobserver reliabilities for SNA, SN_{CEJ}, SN_{NP}, and SN_h were 0.739, 0.977, 0.968, and 0.969, respectively. The micro-F scores for the paranasal and upper lip analysis fitted models were 0.5357 and 0.4615, respectively. AUC values were 0.7019 and 0.6362 for the paranasal and upper lip analysis, respectively.

Table II. Descriptive statistics

Variable	*Value*
Sample size	52
Gender	18 male, 34 female
Age (y)	21.1 ± 10.4
SNA (°)	85.5 ± 5.9
SN_{ANS} (°)	90.1 ± 5.3
SN_{NP} (°)	74.0 ± 4.9
SN_{PR} (°)	78.5 ± 3.6
SN_h (°)	75.6 ± 4.8
SN_{CEJ} (°)	88.4 ± 6.0
Paranasal soft tissue thickness (mm)	12.1 ± 1.7

Table III. Descriptive statistics for paranasal analysis in subjects without clinically protrusive or procumbent upper lips

Category (n)	*SNA (°)*	*SN_{NP} (°)**	*SN_h (°)†*
Aggregate (27)	83.2 ± 4.8	72.9 ± 4.1	74.2 ± 3.9
Normal (9)	85.9 ± 3.6	72.9 ± 3.2	77.1 ± 3.1
Moderately deficient (14)	81.5 ± 4.4	72.1 ± 3.9	73.7 ± 3.3
Severely deficient (4)	83.3 ± 6.5	73.6 ± 3.9	69.7 ± 2.1

*Statistically significant: $P = 0.047$; †Statistically significant: $P = 0.003$.

DISCUSSION

The clinical significance of maxillary cephalometric measurements in dentofacial deformity diagnosis lies in the appearance of the midface. As such, these measurements should be properly correlated with clinically important midfacial regions to be of use in the clinical setting. Norms based on populations with favorable

Table IV. Fitted model of paranasal diagnosis and variables SN_{NP} and SN_h

Clinical diagnosis per SN_h	$SN_h \geq 73$	$SN_h < 73$
Normal	$SN_{NP} < 68.5$	$SN_{NP} < 60.5$
Moderately deficient	SN_{NP} 68.5-82	SN_{NP} 60.5-74
Severely deficient	$SN_{NP} > 82$	$SN_{NP} > 74$

Table V. Descriptive statistics for upper lip analysis

Category (n)	*SNA (°)**	SN_{CEJ} *(°)*†
Aggregate (52)	85.5 ± 5.9	88.4 ± 6.0
Normal (23)	83.3 ± 5.0	85.9 ± 5.1
Moderately deficient (5)	81.2 ± 5.0	82.6 ± 5.0
Moderately protrusive (17)	88.0 ± 5.5	91.1 ± 4.2
Severely protrusive (7)	89.6 ± 6.0	94.5 ± 6.2

*Statistically significant: $P < 0.001$; †Statistically significant: $P < 0.001$.

Table VI. Fitted model of upper lip diagnosis and variables SNA and SN_{CEJ}

Clinical diagnosis per SNA or SN_{CEJ}	*SNA*	SN_{CEJ}
Moderately deficient	SNA ≤71	$SN_{CEJ} \leq 76.5$
Normal	71 < SNA ≤ 88.6	$76.5 < SN_{CEJ} \leq 89.6$
Moderately protrusive/ procumbent	88.6 < SNA ≤ 97	$89.6 < SN_{CEJ} \leq 97.6$
Severely protrusive/ procumbent	SNA >97	$SN_{CEJ} > 97.6$

occlusion (and not facial form) cannot be considered as an adequate tool to diagnose and plan treatment for dentofacial deformities. A "retrognathic maxilla" cannot be reduced to a particular range of numbers and must be defined in clinically relevant terms. To the authors' knowledge, no studies to date have correlated 3D cephalometrics with midfacial form in a blinded manner.

