AJO-DO

Lip position analysis of young women with different skeletal patterns during posed smiling using 3-dimensional stereophotogrammetry

Haizhen Li,[a] Tian Cao,[b] Hong Zhou,[b] and Yuxia Hou[b]
Xi'an, Shaanxi, China

Introduction: The aim of this study was to explore the internal relationship between posed smile characteristics, lip position, and skeletal patterns in young women. **Methods:** Fifty women between the ages of 20 and 30 years were enrolled and divided into 3 groups—vertical, average, and horizontal patterns— using the following parameters: FMA, GoGn-SN, and Jarabak ratio. Each subject was scanned in natural head position and with a posed smile. The interlabial gap, intercommissural width, and smile index were calculated. The frontal region was selected as the reference plane for superimpositions. The changes of the lip landmarks in the vertical, sagittal, and coronal directions were investigated. **Results:** The smile indexes were listed in the following sequence: vertical < average < horizontal. Significant differences were found in the interlabial gap among the 3 groups. Compared with the average and horizontal groups, the upper lip landmarks of the vertical group showed differences and changed more only in the vertical direction. However, the lower lip landmark showed no differences in any direction. **Conclusions:** Different skeletal patterns have characteristic smile features. The vertical skeletal pattern affects upper lip movements because there is more space for upper-lip elevation. However, the vertical skeletal pattern has no effect on lower lip movement. (Am J Orthod Dentofacial Orthop 2019;155:64-70)

A smile conveys emotions and expresses courtesy. A harmonious smile is an important goal in orthodontic treatment. Garber and Salama[1] reported that an esthetic smile is the result of healthy teeth, gingival scaffold, and lip framework. Both excessive and too little exposure of the teeth and gingivae are considered to be unesthetic. The lips create a smile by exposing teeth and gingivae and play an important role in developing a smile. Knowing the effects of lip movement is helpful for orthodontists when designing a beautiful smile.

Posed smiles are widely studied in orthodontics mainly because they are repeatable over time.[2-4] A few studies have reviewed the relationship between posed smile characteristics and skeletal patterns. Toth et al[5] reported that with increasing mandibular plane angle and anterior facial height, the smile index decreased. Wu et al[6] found that skeletal Class II malocclusions and vertical growth patterns accounted for most gummy smiles. Siddiqui et al[7] found that persons with vertical skeletal patterns have greater upper lip elevation. However, the exact relationship between posed smile characteristics, lip positions, and skeletal patterns is unknown.

Traditional smile collection methods include photography and videography.[8] However, Gross et al[9] reported that 2-dimensional methods can study only 43% of facial expressions. Recently, 3-dimensional (3D) stereophotogrammetry has been used to capture soft tissue images because it captures an image in less than

[a]Department of Orthodontics and Clinical Research Center of Shaanxi Province for Dental and Maxillofacial Diseases, College of Stomatology, Xi'an Jiaotong University, Xi'an, Shaanxi, China.
[b]Department of Orthodontics, College of Stomatology, Xi'an Jiaotong University, Xi'an, Shaanxi, China.
All authors have completed and submitted the ICMJE Form for Disclosure of Potential Conflicts of Interest, and none were reported.
Supported by the opening foundation of Clinical Research Center of Shaanxi Province for Dental and Maxillofacial Diseases, College of Stomatology, Xi'an Jiaotong University (2017YHJB04).
Address correspondence to: Yuxia Hou, Department of Orthodontics, College of Stomatology, Xi'an Jiaotong University, 98# Xiwu Road, Xi' an, Shaanxi, 710004, P.R. China; e-mail, 369hyx@163.com.
Submitted, September 2017; revised and accepted, March 2018.
0889-5406/$36.00

