*Original Article*

# A coupled-lines system to determine the anteroposterior position of maxillary central incisors for smiling profile esthetics

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**ABSTRACT**

**Objectives:** To develop a coupled-lines system to determine the anteroposterior position of maxillary central incisors (U1) for smiling profile esthetics.

**Materials and Methods:** Thirty Asian females with ordinary and good facial harmony were selected as the study sample and the control sample, respectively. Three-dimensional facial images and 45°- and 90°-angled profiles were collected. The anteroposterior relationships between U1 and upper- and mid-facial soft tissue landmarks were measured. By morphing photos of the study sample, two artificial images were created to represent the well-balanced 45°- and 90°-angled profiles and were further processed with combined variations of soft tissue subnasale (SSn)–Glabella and the mid-point of facial axial points of the bilateral central incisor (mFA)–SSn distances. Esthetic assessments were performed on these images by layperson (n = 94) and orthodontist (n = 94) raters.

**Results:** Both upper- and mid-facial soft tissue landmarks were indispensable in assessing anteroposterior positions of U1 for well-balanced smiling profiles. As assessed in 45°- and 90°-angled profiles, the most esthetically sensitive parameters were mFA-Glabella and mFA-SSn distances. A coupled-lines system was constructed, comprising the Glabella and SSn vertical lines. In smiling profiles with optimal esthetics, the mFA point was at 2 to 5 mm posterior to the Glabella vertical and concomitantly 4 to 7 mm posterior to the SSn vertical, as perceived by orthodontists. Laypersons gave a wider range for mFA-Glabella distances, at 2 to 6 mm.

**Conclusions:** The coupled-lines system could serve as a reliable reference for determining esthetically optimal anteroposterior positions of U1 for female facial profiles. (*Angle Orthod.* 2023;93:447–457.)

**KEY WORDS**: Smile esthetics; Facial profile; Maxillary central incisor; Soft tissue



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## INTRODUCTION

Positioning of the maxillary central incisors (U1) in the anteroposterior dimension is crucial to achieving optimal dentofacial esthetics.[1–6] Numerous studies[4–9] have been dedicated to determining the ideal or norms for assessing the positions and labiolingual inclinations of U1. The U1 position was assessed relative to the forehead for full-facial harmony.[7–9] However, problems were encountered when clinicians universally used these norms as treatment goals for different faces. The esthetically optimal anteroposterior relationship between U1 and the forehead remains controversial.

An important implication was that it might be interethnically inapplicable or even intraethnically unreliable to use the forehead as the sole reference with which to assess U1 positions for faces with morphologic diversity. Facial structures other than the forehead might still impact dentofacial harmony in profile views. Second, it might be unreliable to evaluate anteroposterior U1 positions based merely on 90°-angled profile views; 45°-angled views should be considered with the same attention as 90°-angled profile views in smile analysis.[7,8] However, evidence is currently lacking on assessments of anteroposterior U1 positions on 45°-angled facial views.

Soft tissue subnasale (SSn) was proposed as a reliable midfacial landmark for assessing lip and chin position.[9] Remarkable interethnic and interindividual variation was found in midfacial prominence in esthetically pleasing profiles.[10–12] Thus, the ideal position for lower-facial soft tissue should be shifted anteroposteriorly in pace with SSn variation rather than staying at a constant relationship with the forehead. It remains unknown whether and how the U1 relates to midfacial landmarks for smile esthetics. Incorporating the forehead and midfacial soft tissue landmarks into the reference system by which the U1 positions are assessed might help develop more reliable and applicable guidelines for treating faces with diverse morphology. Therefore, this study was conducted to assess the anteroposterior position of U1 based on 90°- and 45°-angled facial profiles using a three-dimensional (3D) facial analysis. The hypothesis was that U1 position should harmonize with both upper- and midfacial soft tissue for smiling profile esthetics.

## MATERIALS AND METHODS

This study was approved by the Ethics Committee of West China Hospital of Stomatology, Sichuan University Hospital. The workflow of this study is shown in Figure 1.

### Sample Selection

The study sample consisted of 30 Asian females (age = 23.4 ± 2.6 years) selected from university students in the School of Arts. The inclusion criteria were attractive appearance in smiling profile, with well-aligned and no missing teeth in the upper canine-to-canine segment. The control sample comprised 30 Asian females (age = 24.1 ± 2.2 years, pretreatment) randomly selected from university students with pleasing smiling profiles as neither inclusion nor exclusion criteria. With the forehead and U1 fully visible, each subject was instructed to display a posed smile in natural head position for 3D facial image (3dMDFlex; 3dMD, Atlanta, Ga) and 90°- and 45°-angled two-dimensional (2D) photo acquisition. The attractiveness of the photos in the study sample and the control sample were rated in a survey by 100 laypersons (50 females and 50 males, age = 26.1 ± 2.4 years) using a 0–10-point visual analog scale (VAS, 0 representing "least attractive" and 10 representing "most attractive").

### Measurements

In the 3D facial images, measurements were made (Table 1; Figures 2 and 3) by one investigator with Geomagic wrap software (2017 version, 3D System, Morrisville, NC, USA).

### Digital Image Processing

The 90°- and 45°-angled 2D photos in the study sample were merged into one artificial image for each perspective (framed in green in Figure 4, presented in Figure 5) by averaging and morphing using FantaMorph software (5.6.2 Deluxe, Abrosoft Co, Beijing, China). In the 90°-angled profile image, the U1 crown labial surface tangent was parallel to the true vertical at an ideal inclination, as previously suggested.[13] These two images were used as the original images for photographic modification using Adobe Photoshop (CC2018; Adobe Systems Inc, San Jose, Calif).

