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Customized planning of the visible maxillary arch width in harmony with interparopia width and smile width for female facial esthetics

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Authors' contributions

Xianrui Yang was responsible for the literature search, image collection, image modification, questionnaire construction, and writing of the original draft. Roberto Justus contributed to the conceptualization, methodology, and editing of the manuscript. Bin Li and Chaoran Xue performed the data collection, data analysis, and interpretation. Ding Bai and Xianglong Han contributed to the conceptualization, validation, funding acquisition, and project administration. Hui Xu conceived the idea for the study and participated in the study design, methodology, image processing, data interpretation and visualization, writing and editing of the manuscript. All authors read and approved the final manuscript.

Conflict of interest

All authors claim that there is no conflict of interest.

Data Availability Statement

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The data supporting the findings of this study are available in the article and online supplementary materials. The data that compromise research participant privacy/consent are not publicly available. Data are available via reasonable request to the corresponding author.

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Abstract

Background

The visible maxillary arch width (VAW) is an important esthetic-determining feature. To date, there is no well-established methodology to determine the esthetically optimal VAW in customized treatment planning.

Methods

In this study, the common traits of the dentofacial configuration were investigated in most attractive Asian and Caucasian female smiles. The smiling photo of a subject was digitally modified based on combined variations of VAW, smile width (SW), transverse facial dimensions (TFD), and vertical facial dimensions. These modified photos were assessed for esthetics. The esthetically essential parameters were identified, and their mathematic correlations and reference ranges were determined for different vertical facial patterns. Using the obtained results, a mathematic guidance was constructed for customized smile designing. The applicability of this guidance was tested in Asian females.

Results

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The most attractive Asian and Caucasian female smiles have intraracial and interracial commonalities in the VAW-to-TFD ratios. The interparopia width (IPD) predominated over facial widths in determining well-matched VAW and SW. For optimal smile esthetics, the VAW and SW were correlated as simulated by the formula $1.92IPD \leq VAW + 2.3SW \leq 2.17IPD$, plus the VAW-to-IPD ratio within 0.54-to-0.62 and the SW-to-IPD ratio within 0.61-to-0.71, ranges tailored to vertical facial patterns. This constitutes a mathematic guidance for customized planning of the esthetically optimal VAW. This guidance was preliminarily validated to be applicable to Asian females.

Conclusions

The VAW-to-TFD ratios were essential for Caucasian and Asian female smile esthetics. The mathematic guidance could serve as a reference for customized smile design for Asian females.

Keywords

Esthetics; Smiling; Face; Dental Arch

Background

The visible maxillary arch width (VAW) is one of the most important features in perceived smile esthetics,[1-3] and is subject to anteroposterior or transverse movements of teeth in orthodontic treatment and/or orthognathic surgeries. In other words, esthetic considerations of the VAW have an impact on clinical decision-making (e.g., how much anteroposterior or transverse movement should be planned for a given tooth). Currently, the most frequently used reference to determine an esthetically pleasing arch width is the buccal corridor space.[4-11] However, there is no consensus on the degree to which the buccal corridor affects smile esthetics,[4-11] neither is there

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an agreement on the ideal size of the buccal corridor for a given smile.[9,10] Current studies render rudimentary guidelines that there exists a wide range of buccal corridor sizes esthetically acceptable. Within this range, there is no well-established guide to determine how one smile suits one individual versus another. It is unknown how to determine the esthetically optimal VAW for an individual in customized treatment planning.

Aside from methodological differences, cultural and ethnic differences in previous studies [4-11], there might be other essential parameters yet to be established. Transverse parameters other than the buccal corridor may be crucial in determining esthetics but have been eluded in previous investigations. Smile characteristics should not be dissociated from other facial components, as its spatial relevance in the macro-, mini-, and even microesthetic assembly of facial elements affects the overall perception of esthetics.[12,13] Conducting smile analysis as an integral part of the overall facial analysis may help reveal the essential parameters that determine the individualized optimal VAW.

To date, researchers[1-7] have primarily limited their observations to the perioral area and have not yet addressed how oral components coordinate with facial structures. Evidence is scarce regarding the transverse components of a smile and its integration in full facial analysis. There have been a few published studies on full face analysis, however, those studies did not address the VAW.[14-18]

This study aims to identify the essential parameters for determining the optimal VAW for female smile esthetics in full-face frontal views. We tested the hypotheses that the VAW was highly harmonized with its surrounding soft tissue and with facial structures in the transverse dimension for an attractive smile, and that this harmonization could be mathematically quantified to establish a guidance for customized smile designing.

Methods

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This study was approved by the Ethics Committee of West China Hospital of Stomatology (WCHSIRB-D-2021-221). The workflow of this study was illustrated in Figure 1.

Part. 1 - Identification of the essential parameters

This part of the study investigates the common traits of the transverse smile dimension in most attractive Asian (Group A) and Caucasian (Group B) female smiles.

In 2020, an internet search was conducted using the words: "beautiful Asian actress smiles", "beautiful Asian female model smiles", "beautiful Caucasian actress smiles", and "beautiful Caucasian female model smiles". The smiles of 120 women were collected. A second search was conducted to obtain photos of these 120 women that met the following criteria: full face, frontal view, broad smile, and high-resolution image. Full-facial frontal photos of 30 ordinary Asian females (randomly selected from students in medical schools, age of 25.3±2.7 years, Group C) were taken in natural head positions. A total of 150 photos were collected.

The attractiveness of the above 150 photos was rated in an online survey by 100 laypersons (25 Asian females, 25 Asian males, 25 Caucasian females, and 25 Caucasian males, age of 27.6± 3.5 years) using a 0-10 visual analog scale (VAS, 0 being least attractive and 10 being most attractive). The 150 photos were ranked in descending order according to the esthetic scores. The top 30 photos among the Asian females were selected to be Group A, and the top 30 photos among the Caucasian females were selected to be Group B. Each photo in Group A and B received a significantly higher score than all the photos in Group C. A composite image was obtained by digital averaging and morphing of the photos in Group A or B using FantaMorph software (5.6.2 Deluxe. Abrosoft Co. Beijing, China), representative of the most attractive Asian or Caucasian female smiles (Figure 2).

With landmarks located and measurements made (illustrated in Figure 3A), each photo in Group A and B was analyzed by the same investigator with Adobe Photoshop software (CC2018, Adobe Systems Inc., San Jose, CA).

Part. 2 – Revealing the mathematic correlations and esthetic ranges of the essential parameters

This part of the study examines different parameters that have an effect on perceived smile attractiveness and investigates the esthetic ranges and mathematic correlations of those parameters.

Subject selection

An Asian female with an agreed-on beautiful smile was selected as the subject with informed consent. The eligibility criteria was described in Supplementary material.

Digital image processing

A full-facial frontal photo (the original photo, Supplemental Figure 1A) was taken by a digital camera (EOS 80D; Canon Japan, Tokyo, Japan) with the subject in full posed smile in a natural head position. A three-dimensional digital dental model was obtained by intraoral scanning using 3Shape software (3Shape TRIOS, Copenhagen, Denmark). The original photo was modified into 25 variations using Adobe Photoshop software based on combinations of two independent variables: the ratio of VAW to interparopia width (VAW/IPD) and the ratio of VAW to smile width (VAW/SW), both varying in 4% increments (Supplemental Figure 1B). This resulted in 25 new images that differed in combined variations of VAW and smile width (SW). One image was deleted due to unrealistically over-wide SW. The method of photographic modification was described in detail in Supplementary material. A total of 25 photos (Series 1, 24 modified photos plus the original one) were created (Supplemental Figure 1 A, E) and arranged in a randomized order for the esthetic rating.

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Esthetic rating

For a statistical power of 90% and α level of 0.05, based on a standard deviation of a 12% VAS difference in a pilot study, a sample size of 57 raters per group was necessary to demonstrate a 10% difference on the VAS. A group of orthodontists (n=60, Asian, 30 females and 30 males, age of 30.3±4.5 years, professional experience of 4.47±2.09 years) and a group of laypersons (n=60, Asian, 30 females and 30 males, age of 29.3± 4.6 years) rated the attractiveness of each image on a 0-10 VAS (0 being least attractive and 10 being most attractive). Raters were asked to make a second evaluation of the images in a different random sequence with an interval of 2 weeks. The mean scores of the two evaluations were used for statistical analysis.