https://doi.org/10.1016/j.ajodo.2018.03.014

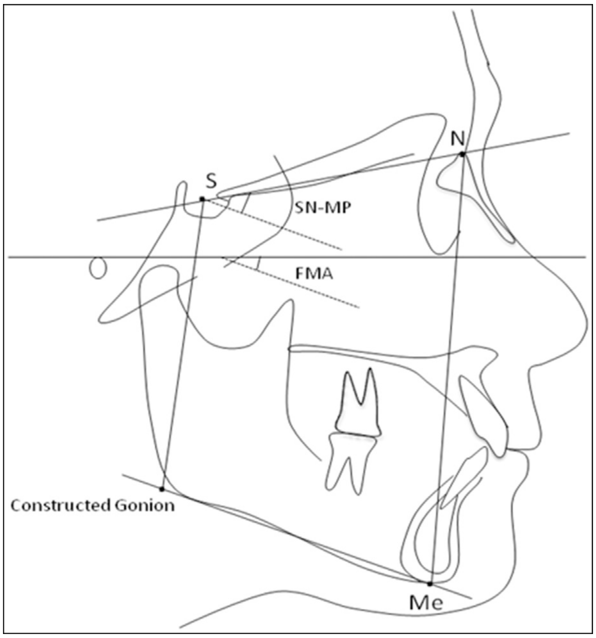

Fig 1. Landmarks and parameters to classify facial patterns: *S*, sella; *N*, nasion; *Me*, menton; *Go* (constructed gonion); *MP*, mandibular plane; *FMA*, angle between mandibular plane and Fankfort plane.

1.5 ms using synchronous digital cameras and provides a 360° view that is not affected by the angle and distance from the patient to the camera. Dindaroglu et al[10,11] used reverse engineering technology to confirm the accuracy and reproducibility of the images at rest and in a posed smile. Therefore, 3D stereophotogrammetry is a new method that can be used to study posed smiles.

To the best of our knowledge, there is no report on the relationship among posed smile characteristics, lip positions, and vertical skeletal patterns. In this study, we used 3D stereophotogrammetry to explore the internal relationship between posed smile characteristics, lip positions, and skeletal patterns.

MATERIAL AND METHODS

The protocols were approved by the medical ethics committee at the College of Stomatology, Xi'an Jiaotong University (xjkqll [2017] number.017), in Xi'an, Shaanxi, China. The subjects were selected based on the following inclusion criterion: women between the ages of 20 and 30 years. Fifty female patients attending the Stomatology Hospital of Xi'an Jiaotong University from September 2016 to June 2017 were randomly selected as the subjects. The number of experimental samples was calculated with this formula: $n = 2\times\left(\frac{t_\alpha + t_\beta}{\delta}\times s\right)^2$.

Table I. Groupings and distributions of subjects based on facial patterns

	Horizontal skeletal pattern	*Average skeletal pattern*	*Vertical skeletal pattern*
SN-MP (°)	<31	31-34	>34
FMA (°)	<22	22-28	>28
Jarabak ratio (%)	>63	59-63	<59
Sample size (n)	15	21	14

Ten subjects with a vertical pattern and 10 with an average pattern were selected to calculate the desired values and standard deviations ($\alpha = 0.05$; $\beta = 0.1$; $\delta = 2.41$; $s = 1.75$). Fourteen subjects were needed in each group. The average age was 24.04 ± 2.42 years. The exclusion criteria were previous orthodontic treatment, appliances on the dentition, and craniofacial abnormalities.

The skeletal landmark measurements were obtained using digital lateral cephalograms taken with a radiography unit (Soredex, Tuusula, Finland). The images were uploaded and traced with software (version 11.8; Dolphin Imaging and Management Solutions, Chatsworth, Calif). For each cephalogram, the following hard tissue landmarks were located: sella, nasion, gonion, gnathion, menton, and porion (Fig 1). According to a previous study, the subjects were divided into different facial patterns based on GoGn-SN, FMA, and the Jarabak ratio (Table I).[12]

Each subject had 2 3D soft tissue facial scans (3dMD, Atlanta, Ga). The first scan (Fig 2, *A*) was obtained in natural head position, with the lips in a relaxed position and the eyes looking into the mirror in front.[13,14] The second scan (Fig 2, *B*) was obtained in the same position by the same investigator (H.L.), who gave the command "give me a big smile like when you see your close friends" to the participants.[13] All facial scans were taken by the first author.

The data were transformed into the Geomagic Control software (3D Systems, Research Triangle Park, NC). The following 9 landmarks were selected according to the previous study: right exocanthion, right endocanthion, soft tissue nasion, left endocanthion, left exocanthion, lip superior, lip inferior, commissure right, and commissure left (Fig 3, *A*).[15] The definitions of these landmarks were according to the study of Toma et al.[15] The lip landmarks were divided into 2 groups. commissure right, commissure left, and labrale superior mean upper lip variations, and labrale inferior means lower lip variations (Table II).