The most commonly used cephalometric measurement to assess maxillary sagittal position is the SNA angle. This is likely due to the paucity of measurements for midfacial projection, which could be explained by the lack of readily identifiable landmarks on a traditional 2D cephalometric radiograph besides the A point. The A point roughly corresponds to the soft tissue A point, which accounts for only the upper lip region and not the paranasal region, which is the area that is most frequently affected by skeletal midfacial deficiency in a clinical setting. Also, given the proximity of the A point to the dentoalveolar unit, this point can be altered by orthodontic movement even in the absence of skeletal movement. Therefore, measurements involving the A point are poor surrogates for the sagittal position of the maxilla, and the lack of statistical significance between SNA and paranasal projection seen in the present study supports the poor correlation of SNA with clinically relevant findings and the authors' view that SNA should not be viewed as the criterion standard by which midfacial form is measured.

Three landmarks were selected to represent the anteroposterior position of the maxilla. Point NP was used to represent an identifiable structure within the maxilla that is not easily subject to change from orthodontic or surgical treatment. This point is used in some cephalometric analyses[25] as a surrogate for the anteroposterior position of the maxilla. This was chosen over a reconstructed point representing the center of the maxilla[26] to maximize reproducibility. The PR point was used to roughly represent the paranasal region. The most lateral point of the piriform rim was chosen to allow reproducible identification. Point h was used to represent the paranasal region with better accuracy, because differences in alar base width could affect the corresponding skeletal counterpart of the paranasal region. Navigation of 3D imaging allowed for easy identification of this patient-specific landmark.

An additional landmark was used to assess upper lip projection. The cementoenamel junction (CEJ) of the maxillary right incisor was chosen because it was within the dentoalveolar unit, and therefore potentially more influential on upper lip form. Soft tissue thickness was taken into account because skeletal deficiencies could be clinically camouflaged by thick soft tissues.

All measurements had no statistically significant correlation with paranasal projection, regardless of the overlying soft tissue thickness. However, when upper lip procumbency and protrusion were accounted for, SN_h and SN_{NP} demonstrated a strong correlation with clinical appearance of the paranasal region. This supports the clinical observation that maxillary dentoalveolar protrusion gives the illusion of a deficient paranasal region owing to the relativity of anteroposterior projection of the different midfacial structures. An example of this finding is shown in Figure 4.

In the upper lip region, both SNA and SN_{CEJ} had a highly statistically significant correlation with upper lip procumbency and protrusion. Because both were nearly equal in predictive accuracy, incorporating a new measurement (SN_{CEJ}) may be of little value, although the suboptimal interobserver reliability of SNA in this study may somewhat justify use of SN_{CEJ}. Instead, SNA should be regarded as an aid in assessing the anteroposterior projection of the maxillary dentoalveolar unit and not the midface, as is common practice. This is further supported in light of the poor correlation of SNA with paranasal projection.

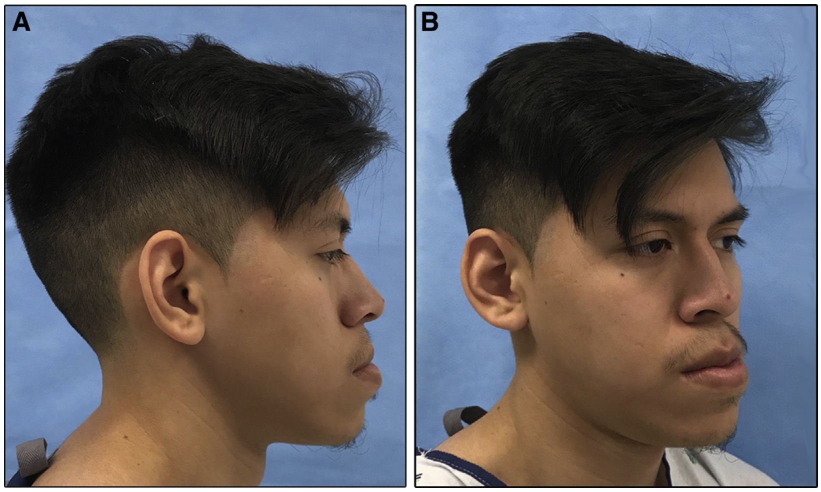

Fig 4. Severely procumbent and protrusive upper lip on profile view **(A)**. Three-quarter profile view shows severely deficient paranasal region **(B)**. Cephalometric measurements showed a high SN_{CEJ} and SNA values, indicating dentoalveolar protrusion, but normal SN_h and SN_{NP} values, indicating a normal paranasal projection.