Statistics

Data analysis was performed using GraphPad Prism software (GraphPad Software Inc., San Diego, CA) and SPSS software (version 25.0, SPSS Inc., Chicago, IL). The intra-observer reliability was determined by intraclass correlation coefficient (ICC). Comparisons of scores between groups were performed using one-way ANOVA. Sidak's multiple comparisons were used to assess how the judges rated between photos. $P < 0.05$ was considered statistically significant.

Part. 3 – Identifying the predominant parameters & Tailoring their esthetic ranges to different vertical facial patterns.

To further investigate which of the transverse facial dimensions（TFD）had a predominant effect in determining the well-matched transverse smile dimension for facial esthetics, we selected the photos in which the SW/IPD ratio ranged from 0.58-0.81 and made additional modifications (Supplemental Figure 2). We decreased the lower-face width (Lf) for each of these photos to the same extent, thus producing varied VAW/Lf ratios within a range of 0.38-0.49. This resulted in 17 images plus the

former 17 ones, a total of 34 images (Series 2, Supplemental Figure 2). Analogously, images of Series 3 were created by increasing the mid-face width (Mf) to produce varied VAW/Mf ratios within a range of 0.32-0.43 (Supplemental Figure 3).

To further access the esthetic ranges of the essential parameters among different vertical facial types, the photos in Series 1 were modified by altering the face height to create photos of brachyfacial type (Series 4, FI= 83%, supplemental Figure 4) and dolicofacial type (Series 5, FI= 91%, Supplemental Figure 5).

Esthetic rating and statistical analysis were performed as described in Part 2. The photos of Series 2, 3, 4, and 5 were rated in separate sessions.

Part. 4 – Constructing a mathematic guidance and testing it in smile designing for various individuals

In summary of Part. 1, 2, and 3, a mathematic guidance was constructed for customized planning of the esthetically optimal VAW. This part of the study investigates the mathematic guidance applied to various individuals in smile designing for facial esthetics.

The Asian females in Group C mentioned in Part. 1 were recruited as subjects. Photo taking and digital dental model construction were performed as described in Part. 2. For each subject, the facial index (FI) was calculated and the vertical facial pattern was identified, the maxillary dental arch was photographically modified to render the VAW/IPD ratio fitting into the range of attractiveness and the VAW harmonized with the SW in accord with the mathematic guidance (Image A), or to render the VAW/IPD ratio out of the range of acceptability by 5% (Image B). These modifications resulted in two images for each subject. The raters picked from the two images the more attractive one for each subject and the votes for each image were calculated. The difference in votes between Images A and B for each subject was analyzed by independent *t*-test.

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Results

Identification of the VAW-to-TFD ratios as the esthetically essential parameters for Asian and Caucasian female smiles.

The percentages of brachyfacial, mesofacial, and dolichofacial types in the subjects in Group A (attractive Asian faces) were 3.3%, 63.3%, 33.3%, respectively, and were 10%, 40%, 50% in the subjects in Group B (attractive Caucasian faces), respectively. These attractive female faces shared some common traits when viewed from the frontal in terms of transverse smile dimension. There were intraracial and interracial commonalities ($P > 0.05$) in the VAW-to-TFD ratios (including the VAW-to-IPD, VAW-to-Mf, and VAW-to-Lf ratios) in the most attractive smiles of Asian and Caucasian female faces, in contrast to remarkable individual variability and interracial difference ($P < 0.05$) in buccal corridor sizes (Supplemental Table 1, Figure 3B, C). These results indicated that the VAW-to-TFD ratios were more esthetically sensitive and interracially consistent than buccal corridor sizes in determining an attractive female smile.

Full-facial smile attractiveness was more profoundly affected by the VAW-to-TFD ratios rather than by buccal corridor sizes.

For the esthetic evaluation of the modified smile photos (Supplemental Figures 1, 2, 3, 4, and 5), no significant difference was found in judgments between genders ($P > 0.05$) in the pooled data of male and female raters that were used for analysis. By multiple comparisons between photos assessed by each group of raters, the photos were divided into grades on the criteria that no significant difference exists in scores within each grade ($P > 0.05$) and significant differences exist between grades ($P < 0.05$). The grades were numbered in alphabetical order in descending order of attractiveness. The photos of the top grade (Grade “a”) were regarded as esthetic optimal, and the top two grades (Grade “a” and “b”) as esthetically acceptable. Orthodontists and laypersons

showed similar tendencies in assessing smile attractiveness, with consistency in the esthetically optimal characteristics (Figure 4).

The photos having varied VAW-to-TFD ratios were rated widely differently ($P < 0.05$) even with the same VAW/SW ratio, while the photos having the optimal VAW-to-TFD ratios (Figure 4 A, B) were given similar scores ($P > 0.05$) even with a wide range of VAW/SW values. These results strengthened the esthetic sensitivity of the VAW-to-TFD ratios as revealed in measurements of the most attractive female smiles (Figure 3).

Negatively correlated VAW and SW plus proper ranges of the VAW-to-TFD and SW-to-TFD ratios were essential to frontal smile esthetics.

The digital modification for photos of Series 1 resulted in variations in VAW/SW ratios (buccal corridor sizes=1-VAW/SW), VAW-to-TFD ratios, and SW-to-TFD ratios. The esthetic range for any single one of these ratios did not necessarily determine an attractive face (Figure 4). On analysis of smile esthetics based on the variables VAW-to-TFD and SW-to-TFD ratios, an interesting phenomenon was found that the optimal smiles were located within a triangle area, and the ranges of esthetic acceptability were defined by two oblique lines (Figure 4 C). The correlation between VAW and SW was mathematically analyzed and simulated by a formula:

For esthetically optimal, $1.92IPD \leq VAW + 2.3SW \leq 2.17IPD$, with the VAW/IPD ratio within the range 0.54-to-0.62 and SW/IPD within 0.61-to-0.71, rated consistently by the orthodontists and laypersons.

For esthetically acceptable, $1.92IPD \leq VAW + 2.3SW \leq 2.17IPD$, with VAW/IPD within 0.50-to-0.62 and SW/IPD within 0.61-to-0.71, rated by the orthodontists; and $1.92IPD \leq VAW + 2.3SW \leq 2.23IPD$, with VAW/IPD within 0.50-to-0.62 and SW/IPD within 0.61-to-0.72, rated by the laypersons.

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These results indicated that on the premise that the VAW and SW were in proper proportional relations with the IPD, a narrow smile width should be matched with a wide dental arch and vice versa. These results supported our hypothesis and led us to further test among IPD, Mf, Lf which parameters had a predominant effect in determining a well-balanced transverse smile dimension.

The IPD predominated over facial widths in determining a well-matched transverse smile dimension.

For photos of Series 2 and 3 (Supplemental Figure 2, 3), there was no significant difference between orthodontists and laypersons in perceived esthetics ($P > 0.05$). The photos were divided into grades on the criteria mentioned above. The esthetic optimal corresponded to the top grade (Grade a) and esthetic acceptability corresponded to the top two grades (Grade a and b).

For a smile with a given VAW/IPD and SW/IPD value setting, variations in VAW/Lf ratios did not lead to a significant difference ($P > 0.05$) in smile esthetics (Figure 5 B). In contrast, smile photos with distinct VAW/IPD ratios had a significant difference ($P < 0.05$) in perceived esthetics even with similar VAW/Lf and SW/Lf value settings, e.g., images No.17 vs 11#, No.12 vs 6#, No.5 vs 1#, No.23 vs 17# (Figure 5 C). These results indicate that the proportional relationship of transverse smile dimensions to IPD was more esthetically sensitive than to Lf. The formula and the ranges of optima or acceptability for the VAW/IPD and SW/IPD ratios obtained in Part. 2 are still applied in the cases of narrower Lf (Figure 5 B).

The smile photos sharing the same VAW/IPD and SW/IPD value setting were rated similarly ($P > 0.05$) even with distinct VAW/Mf ratios (Figure 5 E). In contrast, photos with distinct VAW/IPD ratios were rated widely differently ($P < 0.05$) even with similar VAW/Mf and SW/Mf value settings, e.g., images No.5 vs 8*, No.18 vs 19*, No.13 vs 14* (Figure 5 F). These results indicated that the ratios of transverse smile dimensions to IPD had a more profound effect on smile esthetics than to Mf.