Three reference planes were defined to establish the coordinate system: sagittal (y-z), coronal (x-z), and

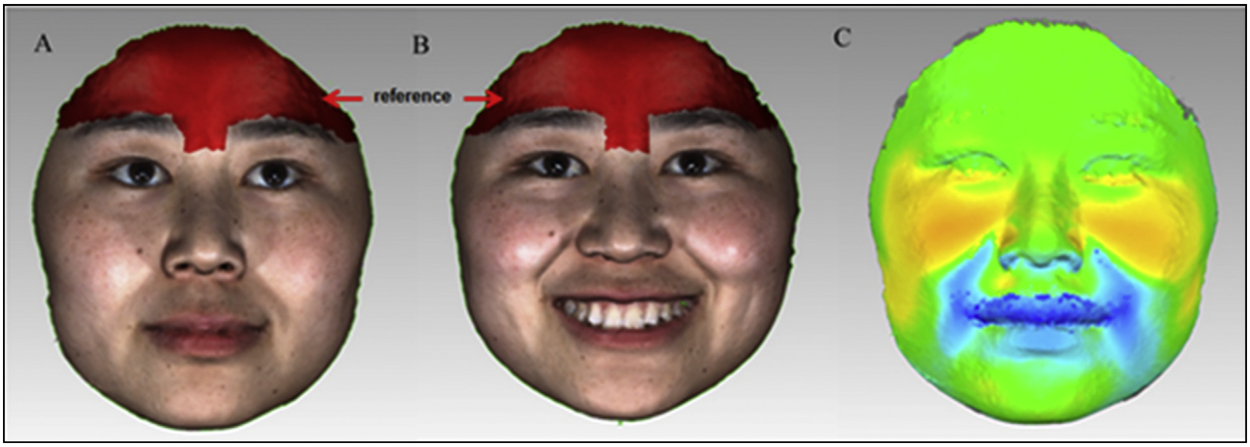

Fig 2. Images of different positions and 3D chromatogram: **A,** facial scan in natural head position; *red* is the reference region; **B,** facial scan in a posed smile; **C,** 3D comparison of the chromatograms of the 2 images; *green* indicates the deviationd between natural head position and the social smile.

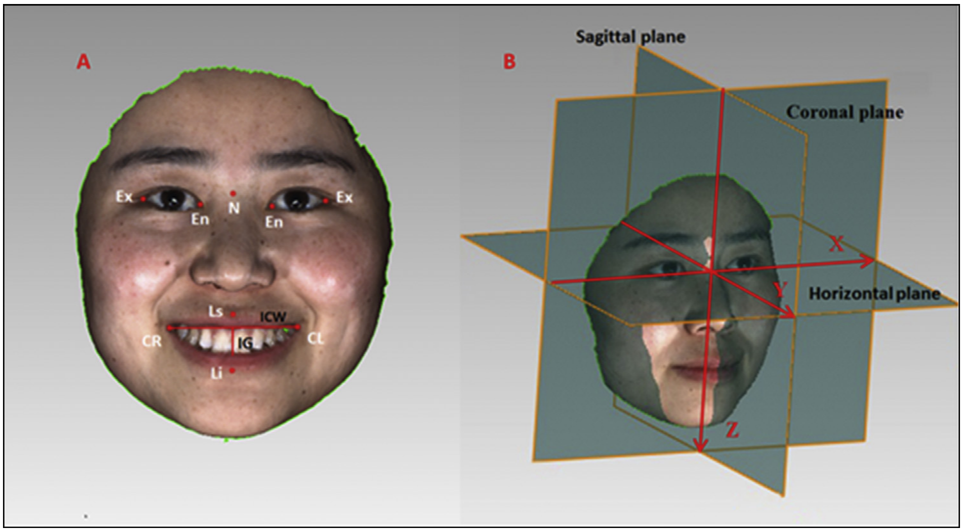

Fig 3. **A,** Landmarks and measurements used in this study; **B,** reference planes and coordinate system.

horizontal (x-y). Soft tissue nasion was selected as the origin of the coordinate system. The horizontal plane went through the bilateral exocanthions and soft tissue nasion. The sagittal plane went through the soft tissue nasion, perpendicular to the line connecting the bilateral exocanthions. The coronal plane went through the soft tissue nasion and was perpendicular to the other 2 planes. The details of the coordinate system are shown in Figure 3, *B*.