For the 90°-angled profile views, image modification was designed based on the combination of two independent variables, ubnasale (SSn)–Glabella (SSn-Glabella) and mid-point of facial axial points of the bilateral central incisor (mFA)–SSn distances, each varying in 1.0-mm increments (Figure 4).

A total of 30 artificial images were created (series 1, Figure 4A). For each profile image in series 1, a corresponding 45°-angled view was created (series 2, Figure 4B) based on the mathematical correlation of the measurements in the right-angled and 45°-angled views (Figure 2B). For the 45°-angled views, SSn-

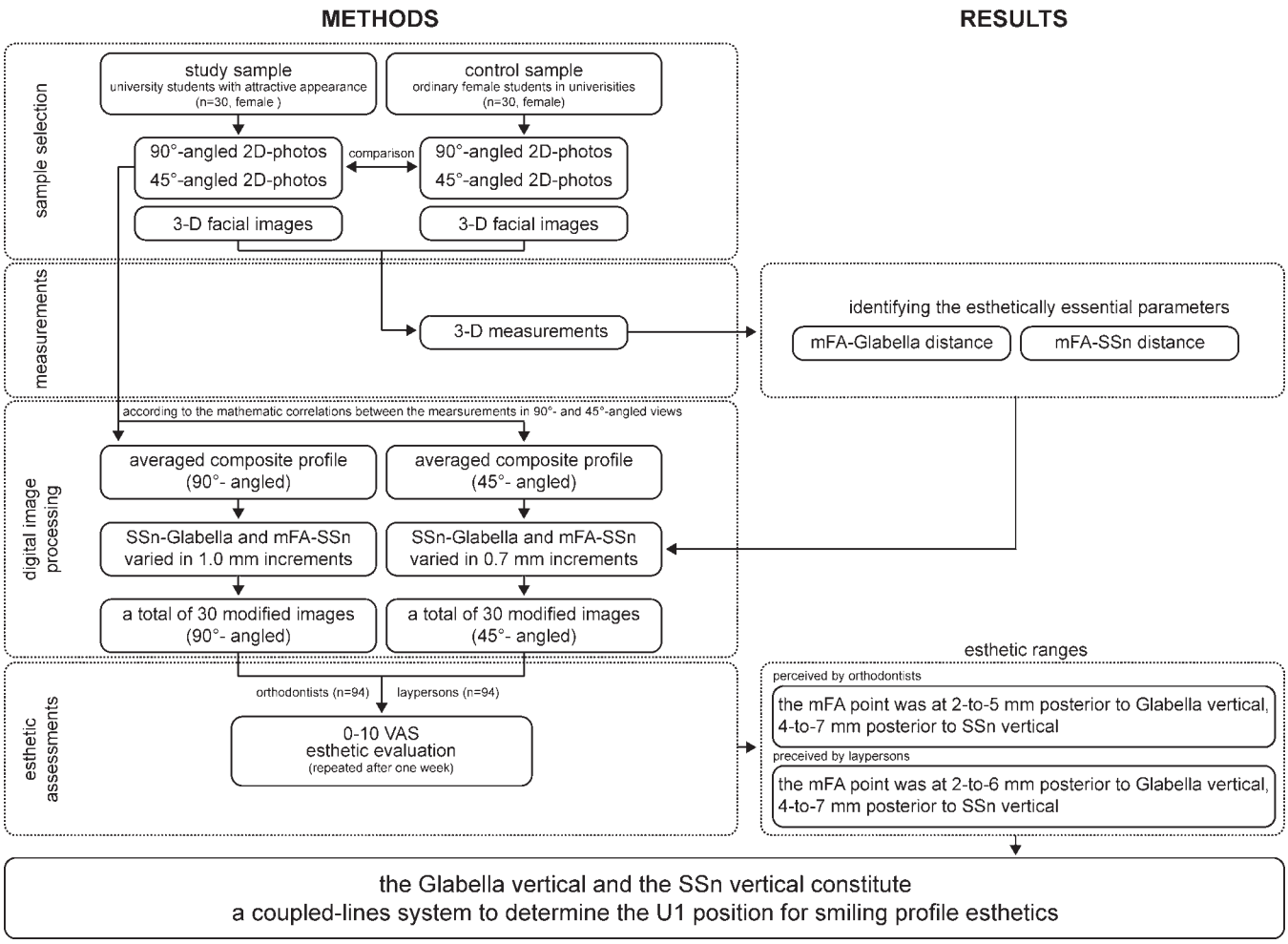


**Figure 1.** Workflow of the study.

Glabella and mFA-SSn distances varied in 0.7-mm increments. Within each series, the images were arranged in a randomized order for esthetic assessment.

## Esthetic Assessment

Based on a standard deviation of a 14% VAS difference, as determined in a pilot study, for a power of 90% and a significance level of .05, a sample size of 84 raters was required. A group of orthodontists (n = 94; 47 females, 47 males; age = 28.9 ± 2.3 years; professional experience of 3.0 ± 1.8 years) and laypersons (n = 94; 47 females, 47 males; age = 25.5 ± 2.1 years) were recruited as raters to evaluate the attractiveness of each image using a 0–10-point VAS (0 indicating "least attractive," 10 representing "most attractive"). The two series of images were evaluated separately, and evaluations were repeated after 1 week. Using images arranged in a newly randomized order, a third evaluation was performed by 30 of the raters 2 weeks after the second assessment to determine intraobserver reliability.