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The formula and the ranges of optima and acceptability for the VAW/IPD and SW/IPD ratios obtained in Part. 2 are still applied in the cases of wider Mf (Figure 5 E), with the exception that image No. 6* was excluded out of the range of acceptability, suggesting less tolerance for narrow arches in the presence of a narrow SW.

Tailoring the esthetic ranges of the VAW-to-IPD and SW-to-IPD ratios to different vertical facial patterns for smile esthetics.

By multiple comparisons between photos in Series 4 or 5 assessed by each group of raters, smile esthetics was divided into grades and the esthetic ranges were defined on the criteria described above.

For the brachyfacial pattern, the acceptability range for the SW/IPD ratio shifted slightly towards lower values than in mesofacial pattern, while the acceptability range for the VAW/IPD ratio stayed unchanged compared to mesofacial types (Figure 6 C). Note that the range of optima for the VAW/IPD ratio narrowed to 0.50-to-0.54, rated by orthodontists and laypersons (Figure 6 C).

For dolicofacial pattern, the acceptability range for the SW/IPD ratio shifted slightly towards higher values than in mesofacial pattern, while the acceptability range for the VAW/IPD ratio stayed at 0.50-to-0.62 rated by orthodontists and widened to 0.50-to-0.66 rated by laypersons (Figure 6 F). The ranges of optima for the VAW/IPD and SW/IPD ratios were the same as that in mesofacial pattern and were perceived consistently between orthodontists and laypersons (Figure 6 F).

In summary of the above results, we proposed a mathematic guidance for customized planning of the optimal VAW for female smile esthetics: $1.92IPD \leq VAW + 2.3SW \leq 2.17IPD$ plus the VAW-to-IPD and SW-to-IPD ratios within esthetic ranges tailored to the vertical facial pattern.

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This mathematic guidance was preliminarily validated to be applicable to Asian female individuals.

The votes for Images A were significantly higher than for Images B (Supplemental Figure 6, $P < 0.05$), indicating improved facial esthetics by holding to the mathematic guidance. This was a preliminary validation of the applicability of the mathematic guidance to Asian female individuals for customized smile designing for facial esthetics.

Discussion

In contrast to achieving smile attractiveness by ideal buccal corridor sizes as previously proposed: buccal corridor size 16% by Ker [9], 10% and 5% by loi[10] and 2% by Moore [8], we found that smile esthetics was not primarily and solely determined by buccal corridor sizes. In our study, the photographic modification produced variations in buccal corridor sizes that fell into the classes of medium-narrow (22% buccal corridor), medium (15%), and medium-broad (10%) smiles [8]. Within this range, smiles with the same buccal corridor size were rated widely differently, depending on different proportional relations of the VAW and SW with the IPD. As small as 4% difference of the VAW/IPD or 1% difference of the SW/IPD ratio caused a significant difference in smile esthetics (Figure 4, 6).

In light of this study, rather than being determined by buccal corridor sizes, the esthetically optimal VAW was determined by proper VAW-to-IPD ratios and proper VAW-to-SW relations. Instead of being positively proportional to each other, the VAW and SW were negatively correlated as mathematically simulated by the formula $1.92IPD \leq VAW + 2.3SW \leq 2.17IPD$. Within the ranges of 8%-to-24% buccal corridor sizes and 61%-to-72% SW/IPD ratios, the wider the smile width is, the larger buccal corridor space it should be matched with, and vice versa. The VAW and SW are two components of transverse smile dimensions. Widening or narrowing of both of the components would exaggerate the visual effect of changes in the transverse dimension,

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while widening one of the two components would somewhat balance out the visual effect of narrowing the other. This visual effect lent support to the viewpoint that interactions among elements of facial structures might accentuate imbalance and determine the actual perception of a smile[20,21], and helped explain why the esthetically pleasing VAW-to-SW relation revealed in our study was different from or even conflicting with those observed in the localized oral region [4-10].

The VAW is not simply determined by arch width but should be based on comprehensive considerations including arch width, the anterior-posterior position of the maxillary dental arch, inclinations, rotations of posterior teeth, and perioral soft-tissue factors. Esthetic considerations of the VAW impact on clinical decision-making such as maxillary expansion or constriction, and extraction or non-extraction. In customized planning of the transverse smile dimension, it could be recommended that we first determine the esthetic range for the VAW according to proper VAW/IPD ratios, then within this range tailor the VAW to the SW according to the formula. This mathematic guidance can help determine the VAW best matched with the face. Note that the SW and IPD are two essential elements that the VAW is tailored to, representing harmonization of the dental arch with surrounding soft tissue and upper facial structures -- these are referred to as miniesthetics and macroesthetics [20]. In addition to proper VAW-to-SW relations, both VAW and SW should be in proper proportional relations with the IPD, lending support to the concept that a miniesthetic feature of the smile can be influenced by the macroesthetic feature of a face [21].

Interestingly, we demonstrated that IPD predominated over facial widths in determining a well-matched VAW. This phenomenon might have roots in underlying anthropological and morphological aspects.[22,23] The eyes and the mouth were the most important elements in a hierarchy of facial features for determining esthetics [3], and were the main subjects that human attention focuses on during social communication. The spatial relationship of them reasonably has a profound effect on

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facial harmony. Note that the esthetic range of the VAW-to-IPD ratio obtained by assessments of the digitally modified photos of one individual (Figure 4 C) was highly consistent with the range observed in most attractive Asian female faces (Figure 3 B). The esthetic range of this ratio was further validated to be applicable to ordinary Asian females in customized smile design.

Transverse smile dimensions interacted with vertical facial dimensions in esthetic perception. Our findings were in line with previous reports [12,22], and brought up new perspectives by revealing different esthetic sensitivity of the VAW- and SW-to-IPD ratios to changes in vertical facial dimensions. Narrow smiles were more tolerable while wide smiles were less tolerable in brachyfacial types than in mesofacial types (Figure 6 A-C). Moderately wide smiles resulted in acceptable esthetics in dolicofacial types (Figure 6 D-F). Although the ranges of acceptability were subject to different vertical facial patterns, the range of optimal SW-to-IPD ratios stayed unchanged, suggesting that the esthetically optimal SW-to-IPD relations hold stable regardless of variations in vertical facial pattern. In contrast, there was a narrower range of optimal VAW-to-IPD ratios in brachyfacial types than in mesofacial types. These findings indicated that the esthetically optimal VAW-to-IPD relations were more sensitive to changes in vertical facial types than optimal SW-to-IPD relations. The brachyfacial types might be pickier for the optimal VAW and need more caution in customized treatment planning.

Altered dental esthetics in transverse smile dimensions was perceived similarly between orthodontists and laypersons, while orthodontists tended to be more critical in detecting a small discrepancy [2,5,7,8,11,19]. This is reasonable because orthodontists' perception of dental esthetics might be shaped by professional training. Our study demonstrated that this phenomenon also existed in judgments of full-facial smile esthetics. In any one of the three vertical facial types, the orthodontists and laypersons had the same preference for the optimal VAW- and SW-to-IPD ratios, while the

orthodontists were more critical when identifying the acceptability ranges of these ratios (Figure 4 C, Figure 6 C, F).

The ethnic background of the subjects and raters in Part.2, 3, and 4 of this study limits the applicability of the mathematical guidance to Asian females. The measurements in most attractive Asian and Caucasian female smiles showed interracial commonalities in the VAW-to-TFD ratios and greater sensitivity of these ratios than buccal corridor sizes in determining smile esthetics, suggesting the importance of harmonization of transverse smile dimensions with facial structures. Further studies are of interest to reveal gender- or ethnic-specific characteristics. The mathematical guidance proposed in this study should be viewed not as a strict rule but as a guideline to help optimize treatment design.

Conclusions

The transverse smile dimensions were harmonized with the TFD for smile esthetics in Caucasian and Asian females. The mathematic guidance could serve as a reference for customized planning of the esthetically optimal VAW for Asian females.