The resting position was used as the reference image, and the social smile image was aligned on this image. We first merged these 2 images roughly depending on the right exocanthion, left exocanthion, right endocanthion, left endocanthion, and soft tissue nasion. Then, we selected the forehead and nasal root region to merge the images with the surface best-fit method[10,11,13,16] (Fig 2, *C*). Using the superimpositions, the changes of lip landmark coordinates from natural head position to social smiling were recorded in the x, y, and z dimensions.

Statistical analysis

Data are shown as means (with standard deviations). The groups were compared by 1-way analysis of variance, and the significance of the mean differences within (intragroup) and between (intergroup) groups was

Table II. Landmarks and measurements used in this study

Landmark	*Definition*
Nasion (N)	Midpoint of the bilateral exocanthions
Endocanthion (En L/R)	Inner commissure of the left and right eye fissures
Exocanthion (Ex L/R)	Outer commissure of the left and right eye fissure
Labrale superior (Ls)	Midpoint of the upper vermilion line
Labrale inferior (Li)	Midpoint of the lower vermilion line
Commissure (L/R)	Points at left and right labial commissures
Interlabial gap (IG)	Millimetric measurement of the line connecting the most inferior portion of the upper lip and the most superior point of the lower lip
Intercommissural width (ICW)	Millimetric measurement of the line connecting the right and left commissures of the mouth
Smile index	ICW ÷ IG
Commissure right: CRx, Cry, CRz	Variations of the landmark CR from natural head position to posed smile position
Commissure left: CLx, CLy, CLz	Variations of the landmark CL from natural head position to posed smile position
Lip superior: Lsx, Lsy, and Lsz	Variations of the landmark Ls from NHP to posed smile positions
Lip inferior: Lix, Liy, and Liz	Variations of the landmark Li from NHP to posed smile positions

determined using the Tukey post hoc test after we ascertained the normality with the Shapiro-Wilk test and the homogeneity of variance between groups with the Levene test. Correlations between the vertical smile index and IG and ICW were also calculated. A 2-tailed *P* value less than 0.05 was considered to be statistically significant. All analyses were performed using software for Windows (version 17.0; SPSS, Chicago, Ill).

Operator reliability of lateral cephalogram and soft tissue scan measurements was evaluated using intraclass correlation coefficients. Ten subjects were randomly selected to test for intraoperator and interoperator reliabilities. Intraoperator reliability was done by the same operator (H.L.) who defined the landmarks twice in 1 week. Interoperator reliability was done by 2 operators (H.L, T.C.) who defined the landmarks at the same time.

RESULTS

The intraoperator reliability coefficients varied between 0.862 and 0.961. The interoperator reliability coefficients ranged from 0.841 to 0.942. The smile index was maximal for the horizontal pattern followed by average and minimum for the vertical pattern. IG had

Table III. Measurements (and standard deviations) of IG, ICW, and smile index in the 3 groups

Pattern	*ICW (mm)*	*IG (mm)*	*Smile index*
Horizontal	58.93 (5.35)	10.56 (1.79)	5.73 (1.12)
Average	57.30 (3.44)	11.78 (2.00)*	4.99 (0.92)
Vertical	59.44 (4.89)	13.82 (2.97)†	4.42 (0.72)†

*P <0.05, compared with vertical pattern; †P <0.001, compared with horizontal pattern.

a pattern opposite to that of the smile index, whereas ICW was erratic among the 3 groups. The Tukey post hoc test results are given in Table III. Compared with the other 2 groups, the vertical groups showed differences in smile index and IG, but not in ICW. The Pearson correlation test showed that IG was closely related to the smile index ($r = -0.845$; P <0.001), but ICW was not ($r = 0.258$; P <0.05).

The 3D chromatogram of 2 images suggested that the domains of variation were the cheekbones and the perioral area. The mean values of the variations and statistical results for the 4 points are shown in Table IV.