## Statistics

Data analysis was conducted using GraphPad Prism and SPSS. Differences in measurements between the study and control samples were detected by an independent *t*-test. Correlations between forehead inclinations and measurements of distances were detected by the Pearson correlation coefficient. Intraobserver reliability of esthetic evaluations was determined by intraclass correlation coefficient (ICC). The effect of gender or group of the raters on esthetic assessment was evaluated by two-way analysis of variance. Differences in esthetic assessments between images within series were detected by Sidak's multiple comparisons. The level of significance was set at .05.

**Table 1.** Facial and Dental Landmarks, Reference Lines, and Measurements

| |
|---|
| Landmarks |
| Tr: soft tissue trichion |
| Su: superion, the most superior aspect of the forehead with angular or rounded contour |
| Gl: soft tissue glabella |
| FFA: the midpoint of the clinical forehead (between superion and glabella for foreheads with angular or rounded contours or between trichion and glabella for foreheads with flat contour) |
| SSn: soft tissue subnasal point |
| mFA: first locate the facial axial (FA) points of the left and right central incisors, then draw a line segment between these two points; the mFA point is the mid-point of this line segment. In the profile view, the mFA point is frequently located in the same place as the FA point |
| Reference lines |
| FFA vertical: the vertical line through the FFA point |
| Gl vertical: the vertical line through the Gl point |
| SSn vertical: the vertical line through the SSn point |
| GALL: the goal anterior limit line (GALL) is the FFA vertical when the forehead inclination is less than or equal to 7°. For every degree the forehead inclination is more than 7°, the GALL is modified into a line parallel to and 0.6 mm anterior to the FFA vertical, but never beyond the glabella |
| All of the above lines were perpendicular to the true horizontal |
| Measurements |
| Distances: the horizontal distances from the mFA point to the FFA vertical (mFA-FFA), to the GALL (mFA-GALL), to the Gl vertical (mFA-Glabella), and to the SSn vertical (mFA-SSn); the horizontal distances from the SSn point to the Gl vertical (SSn-Glabella) |
| Forehead inclination: first construct a line connecting the glabella to the uppermost point of the clinical forehead (trichion point for foreheads with flat contour, superion point for foreheads with rounded or angular contours). Forehead inclination was defined as the angle between this line and FFA vertical |