Abbreviations

VAW visible maxillary arch width
SW smile width
TFD transverse facial dimension
IPD interparopia width
VAS visual analog scale
Lf lower-face width
Mf mid-face width
FI facial index

References

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1. Oliveira PLE, Motta A, Pithon M, Mucha J. Details of pleasing smiles. Int J Esthet Dent. 2018;13(4):494-514.

2. Al Taki A, Khalesi M, Shagmani M, Yahia I, Al Kaddah F. Perceptions of Altered Smile Esthetics: A Comparative Evaluation in Orthodontists, Dentists, and Laypersons. Int J Dent. 2016;(2016):7815274.

3. Parrini S, Rossini G, Castroflorio T, Fortini A, Deregibus A, Debernardi C. Laypeople's perceptions of frontal smile esthetics: A systematic review. Am J Orthod Dentofacial Orthop. 2016;150(5):740-750.

4. Martin AJ, Buschang PH, Boley JC, Taylor RW, McKinney TW. The impact of buccal corridors on smile attractiveness. Eur J Orthod. 2007; 29(5):530-537.

5. Roden-Johnson D, Gallerano R, English J . The effects of buccal corridor spaces and arch form on smile esthetics. Am J Orthod Dentofacial Orthop. 2005;127(3):343-350.

6. Mollabashi V, Abolvardi M, Akhlaghian M, Ghaffari MI. Evaluation of the effect of buccal corridor size on smile attractiveness. Eur J Esthet Dent. 2010;5(4):370-380.

7. Parekh SM, Fields HW, Beck M, Rosenstiel S. Attractiveness of variations in the smile arc and buccal corridor space as judged by orthodontists and laymen. Angle Orthod. 2006;76(4):557-563.

8. Moore T, Southard KA, Casko JS, Qian F, Southard TE. Buccal corridors and smile esthetics. Am J Orthod Dentofacial Orthop. 2005;127(2):208-213.

9. Ker AJ, Chan R, Fields HW, Beck M, Rosenstiel S. Esthetic and smile characteristics from the layperson’s perspective: a computer-based survey study. J Am Dent Assoc. 2008;139(10):1318-1327.

10. loi H, Nakata S, Counts AL. Effects of buccal corridors on smile esthetics in Japanese. Angle Orthod. 2009;79(4):628-633.

11. Ioi H, Kang S, Shimomura T, Kim S, Park S, Son W, Takahashi I. Effects of

Author Manuscript

buccal corridors on smile esthetics in Japanese and Korean orthodontists and orthodontic patients. Am J Orthod Dentofacial Orthop. 2012;142(4):459-465.

12. Ackerman MB. Buccal smile corridors. Am J Orthod Dentofacial Orthop. 2005; 127(5):528-529.

13. Brandão R.C.B, Brandão L.B.C. Finishing procedures in orthodontics: dental dimensions and proportions (microesthetics). Dental Press J Orthod. 2013;18:147-174.

14. Kini AY, Angadi GS. Biometric ratio in estimating widths of maxillary anterior teeth derived after correlating anthropometric measurements with dental measurements. Gerodontology. 2013;30(2):105-111.

15. Hasanreisoglu U, Kerem A, Icker A. An analysis of maxillary anterior teeth: facial and dental proportion. J Prosthet Dent. 2005;94(6):530–538.

16. Al Wazzan KA. The relationship between intercanthal dimension and the widths of maxillary anterior teeth. J Prosthet Dent. 2001;86(6):608–612.

17. Gomes VL, Gonc¸alves LC, Do Prado CJ, Junioi IL, De Lima BL. Correlation between facial measurements and the mesiodistal width of the maxillary anterior teeth. J Esthet Restor Dent. 2006;18(4):196–205.

18. Zhang K, Huang L, Yang L, Xu L, Xue C, Xiang Z, Zhao M, Li S, Bai Y, Bai D. Effects of transverse relationships between maxillary arch, mouth, and face on smile esthetics. Angle Orthod. 2016;86(1):135-141.

19. Mollabashi V, Abolvardi M, Akhlaghian M, Ghaffari MI. Smile attractiveness perception regarding buccal corridor size among different facial types. Dent Med Probl. 2018;55(3):305-312.

20. Sarver DM, Ackerman MB. Dynamic smile visualization and quantification and its impact on orthodontic diagnosis and treatment planning. In: The art of smile: integrating Prosthodontics, Orthodontics, Periodontics, Dental Technology and Plastic Surgery. Chicago: Quintessence. 2005;99-139.

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21. Ackerman MB, Ackerman JL. Smile analysis and design in the digital era. J Clin Orthod. 2002;36(4):221-236.

22. Rhodes G. The evolutionary psychology of facial beauty. Annu Rev Psychol. 2006;57:199-226.

23. Enquist M, Ghirlanda S. Evolutionary biology: The secrets of faces. Nature. 1998;394(6696):826-827.

Figure captions

Figure 1. The workflow and the main findings of this study.

Figure 2. Composite photos representing the most attractive Asian and Caucasian female smiles.

Figure 3. Dentofacial measurements in most attractive Asian and Caucasian female smiles.

(A) Landmarks and measurements in frontal smile photos. The VAW-to-SW and VAW-to-TFD ratios in most attractive Asian (B) and Caucasian (C) female smiles were presented as individual scatter points. These points were grouped into two clusters, corresponding to the individuals having 12 teeth (molar-to-molar) or 10 teeth (premolar-to-premolar) displayed when smiling, respectively.

Figure 4. Esthetic assessments of digitally modified smiles with combined variations of the VAW/IPD and VAW/SW ratios.

Descriptive statistics of the esthetic ratings for photos in Series 1 were displayed in a heat-map manner, with the color representing the means of the scores. Each photo was represented by a colored dot, with the photo number on it and a letter representing the esthetic grade (Grade ‘a’ being most attractive, ‘g’ being least

attractive). With the orthodontists' (A) or laypersons' (B) esthetic judgments marked on, the dots were arranged in a panel corresponding to their variable assignments (VAW-to-TFD and VAW/SW ratios). The combined variables of VAW-to-TFD and VAW/SW ratios caused variations in the SW-to-TFD ratios. To show the esthetic assessments in relation to the SW-to-TFD ratios, the dots were rearranged in another panel (C) according to the variable assignments. The range of optimal esthetics was outlined by a red dotted-line triangle, and the ranges of acceptability were divided by green dotted lines (C).

Figure 5. Esthetic assessments of digitally modified smiles with combined variations of transverse smile dimensions and facial widths.

The esthetic scores rated by the orthodontists for photos in Series 2 (A-C) and 3 (D-F) were displayed in a heat-map manner. Each photo was represented by a colored dot. On each dot, the figure and '#' represented the photo number, and the letter represented the esthetic grade ('a' being most attractive; 'b' being esthetically acceptable). The smile photos were modified based on combined variations of VAW/IPD, VAW/SW and VAW/Lf ratios (A), or on combined variations of VAW/IPD, VAW/SW and VAW/Mf ratios (D). The combined variables produced variations in SW/IPD and SW-to-facial width ratios. To show the esthetic assessments in relation to the SW/IPD (B) and SW/Lf (C) ratios, or in relation to the SW/IPD (E) and SW/Mf (F) ratios, the dots were rearranged in another two panels. The red dotted-line triangle indicated the range of optimal esthetics, and the green dotted lines indicated the ranges of acceptability (B, E).

Figure 6. Effects of varied transverse smile dimensions on perceived esthetics in different vertical facial patterns.

The esthetic ratings for photos in Series 4 (A-C) and 5 (D-F) were displayed in a heat-map manner. Variable assignments, panel constructions, information marking, and arrangements of the dots were presented in a manner analogous to those described

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in the captions for Figure 3. The red dotted-line triangle indicated the range of optimal esthetics, and the green dotted lines indicated the ranges of acceptability.

Supplemental Figure 1. Variable assignments and digital image processing of the smile photo of the subject

The original photo (A) of the female subject was designed into 24 variations (B), each based on a combination of two independent variables, the VAW/SW and VAW/IPD ratios. The altered VAW/IPD ratio caused concomitant alterations in VAW/Mf and VAW/Lf ratios. (C) According to the variable assignments, the maxillary posterior arch width was altered by virtual teeth alignment. (D) The alterations were transferred to the smile photos by photographic modifications. As above, 24 photos were produced and numbered (E). With the original photo numbered as No.5 (A), a total of 25 images were created for Series 1. The eyes of the subject were covered for privacy protection in publications but were shown during esthetic assessments.