The variations of the upper lip landmarks were not statistically significant in the x-y direction among the 3 groups. In the z-axis, variations of the upper lip landmarks in the vertical group were statistically significantly increased compared with the average (P <0.05) and horizontal (P <0.05) groups. However, there was no statistical significance in the z-axis between the average and horizontal groups. The variations of the 3 points were arranged from high to low as follows: vertical > average > horizontal. The lower lip landmark, Li, showed no significant changes in the x, y, and z axes among the 3 groups.

DISCUSSION

Many factors affect smile characteristics: age, sex, and orthodontic treatment.[5,7,12] In this study, 50 untreated young women were selected to eliminate interference factors. By analyzing the smile index, ICW, IG, and lip variations, we tried to determine the relationship between posed smiles, lip elevations, and vertical skeletal patterns.

Hata and Arai[17] compared 100 female subjects after orthodontic treatment using a digital caliper and found that only the vertical dimension was responsible for postorthodontic frontal smile attractiveness. The smile index reflects the transverse and vertical relationships of a smile.[4] Therefore, we chose the smile index as the fundamental parameter to describe the smile. A smaller smile index value means greater exposure of the teeth and gingiva, and a larger smile index value has the

Table IV. Measurements (and standard deviations) of lip movements in the 3 groups

Pattern	*CR* (•••)			*CL* (•••)			*Ls* (•••)			*Li* (•••)		
	x	*y*	*z*	*x*	*y*	*z*	*x*	*y*	*z*	*x*	*y*	*z*
Horizontal	−4.05 (1.26)	−7.65 (2.51)	−5.36 (2.02)	5.01 (2.18)	−8.21 (2.62)	−5.48 (2.09)	0.35 (.76)	−3.92 (1.42)	−3.73 (1.59)	0.96 (.82)	−5.82 (1.70)	2.61 (2.00)
Average	−4.86 (1.21)	−8.14 (2.22)	−6.01* (1.14)	5.15 (1.40)	−8.61 (1.94)	−5.68* (1.78)	0.26 (1.04)	−3.96 (1.45)	−4.39* (1.23)	0.33 (1.34)	−6.69 (1.25)	3.87 (1.62)
Vertical	−5.17 (1.86)	−6.63 (2.58)	−8.42† (2.52)	5.62 (1.53)	−7.86 (2.00)	−8.63† (2.73)	0.59 (2.73)	−3.63 (2.30)	−6.85† (2.60)	0.71 (1.32)	−5.97 (2.44)	2.65 (2.61)

*P <0.05, compared with vertical pattern; †P <0.05, compared with horizontal pattern.

opposite meaning. In this study, we found that the vertical groups had the smallest smile index values, indicating that patients with vertical patterns have greater smile display zones. This result agrees with a study by Wu et al,[6] who reported that patients with vertical facial patterns are more likely to have gummy smiles.

The smile index is defined as ICW ÷ IG. For further study of the smile index, Pearson analysis was conducted with ICW and IG. Statistical results demonstrated that the smile index is closely related to IG and irrelevant to ICW. IG causes different smile index values in different facial patterns.

IG is greatly influenced by the vertical variations of the upper and lower lips. When a smile occurs, the upper lip moves upward, and the lower lip moves downward; this produces the space between the upper and lower lips, which is defined as IG. Since there is no difference of the lower lip variations in the z direction, the upper lip variations in the z direction cause the differences in IG among the 3 groups. The upper lip changes in the z direction determine the IG and were in proportion to the smile index. The upper lip changes in the z direction mean the upper lip elevation. This result shows that subjects with vertical skeletal patterns have a greater upper lip elevation than do those with other patterns. This conclusion is the same as that of Siddiqui et al[7] using 2-dimensional videography.

According to Matthews,[18] the direction and strength of the muscles are the basic reasons for variations in the smile. The muscles raising the upper lip mainly are levator labii superioris, levator labii superioris alaeque nasi, and zygomaticus minor, which originate from the bony surface of the maxilla and cheekbones and insert into the upper lip skin (Fig 4, *A*).[7,18,20] Comparing the 3D results of the 2 images, we intuitively saw that the main changing regions were around the cheekbones and the perioral area (Fig 4, *B*). This phenomenon is associated with the distribution of the facial musculature raising the upper lip. The directions of these muscles affect the upper lip variations.[18] In a face with a vertical pattern, the lip elevator muscle has a larger angle to the horizontal plane. When the muscle shrinks, it creates a greater distance in the vertical plane, and this explains why subjects in the vertical group have greater lip elevation.