Statistically significant measurements SN_{CEJ} (for upper lip assessment), SN_{NP}, and SN_h (for paranasal analysis) had good inter- and intraobserver reliability (intraclass correlations all ≥0.968). Interestingly, SNA had a low interobserver reliability despite its routine use in everyday clinical practice.

The strength of this study was the heavy emphasis on using patient-oriented variables that had clinical significance—subjective perception of midfacial projection—when correlating with the cephalometric measurements. For the purposes of this study, the maxilla was viewed in isolation from the mandible to eliminate any confounding effects of the mandible on the facial profile in addition to the relative straightforwardness of the relationship between the hard tissue progonion and its soft tissue counterpart. Another strength of this study is the use of newly defined landmarks easily identifiable on CBCT (points PR and h) and the use of a patient-specific landmark that corresponds directly to the clinical area of interest (point h). In addition, this study was blinded to avoid any potential bias in correlating the clinical findings with the cephalometric measurements.

This study used the cranial base (sella-nasion) as a reference for most of the cephalometric measurements. Variations in cranial base inclination are known to affect measurements such as SNA,[27] and this was not accounted for in this study. This could have potentially introduced variations in measurements based on the cranial base. Also, no distinction was made between a clinically procumbent upper lip versus a protrusive one. This was due to the complexity in thoroughly analyzing factors potentially affecting procumbency of the upper lip, such as upper incisal angulation, contours of the labial bone and the anterior nasal spine. This will be analyzed in a future study at the authors' institution. Unlike the cephalometric measurements, the clinical examination was not repeated primarily because the study protocol explicitly excluded clinic patients' return solely for research purposes. Instead, the ordinal variables were set so as to minimize ambiguity: Instead of introducing a "mild-normal-moderate-severe" scale, in which there could be significant overlap (especially among different examiners), "mild" categories were eliminated. Another limitation was the small sample size when controlling for upper lip procumbency and protrusion. After eliminating subjects with clinically procumbent or protrusive upper lips, the total sample size decreased to 27. Further research involving a larger sample size will help to elucidate the utility of SN_h and SN_{NP} as aids in paranasal diagnosis. This fact is particularly highlighted by the rather low micro-F scores, which suggests less-than-ideal precision and recall (analogous to sensitivity and specificity in a binary classification) of this multiclass classification. As such, the fitted models presented in this study should not be regarded as appropriate for clinical use at this time. Instead, the results of this study should merely highlight some new measurements that could potentially find clinical use with a large sample size. The authors anticipate a clearer picture of the precision and recall of this multiclass classification with the use of a substantially larger sample size, particularly of those without a procumbent or protrusive upper lip.

Finally, this study did not take into consideration the effect of malar and nasal projection on the perception of paranasal projection. Like the upper lip's relative influence on the perception of paranasal projection, malar and nasal projection could influence the perception of the midface.

The results of this study illustrate the complexity of midfacial diagnosis, especially the relative nature regarding projection of adjacent structures. It goes without saying that the same holds true for the influence of the mandible on the appearance of the midface and the face as a whole. It must be emphasized that the soft tissue end goal of surgical-orthodontic treatment is predominantly favorable esthetics. Regardless of how it is quantified, esthetics remains a highly subjective quality that is subject to change over time and in different social and cultural settings. It is therefore important to stress that, regardless of statistical significance, any "objective" measure should be used only as an adjunct to subjective clinical assessment, and that clinical experience remains crucial in diagnosing and treating dentofacial deformities.

CONCLUSIONS

The findings of this study demonstrate the highly subjective and relative nature of midfacial projection and underscore the importance of clinical judgement in diagnosing and treatment planning dentofacial deformities. In particular, heavy reliance on clinical experience and meticulous assessment remain essential in diagnosing and managing dentofacial deformities of the maxilla. However, in the absence of upper lip protrusion or procumbency, SN_h and SN_{NP} are measurements that could potentially be useful to aid in treatment planning maxillary movements and in orthognathic surgery. Use of SNA as a diagnostic aid for the paranasal region (ie, the maxillary skeletal unit) should be discouraged and instead it should be used as an adjunct, not a substitute, for diagnosing the maxillary dentoalveolar unit. The small sample size, low micro-F scores, but reasonable AUC values highlight the need for follow-up studies before putting the newly defined measurements to clinical use.

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