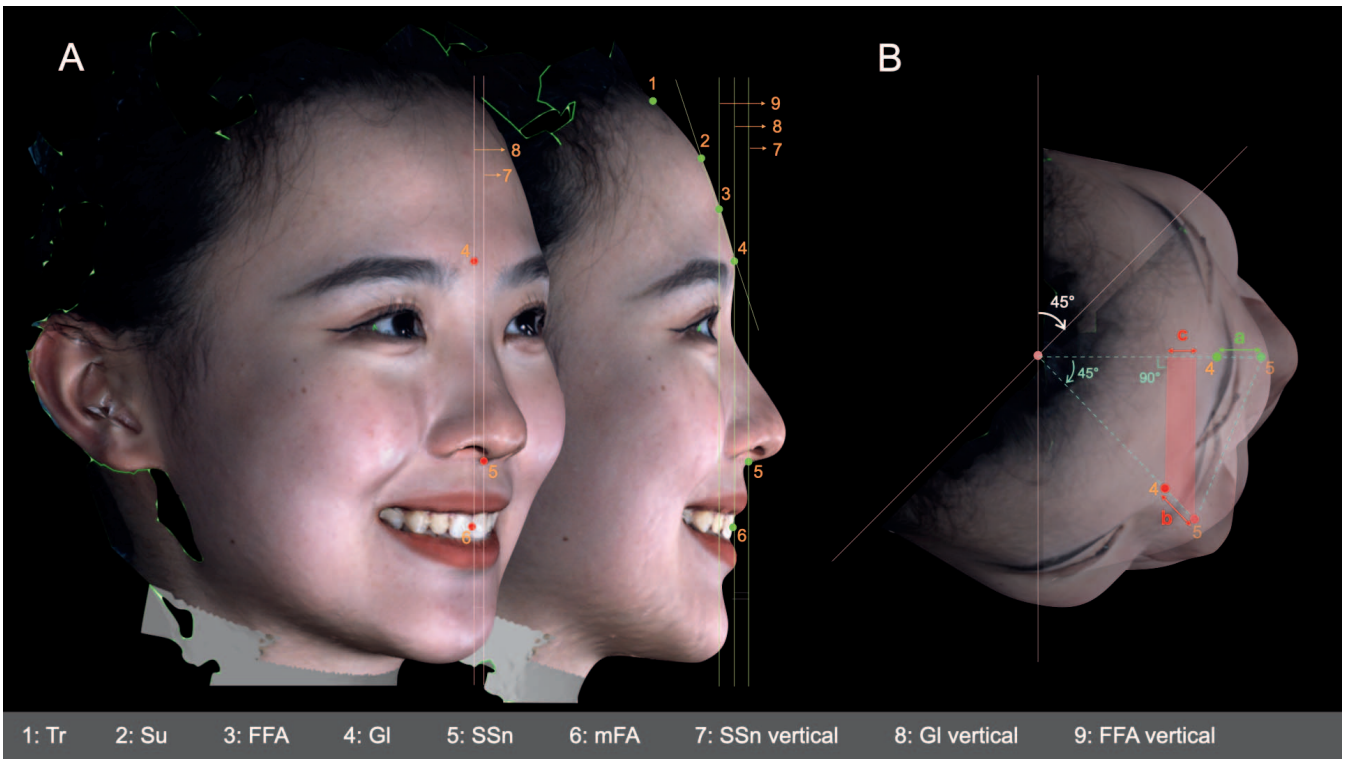


**Figure 2.** Landmarks and reference lines. (A) A 3D facial image example of the subjects of the study sample (shown in 45°- and 90°-angled views). (B) Mathematical correlations of the measurements of distances in the 45°- and 90°-angled views. Distance "a": the SSn-Glabella horizontal distance in the 90°-angled profile view. Distance "b": the 90°-angled profile rotated 45° to the front with the SSn-Glabella distance marked. Distance "c": the SSn-Glabella horizontal distance in the 45°-angled facial view. The value of distance "a" equals distance "b," and the value of distance "c" is approximately 0.7 × distance "a."

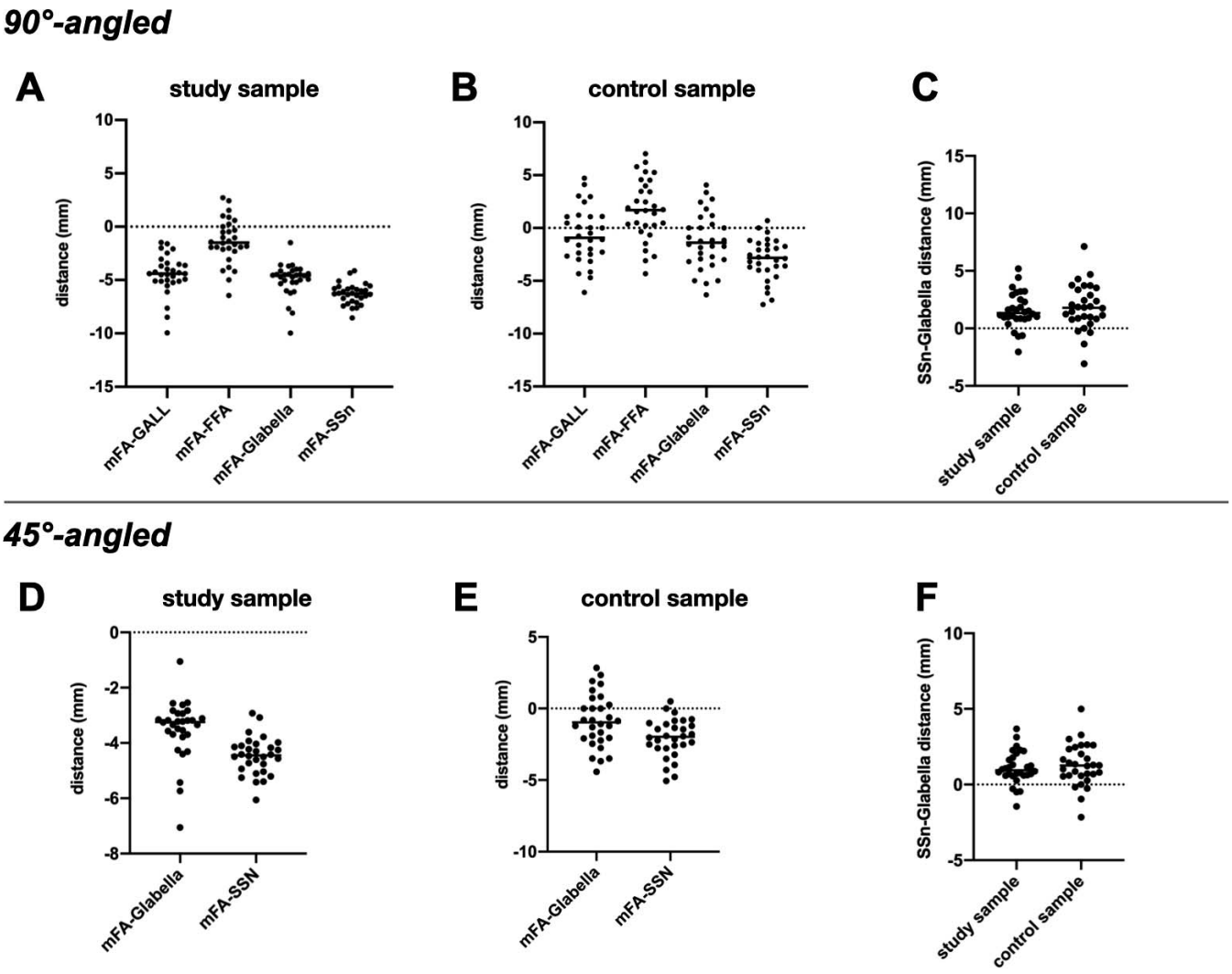


**Figure 3.** The anteroposterior relationship of U1 to the upper- and midfacial soft tissue landmarks in profile views. The anteroposterior positions of the U1 relative to facial landmarks were measured as mFA-FFA, mFA-GALL, mFA-Glabella, and mFA-SSn horizontal distances in 90°-angled smiling profiles of the study (A) and control (B) (B) and in 45°-angled views of the study (D) and control (E) samples. The anteroposterior positions of SSn relative to Glabella were measured as SSn-Glabella distances in the 90°-angled (C) or 45°-angled (F) views. Data are presented as individual scatter points. A positive value is assigned when the mFA point of U1 was anterior to the reference line or when the SSn point was anterior to Glabella.