The upper lip elevation in the average group was not significantly different compared with the horizontal group. The reason may be that the muscular distribution was not the determining factor between the average and horizontal groups. The strength and the bulk of the muscles between the 2 groups are the interference factor. These factors make up for the difference caused by the muscle distribution.

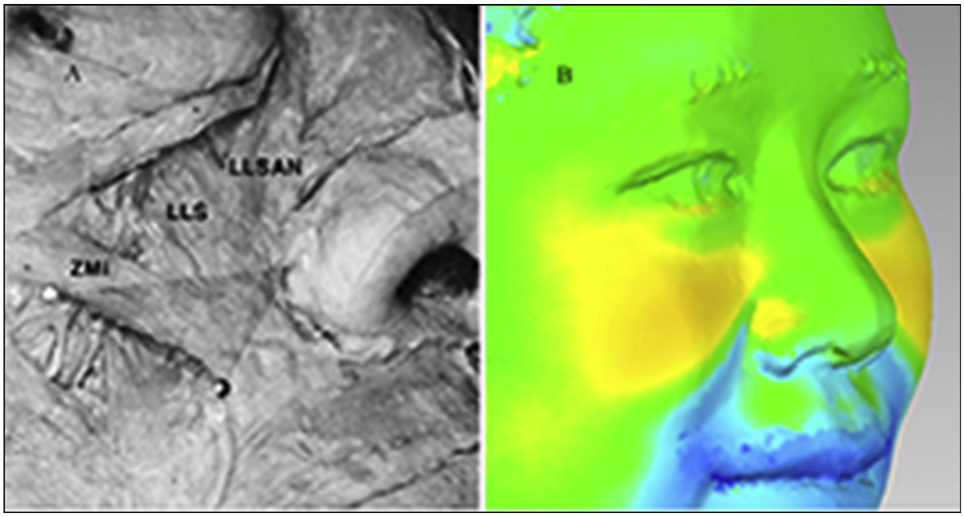

Fig 4. A, Distribution of muscles responsible for upper lip elevation.[19] *LLS*, Levator labii superioris; *LLSAN*, levator labii superioris alaeque nasi; *ZMI*, zygomaticus minor. **B,** Chromatogram of the 3D compared results.

The skeletal patterns affect the upper lip muscle direction. With a posed smile, vertically distributed muscles are more likely to produce a greater distance in the vertical dimension, which means an increase in upper lip elevation. This results in a larger IG and a smaller smile index value. However, because of the varying strengths of the muscles, the average and horizontal groups did not show a difference. We concluded this by analyzing the statistical results and observing the facial changes during posed smiling. We think it scientifically and rationally explains the relationships among skeletal patterns, lip variations, and smile characteristics. However, further evidence is required in studies based on magnetic resonance imaging or anatomic findings.

Quantifying a smile is difficult with traditional methods such as videography and photography.[8] The measurements are easily affected by the distance and angle between the patient and the dentist. The data collected by 3D stereophotogrammetry can be analyzed with the Geomagic control software.[11] By establishing a coordinate system, it is easy to quantify and describe the variations of the lips. The measurements we used were all obtained by 3D methods, which have high accuracy and reproducibility. In addition, compared with previous studies, we detected a difference in the vertical changes of the lips as well as similarity in the x and y axes. The vertical skeletal relationship affects only the upper lip variations in the vertical dimension, and the sagittal and horizontal dimensions showed no differences.

The lower lip variations are closely related to the mandibular incisor display. Too much exposure of the mandibular incisors reduces the attractiveness of the smile and is closely related to an older look. The variations of the Li point showed no difference among the 3 groups. Similar results were found by Toth et al,[5] who also proved that different vertical facial types have no effect on lower lip variations. The lower lip movement is controlled by the mentalis muscles, and the vertical facial type may have little effect on the mentalis muscles.

This conclusion is suitable for women between 20 and 30 years of age who have high expectations for smile esthetics. Men have different smile characteristics, and this conclusion may not apply to them. Further study should be done with men.

Lip vermilion variations also affect the vertical features of the smile.[21] The authors of this 2-dimensional study measured the length directly on the photos. However, finding a fixed marker of the lip vermilion on the 3D image is difficult. In this study, we did not record the changes in the vermilion. Further studies are required to determine the exact influence of the lip vermilion on the vertical features of the smile.