Supplemental Figure 2.

The photos of Series 2 were created by maintaining or decreasing the lower-face width of the 17 photos selected from Series 1. Values of the variables assigned to each photo were shown in the table.

Supplemental Figure 3.

The photos of Series 3, created by maintaining or increasing the mid-face width of the 17 photos selected from Series 1. The values of the variables assigned to each photo were shown in the table.

Supplemental Figure 4.

The photos of Series 4 were obtained by altering the face height of the photos in Series 1 to create brachyfacial types (FI= 83%). The values of the variables assigned

to each photo were shown in the table.

Supplemental Figure 5.

The photos of Series 5, obtained by altering the face height of the photos in Series 1 to create dolicofacial types (FI= 91%). The values of the variables assigned to each photo were shown in the table.

Supplemental Figure 6. The votes for Images A and B were rated by the orthodontists and laypersons.

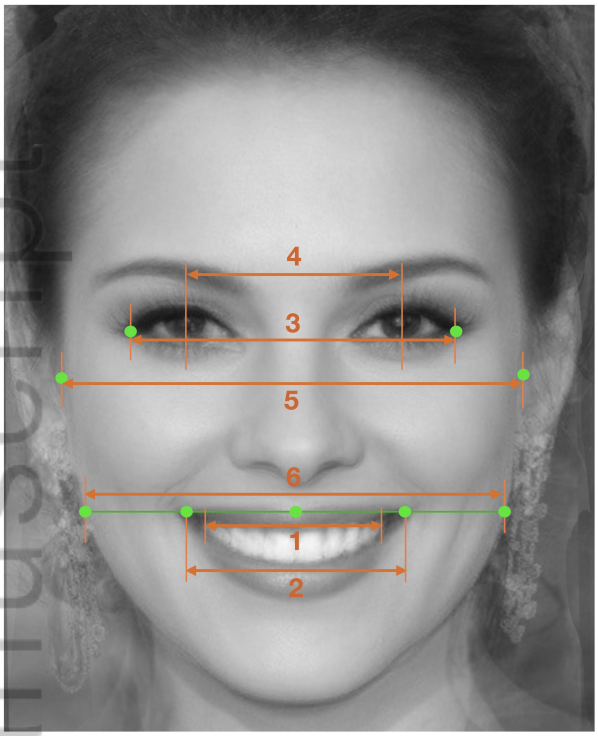
Smile photos of the 30 ordinary Asian females with different vertical facial patterns were photographically modified to conform with (Images A) or deviate from (Images B) the mathematic guidance. The votes for the more attractive one between Image A and B given by orthodontists (A) and laypersons (B) were presented for each subject.

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A



- ***Transverse smile dimensions***

1. Visible maxillary arch width (VAW): the horizontal distance between the most distal surfaces of the last visible maxillary posterior teeth from the left to the right sides
2. Smile width (SW): the horizontal distance between left and right cheilion when smiling

- ***Transverse facial dimensions*** **(*TFD*)**

3. Interparopia width (IPD): the horizontal distance from left to right exocanthion. The method is to first locate the exocanthion, i.e., the soft tissue point at the outer commissure of each eye fissure, then measure the horizontal distance beween the two.
4. Interpupillary distance (Pu): the horizontal distance between left and right pupil centers.
5. Mid-face width (Mf): the horizontal distance between the most lateral aspects of the left and right zygomatic arches.
6. Lower-face width (Lf): The facial width at the level of the oral commissures when smiling. The method is to first draw a line between the left and right oral commissures, then locate the mid-point of the line segment and draw a horizontal line across this mid-point. This horizontal line intersects with the contour of the lower face and makes two intersection points at the left and right side. The lower-face width was measured as the horizontal distance between these two intersection points.

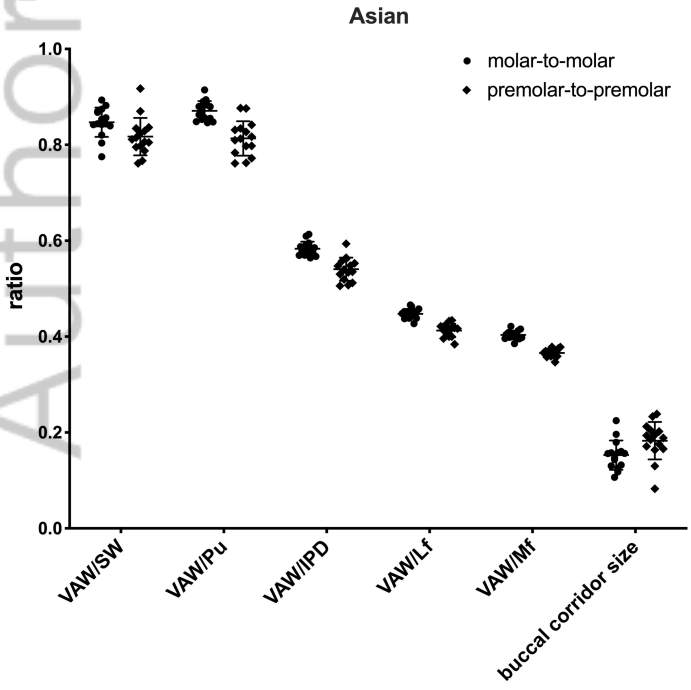
- ***Vertical facial dimension***

Facial height: the vertical distance between the soft tissue nasion and the soft tissue menton.

- ***Ratios***

Visible maxillary arch width / smile width (VAW/SW),
Visible maxillary arch width / interparopia width (VAW/IPD),
Visible maxillary arch width / interpupillary distance (VAW/Pu),
Visible maxillary arch width / mid-face width (VAW/Mf),
Visible maxillary arch width / lower-face width (VAW/Lf).
Facial index inter-zygomatic width divided by facial height[19].