## RESULTS

### Interindividual Consistency and Esthetic Sensitivity of mFA-Glabella and mFA-SSn Distances in Determining U1 Positions

The esthetic superiority of the study sample compared to the control sample was validated by the survey, in which all photos of the study sample were given significantly higher scores than were photos within the control sample ($P < .05$, study vs control: average score = 8.46 vs 5.31), with consistency between genders of the raters ($P > .05$). Significant differences ($P < .05$) were found in mFA–goal anterior limit line (GALL), mFA–midpoint of the clinical forehead (FFA), mFA-Glabella, and mFA-SSn distances between samples (Figure 3; Table 2). For the 90°-angled profile views of the study sample, the distributions of mFA-Glabella and mFA-SSn distances had narrower ranges and smaller standard deviations than did those of the mFA-GALL and mFA-FFA distances. In the 45°-angled views, the values of mFA-Glabella and mFA-SSn distances of the study sample were distributed with smaller standard deviations than were noted with the control sample. These results suggested mFA-Glabella and mFA-SSn distances to be esthetic-essential parameters in determining facial harmony for female profiles.


**Figure 4.** Variable assignments and image processing. Image modifications of the 90°-angled (A, images of series 1) and 45°-angled (B, images of series 2) smiling profiles were based on the combination of two independent variables: SSn-Glabella (a) and mFA-SSn distance (b). A positive value is when the SSn point was anterior to the Glabella or mFA point. The original images are framed in green.