B



C

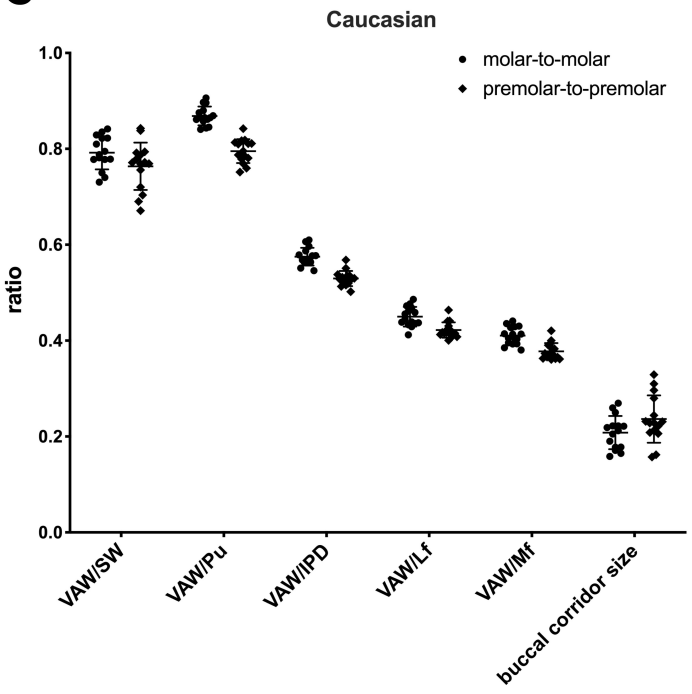


figure 3 reduced file size.jpeg

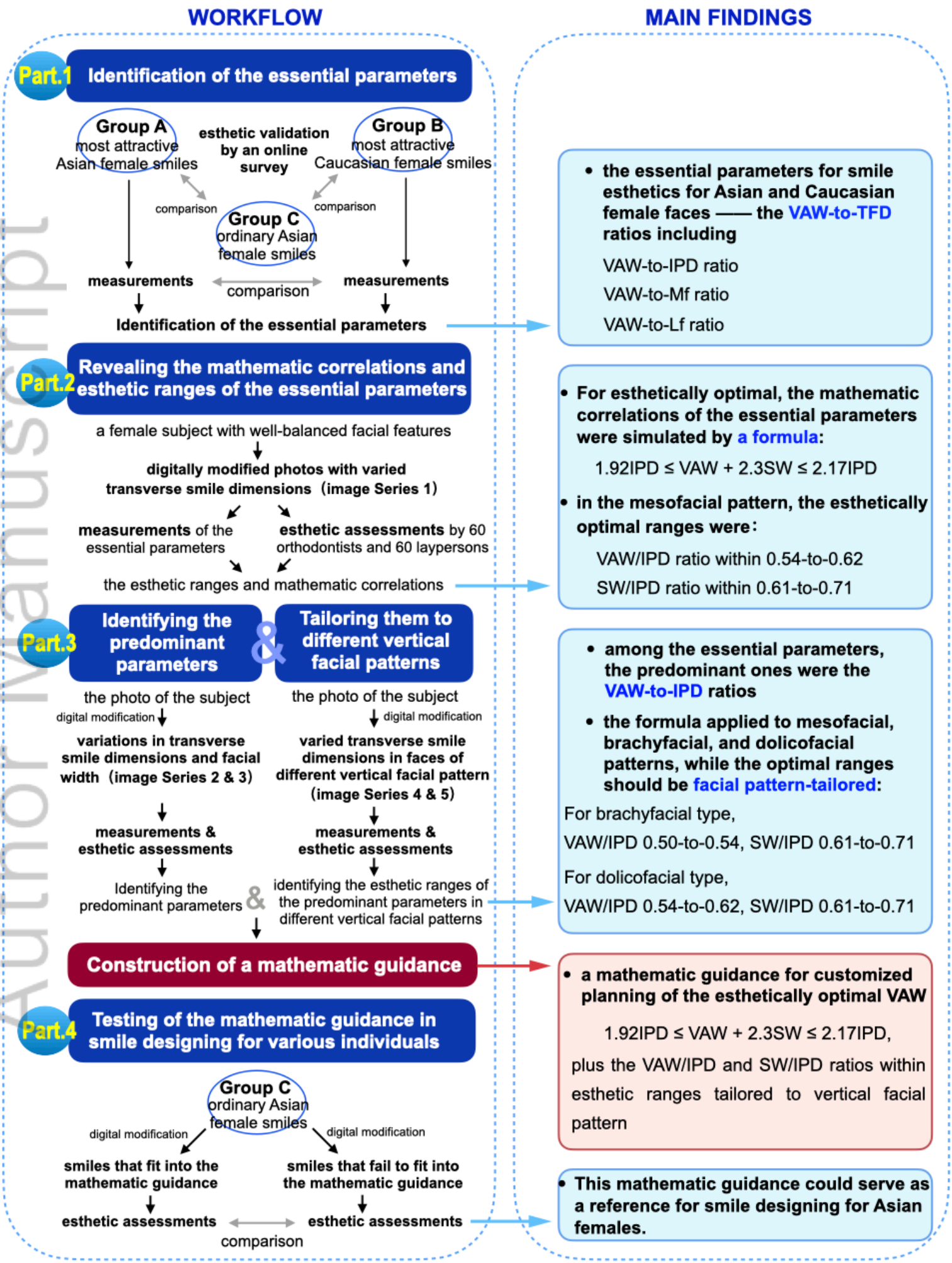


Figure 1.tiff

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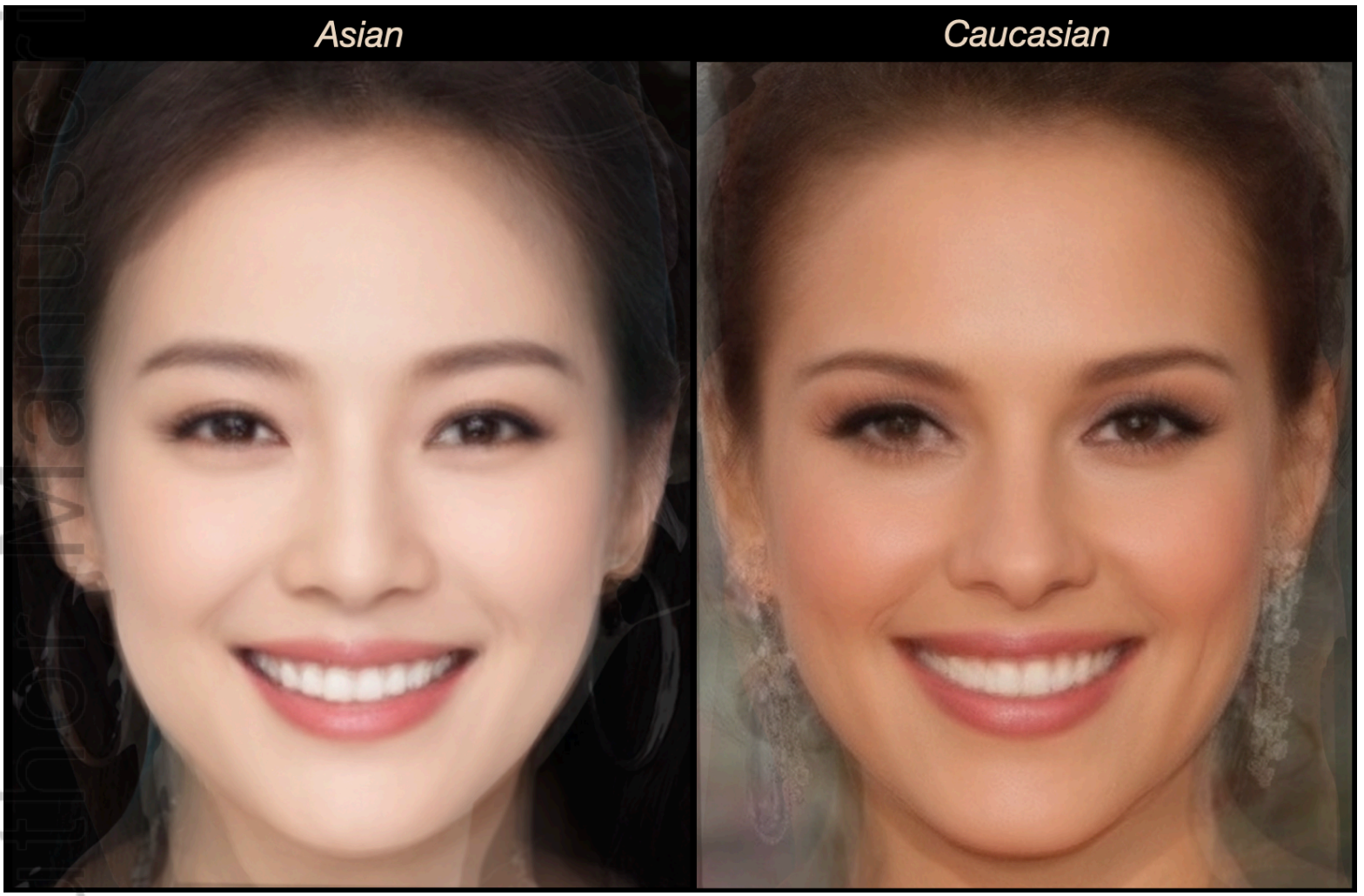


Figure 2.tiff

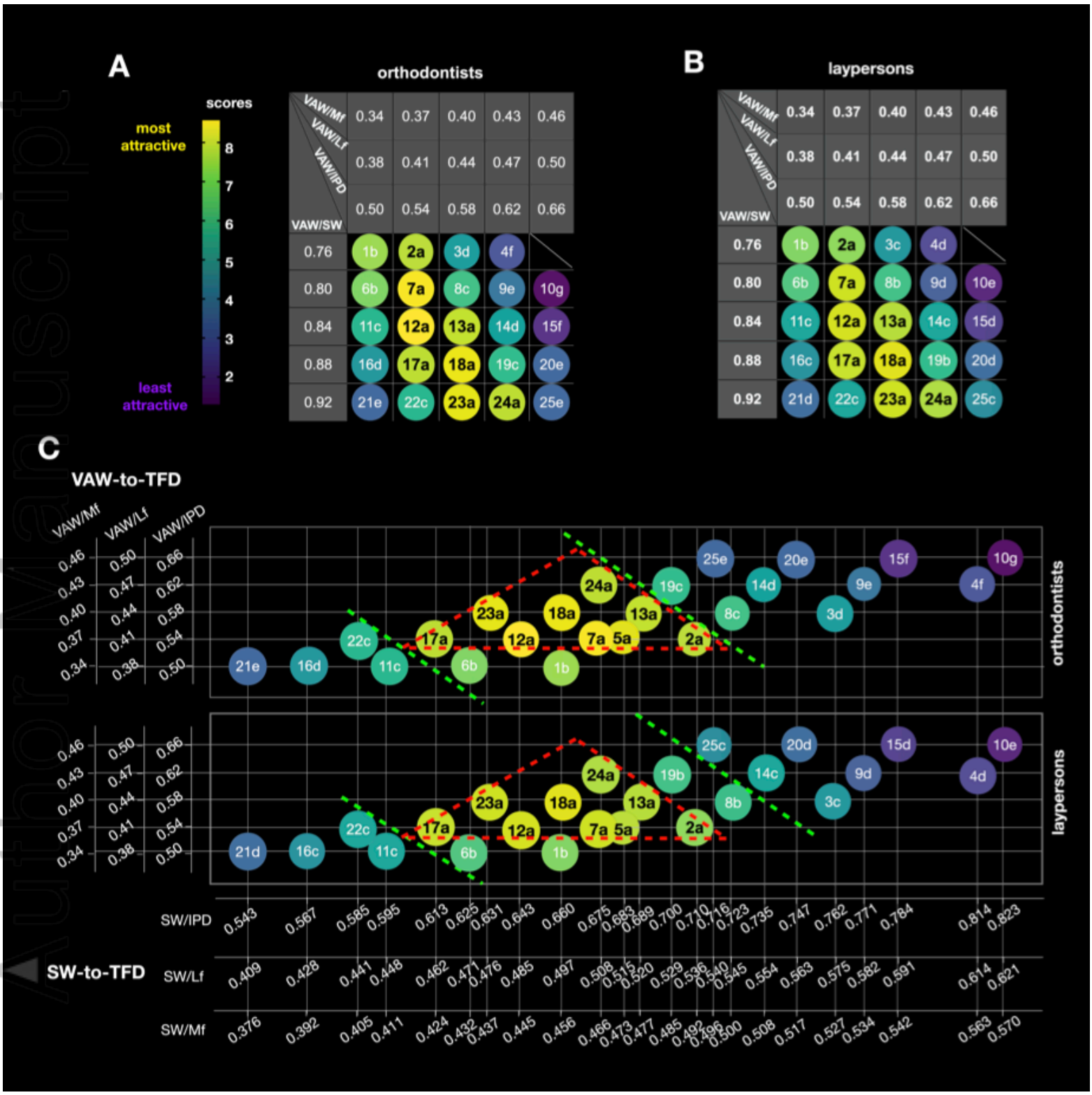
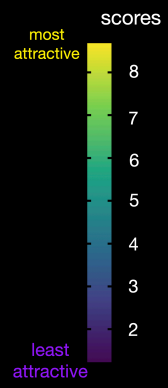


Figure.4.tiff

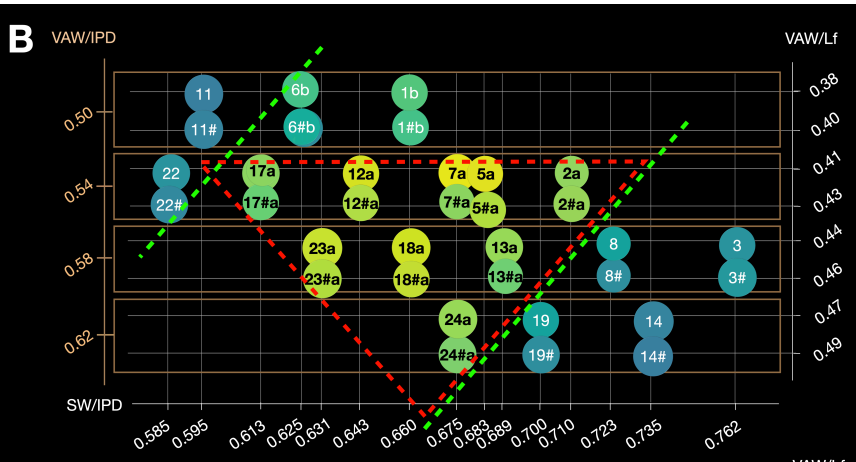
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A

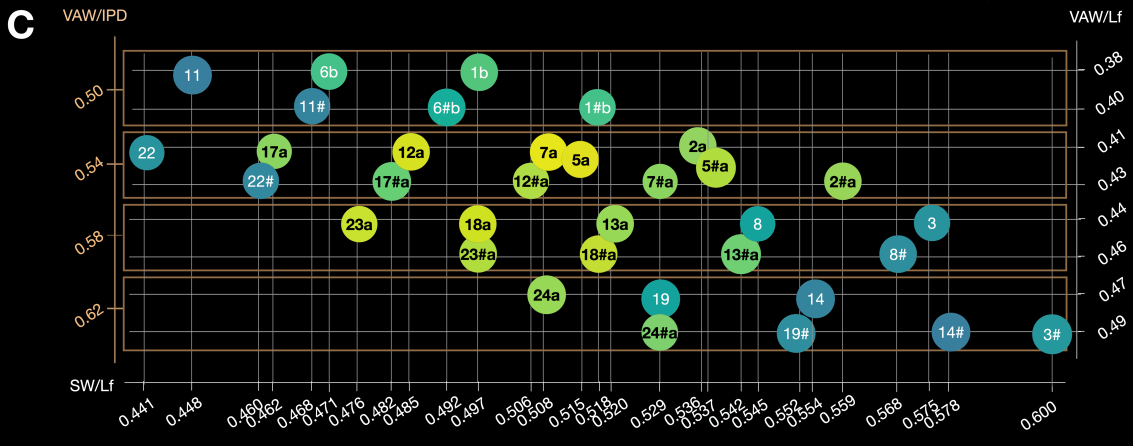
VAW/Lf / VAW/IPD / VAW/SW	0.38	0.40	0.41	0.43	0.44	0.46	0.47	0.49
	0.50	0.50	0.54	0.54	0.58	0.58	0.62	0.62
0.76	1b	1#b	2a	2#a	3	3#		
0.80	6b	6#b	7a	7#a	8	8#		
0.84	11	11#	12a	12#a	13a	13#a	14	14#
0.88			17a	17#a	18a	18#a	19	19#
0.92			22	22#	23a	23#a	24a	24#a