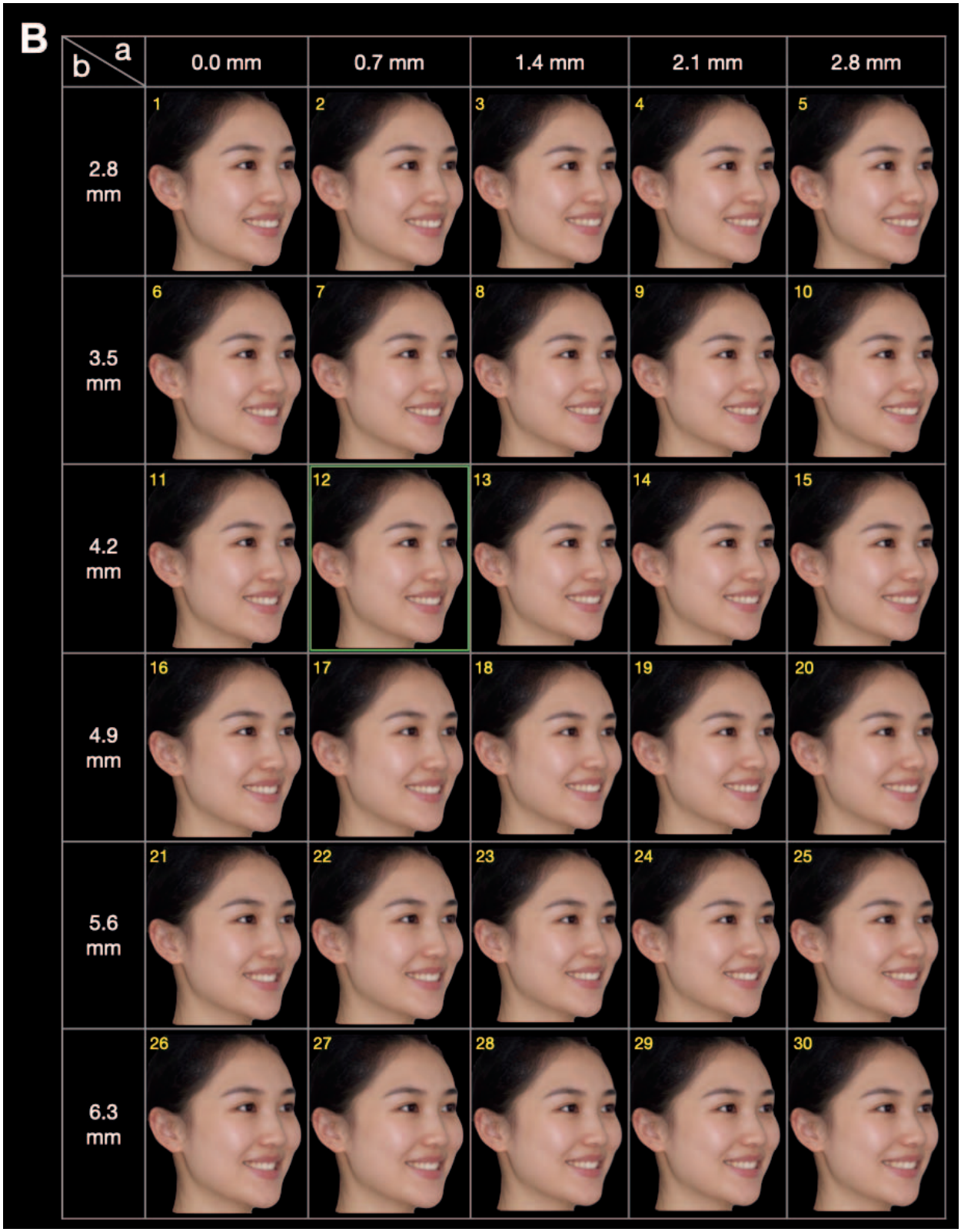


**Figure 4.** Continued

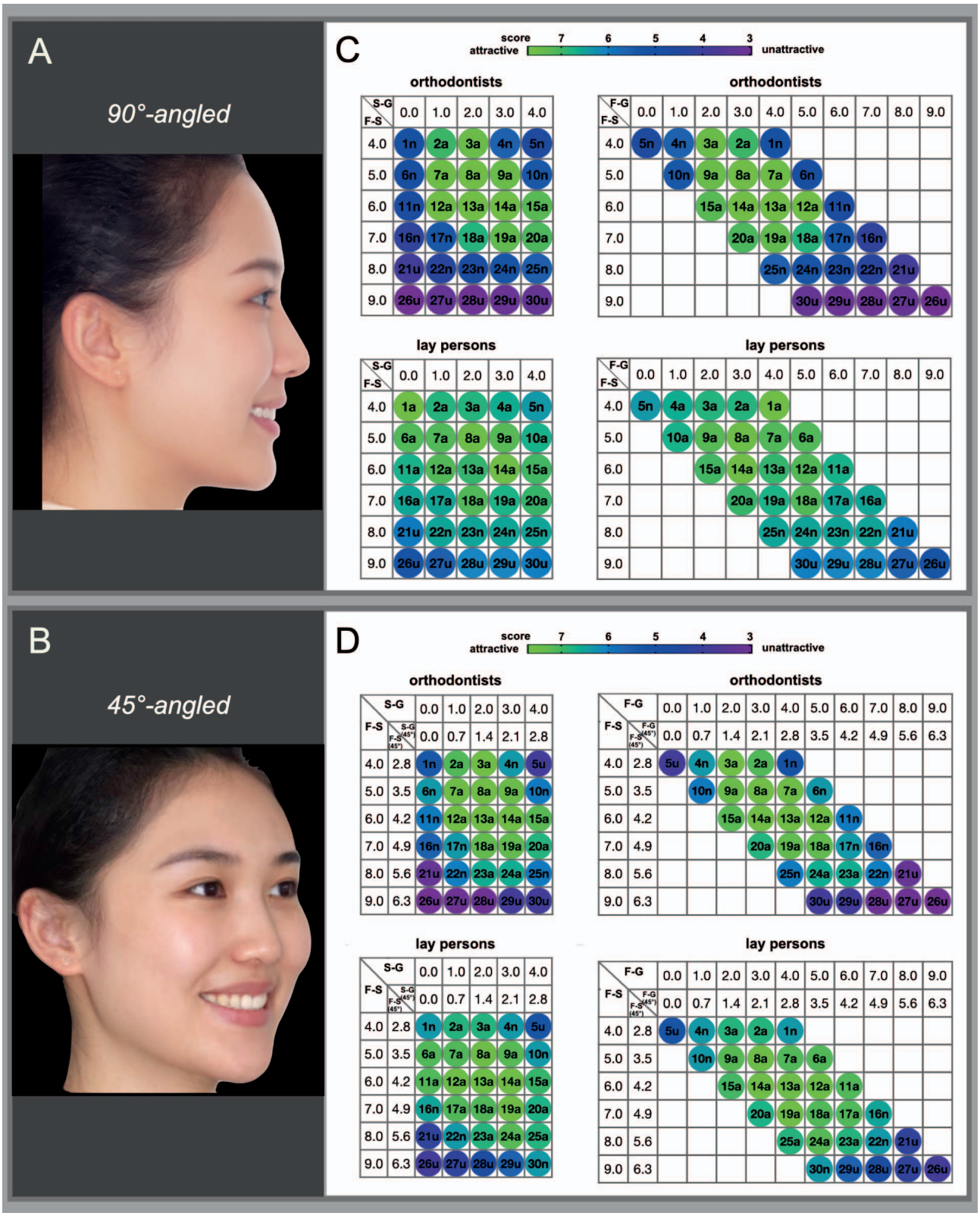


**Figure 5.** Esthetic assessments for the smiling profiles. Images of the 90°-angled (A) and 45°-angled (B) profiles representing Asian females with well-balanced facial features. A table was constructed to show the esthetic ratings for each image with specific variable assignments, for the 90°-angled (C, series 1) or 45°-angled (D, series 2) facial views rated by each group of raters. With the number of images and the esthetic grade marked, each dot carries a color that reflected the level of the esthetic score. S-G indicates SSn-Glabella; F-S, mFA-SSn; F-G, and mFA-Glabella distances measured in 90°-angled profiles. S-G (45°) indicates SSn-Glabella; F-S(45°), mFA-SSn; and F-G(45°), mFA-Glabella distances measured in 45°-angled profiles. A positive value occurs when the mFA point of the central incisor is posterior to the Glabella or SSn vertical or when the Glabella is posterior to the SSn point.