B

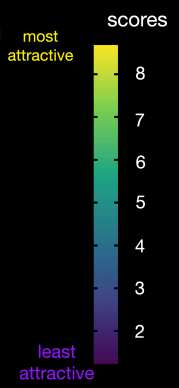


C

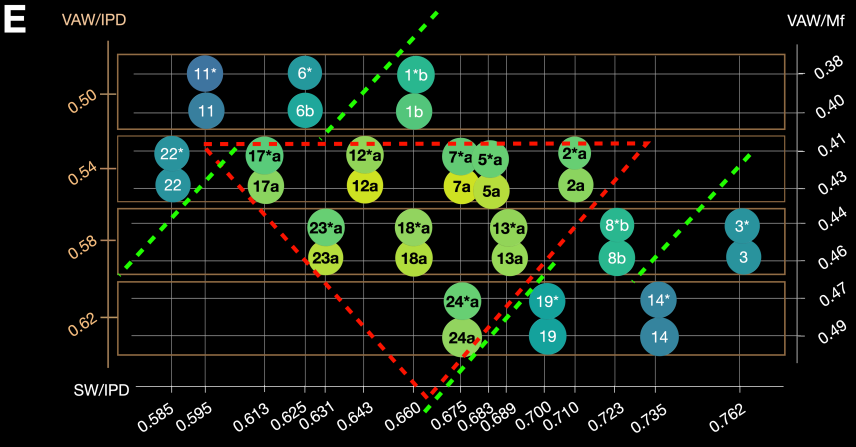


D

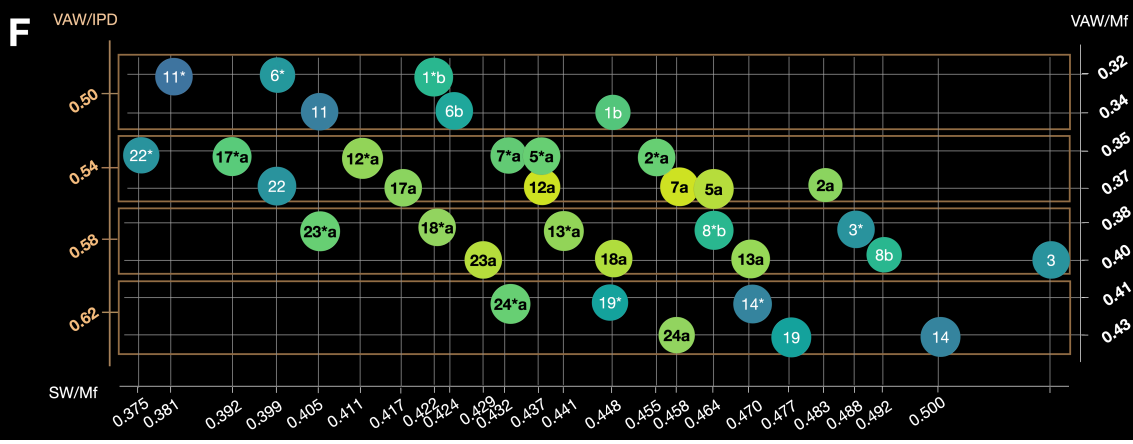
VAW/Mf / VAW/IPD / VAW/SW	0.34	0.32	0.37	0.35	0.40	0.38	0.43	0.41
	0.50	0.50	0.54	0.54	0.58	0.58	0.62	0.62
0.76	1b	1*b	2a	2*a	3	3*		
0.80	6b	6*	7a	7*a	8b	8*b		
0.84	11	11*	12a	12*a	13a	13*a	14	14*
0.88			17a	17*a	18a	18*a	19	19*
0.92			22	22*	23a	23*a	24a	24*a

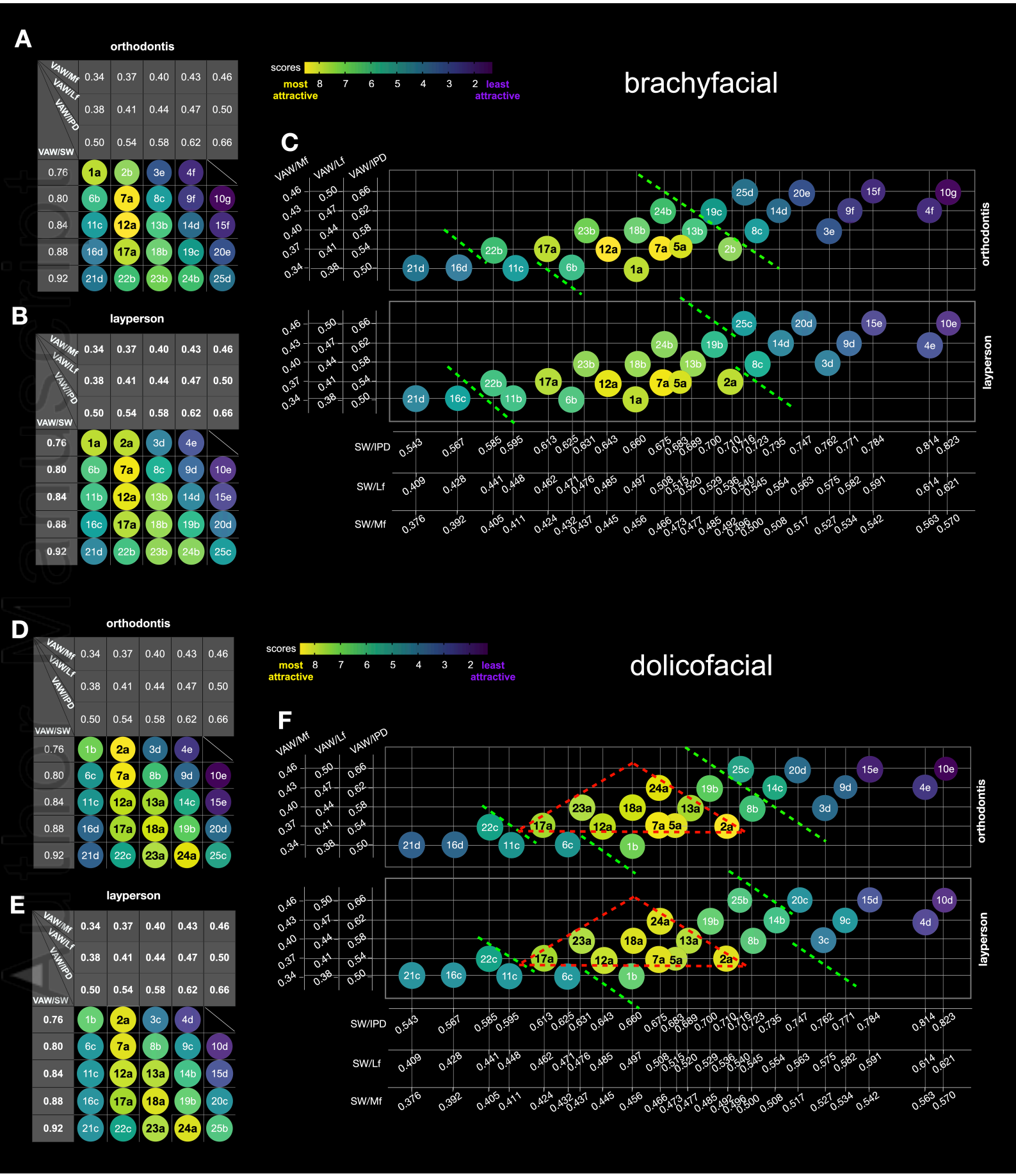


E



F




A
orthodontis
VAW/Mf
VAW/Lf
VAW/IPD
VAW/SW
0.34 0.37 0.40 0.43 0.46
0.38 0.41 0.44 0.47 0.50
0.50 0.54 0.58 0.62 0.66
0.76 1a 2b 3e 4f
0.80 6b 7a 8c 9f 10g
0.84 11c 12a 13b 14d 15f
0.88 16d 17a 18b 19c 20e
0.92 21d 22b 23b 24b 25d
B
layperson
VAW/Mf
VAW/Lf
VAW/IPD
VAW/SW
0.34 0.37 0.40 0.43 0.46
0.38 0.41 0.44 0.47 0.50
0.50 0.54 0.58 0.62 0.66
0.76 1a 2a 3d 4e
0.80 6b 7a 8c 9d 10e
0.84 11b 12a 13b 14d 15e
0.88 16c 17a 18b 19b 20d
0.92 21d 22b 23b 24b 25c
scores
most attractive 8 7 6 5 4 3 2 least attractive
brachyfacial
C
VAW/Mf
VAW/Lf
VAW/IPD
orthodontis
layperson
SW/IPD
SW/Lf
SW/Mf
D
orthodontis
VAW/Mf
VAW/Lf
VAW/IPD
VAW/SW
0.34 0.37 0.40 0.43 0.46
0.38 0.41 0.44 0.47 0.50
0.50 0.54 0.58 0.62 0.66
0.76 1b 2a 3d 4e
0.80 6c 7a 8b 9d 10e
0.84 11c 12a 13a 14c 15e
0.88 16d 17a 18a 19b 20d
0.92 21d 22c 23a 24a 25c
E
layperson
VAW/Mf
VAW/Lf
VAW/IPD
VAW/SW
0.34 0.37 0.40 0.43 0.46
0.38 0.41 0.44 0.47 0.50
0.50 0.54 0.58 0.62 0.66
0.76 1b 2a 3c 4d
0.80 6c 7a 8b 9c 10d
0.84 11c 12a 13a 14b 15d
0.88 16c 17a 18a 19b 20c
0.92 21c 22c 23a 24a 25b
scores
most attractive 8 7 6 5 4 3 2 least attractive
dolicofacial
F
VAW/Mf
VAW/Lf
VAW/IPD
orthodontis
layperson
SW/IPD
SW/Lf
SW/Mf