**Table 2.** Descriptive Statistics of the Measurements, Shown as Mean ± Standard Deviation (SD) and Interquartile Range (IQR), for the Study Sample and Control Sample[a]

| | Study Sample, mm | | Control Sample, mm | |
|---|---|---|---|---|
| | Mean ± SD | IQR | Mean ± SD | IQR |
| 90°-angled views | | | | |
| mFA-GALL | −4.48 ± 1.87 | 1.61 | −0.70 ± 2.65 | 3.62 |
| mFA-FFA | −1.35 ± 2.10 | 2.22 | 1.74 ± 2.89 | 4.02 |
| mFA-Glabella | −4.97 ± 1.54 | 1.10 | −1.25 ± 2.64 | 3.55 |
| mFA-SSn | −6.31 ± 0.96 | 1.23 | −2.96 ± 1.94 | 2.50 |
| forehead inclination, ° | 13.10 ± 2.06 | 2.55 | 12.79 ± 3.01 | 3.17 |
| 45°-angled views | | | | |
| mFA-Glabella | −3.51 ± 1.09 | 0.78 | −0.88 ± 1.85 | 2.48 |
| mFA-SSn | −4.46 ± 0.68 | 0.87 | −2.07 ± 1.35 | 1.82 |

[a] See Table 1 for view definitions.

### Forehead Inclination Correlated Weakly with Anteroposterior Spatial Relations of the mFA Point to Upper- and Midfacial Landmarks

There was no significant difference in forehead inclination ($P > .05$) between the control and study samples. The forehead inclination did not significantly correlate ($P > .05$; $r \leq 0.28$) with mFA-GALL, mFA-Glabella, or mFA-SSn distances in the profiles of the control and study samples. There were weak correlations ($P < .05$; $r = 0.38$) between forehead inclination and mFA-FFA distance for the study sample and moderate ($P < .05$; $r = 0.52$) correlations for the control sample. These results suggested that forehead inclination had no significant effect on spatial harmony of anteroposterior positions of U1 with Glabella and SSn point.

### Smile Esthetics Determined by Coupled Parameters of the mFA-Glabella and mFA-SSn Distances

Excellent intraobserver reliability was demonstrated for orthodontists (ICC, 0.761–0.856) and laypersons (ICC, 0.754–0.849). There was no significant difference ($P > .05$) between esthetic assessments by males and females. The orthodontists and laypersons differed significantly ($P < .05$). According to the esthetic assessments, the 30 images of each series were divided into three grades: "attractive" (grade "a"), "neutral" (grade "n"), and "unattractive" (grade "u"), according to Sidak's multiple comparisons (Figure 5). Each image in grade "a" had a significantly higher ($P < .05$) score than did all of the images in grade "u". Images in grade "n" had scores that were neither significantly lower than the images in grade "a" nor higher than the images in grade "u."

There were different grades of esthetics ($P < .05$) for images with the same mFA-Glabella but varying mFA-SSn, indicating that relying solely on either one of the two measurements would not necessarily lead to good facial esthetics (Figure 5). Optimal esthetics in a 90°-angled profile were achieved when the mFA-Glabella was 1 to 7 mm and, concomitantly, when the mFA-SSn was 4 to 7 mm, as perceived by laypersons. The esthetic range narrowed to 2 to 5 mm for mFA-Glabella, while staying unchanged for mFA-SSn, as perceived by orthodontists. Having an mFA-SSn of more than 8 mm would significantly compromise ($P < .05$) smiling profile esthetics, as rated by both orthodontists and laypersons.

### Smiling Facial Esthetics Perceived Differently in 45°-Angled Views than in 90°-Angled Profile Views

Perceived smiling facial esthetics in 45°-angled views followed a similar trend to that in 90°-angled views, with minor but noteworthy differences (Figure 5C compared with 5D). Having an mFA-Glabella of less than 0.7 mm led to significantly compromised smile esthetics ($P < .05$) at a 45°-angled facial view. In contrast, the negative effect on smile esthetics was less sensitively perceived in the 45°-angled view than in the 90°-angled view when the mFA-SSn was 5.6 mm and, concomitantly, the mFA-Glabella was 2.8 to 4.2 mm. Having an mFA-Glabella of more than 4.9 mm at a 45°-angled view compromised smile esthetics as much as perceived in the 90°-angled profile views.

### Determining Esthetically Optimal Anteroposterior U1 Position Using a Coupled-Lines System

The two sets of esthetic ranges for parameters in 90°- and 45°-angled profile views could be incorporated into one, as assessed in 90°-angled profiles, based on the mathematic correlations (Figure 2B). In view of that, by combining upper- and midfacial reference frames and incorporating the esthetic considerations for 45°- and 90°-angled facial profiles, a coupled-lines system (Figure 6) was developed to help determine the anteroposterior U1 position for smiling profile esthetics. For clinical use, two reference lines were constructed, first on the photo of a 90°-angled smiling profile, the Glabella vertical and the SSn vertical, with two scales attached posteriorly to these two lines. Carried on these scales were two bands indicating the esthetic ranges for mFA-Glabella (2 to 6 mm for laypersons and 2 to 5 mm for orthodontists) and mFA-SSn (4 to 7 mm) distances, respectively. Second, the overlapping area of the blue (or green) and the yellow bands (Figure 6) was identified. This area (red) indicated the esthetic goal for positioning the FA point of the U1.

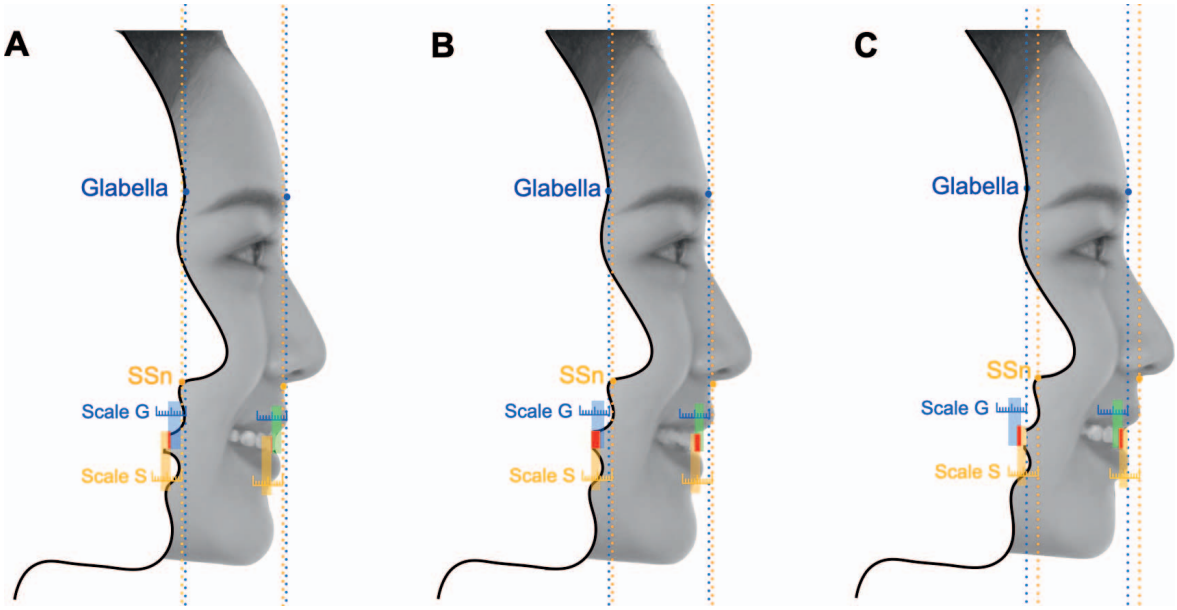


**Figure 6.** The coupled-lines system for determining the anteroposterior position of the U1 for smile esthetics. The coupled-lines system was constructed by two coupled scales indicating the horizontal distances posterior to the Glabella vertical (scale G), and to the SSn vertical (scale S), respectively. The bands marked on the scales indicate the esthetic ranges (blue: laypersons' judgments; green: orthodontists' judgments; yellow: judged consistently by laypersons and orthodontists). The overlapping area (red) is the esthetic goal for U1 positions. Examples are shown in the cases in which the SSn point was slightly posterior (A), slightly anterior (B), or remarkably anterior (C) to the Glabella vertical.

## DISCUSSION

In facial profiles of Asian females with pleasing appearances, the anteroposterior positions of U1 were not on or around GALL, as proposed by Andrews.[14] They were as far as 5 mm posterior to this line, with a variation range as wide as 8 mm. The definition of GALL was developed based on a strong correlation between forehead inclinations and FA-FFA distances observed in attractive Caucasian profiles.[14] The weak correlation between forehead inclinations and mFA-FFA distances observed in this study sample might indicate that GALL is not applicable for determining the esthetically pleasing incisor position for an Asian face.

The findings revealed a wide range of SSn-Glabella distances in the facial profiles of the study sample. Considering the esthetic sensitivity of the anteroposterior relations between SSn and lower facial soft tissue,[11] the great individual variability in SSn positions emphasized the importance of incorporating midfacial landmarks into the reference system when evaluating U1 positions. By using photos of natural individuals, with each possessing unique facial features and digitally modified images with variables controlled, it was revealed that both mFA-Glabella and mFA-SSn distances were esthetically sensitive in determining U1 positions.

It is noteworthy that having an SSn point more than 2 mm posterior or more than 5 mm anterior to the Glabella vertical would lead to total separation of the esthetic ranges of mFA-Glabella and mFA-SSn (no overlapping area). Failing to identify an esthetically optimal U1 position in these cases might indicate a compromised skeletal relationship. Interestingly, the acceptable range of −2 to 5 mm for the SSn-Glabella distances, indicated by the coupled scales based on the laypersons' judgments, was just where the mid- to upper-facial relationship varied in profiles of the study sample of Asian females. This range narrowed to −1 to 5 mm, as perceived by orthodontists. In this sense, the coupled-lines system could serve as an indicator of the acceptability of the maxilla position.

In this study, the dental-facial discrepancies were perceived differently in 45°-angled views than they were in 90°-angled views, especially when the subject had excessively protrusive or retrusive teeth.[7,8] The difference in perceived esthetics between 45°- and 90°-angled views might have resulted from different perceivability of anteroposterior disharmony between the incisors and the face. There was also a possibility that the 45°-angled views revealed some disharmony in the perioral region (eg, canine-to-lip spatial relations),[8] which was imperceivable when viewed from the 90°-angled profile. These phenomena suggest the necessity of incorporating the 45°-angled facial views in pre- and posttreatment recording, assessment, and planning.

Considering sexual dimorphism[15] and interethnic differences,[10–12] the reference ranges suggested by

this study should not be used as a universal guideline across diverse ethnic populations. Nevertheless, the coupled-lines system brought forward a new perspective that both upper- and midfacial soft tissue landmarks should be incorporated into the reference system for U1 positioning. By using coupled parameters, this reference system could be more applicable and reliable for faces with diverse morphology, even among patients of the same ethnic background.

## CONCLUSIONS

- The esthetically optimal anteroposterior position of the U1 was determined by being in harmony with the upper- and midfacial soft tissue landmarks, among which the most esthetically sensitive were the Glabella and SSn point for Asian females.
- The coupled-lines system could help determine the anteroposterior position of the U1 for an esthetic smiling profile.

## ACKNOWLEDGMENT

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