CONCLUSIONS

1. IG is different among the 3 vertical pattern groups, resulting in the values of the smile index changing from high to low in the following sequence: vertical > average > horizontal.
2. Compared with the average and horizontal groups, there was more upper lip elevation in the vertical

group. Moreover, the upper lip changes were more significant in the vertical plane compared with the sagittal and coronal planes.

3. The variations of the lower lip are not related to the vertical facial patterns.

REFERENCES

1. Garber DA, Salama MA. The aesthetic smile: diagnosis and treatment. Periodontol 2000 1996;11:18-28.
2. Krishnan V, Daniel ST, Lazar D, Asok A. Characterization of posed smile by using visual analog scale, smile arc, buccal corridor measures, and modified smile index. Am J Orthod Dentofacial Orthop 2008;133:515-23.
3. Hosseinzadeh-Nik T, Yazdani-Damavandi L, Kharazi-Fard MJ. The correlation of smile line with the vertical cephalometric parameters of anterior facial height. Journal of Dentistry, Tehran University of Medical Sciences 2005;2:21-8.
4. Ackerman JL, Ackerman MB, Brensinger CM, Landis JR. A morphometric analysis of the posed smile. Clin Orthod Res 1998;1:2-11.
5. Toth EK, Oliver DR, Hudson JM, Kim KB. Relationships between soft tissues in a posed smile and vertical cephalometric skeletal measurements. Am J Orthod Dentofacial Orthop 2016;150:378-85.
6. Wu H, Lin J, Zhou L, Bai D. Classification and craniofacial features of gummy smile in adolescents. J Craniofac Surg 2010;21:1474-9.
7. Siddiqui N, Tandon P, Singh A, Haryani J. Dynamic smile evaluation in different skeletal patterns. Angle Orthod 2016;86:1019-25.
8. Sarver DM, Ackerman MB. Dynamic smile visualization and quantification: part 1. Evolution of the concept and dynamic records for smile capture. Am J Orthod Dentofacial Orthop 2003;124:4-12.
9. Gross MM, Trotman CA, Moffatt KS. A comparison of three-dimensional and two-dimensional analyses of facial motion. Angle Orthod 1996;66:189-94.
10. Dindaroglu F, Duran GS, Gorgulu S. Reproducibility of the lip position at rest: a 3-dimensional perspective. Am J Orthod Dentofacial Orthop 2016;149:757-65.
11. Dindaroglu F, Duran GS, Gorgulu S, Yetkiner E. Social smile reproducibility using 3-D stereophotogrammetry and reverse engineering technology. Angle Orthod 2016;86:448-55.
12. Grover N, Kapoor DN, Verma S, Bharadwaj P. Smile analysis in different facial patterns and its correlation with underlying hard tissues. Prog Orthod 2015;16:28.
13. Duran GS, Dindaroglu F, Gorgulu S. Three-dimensional evaluation of social smile symmetry. Angle Orthod 2017;87:96-103.
14. Maal TJ, Verhamme LM, van Loon B, Plooij JM, Rangel FA, Kho A, et al. Variation of the face in rest using 3D stereophotogrammetry. Int J Oral Maxillofac Surg 2011;40:1252-7.
15. Toma AM, Zhurov A, Playle R, Ong E, Richmond S. Reproducibility of facial soft tissue landmarks on 3D laser-scanned facial images. Orthod Craniofac Res 2009;12:33-42.
16. Maal TJ, van Loon B, Plooij JM, Rangel F, Ettema AM, Borstlap WA, et al. Registration of 3-dimensional facial photographs for clinical use. J Oral Maxillofac Surg 2010;68:2391-401.
17. Hata K, Arai K. Dimensional analyses of frontal posed smile attractiveness in Japanese female patients. Angle Orthod 2016;86:127-34.
18. Matthews TG, Blatterfein L, Morrow RM, Payne SH. The anatomy of a smile. J Prosthet Dent 1978;39:128-34.
19. Hwang WS, Hur MS, Hu KS, Song WC, Koh KS, Baik HS, et al. Surface anatomy of the lip elevator muscles for the treatment of gummy smile using botulinum toxin. Angle Orthod 2009;79:70-7.
20. Lin AI, Braun T, McNamara JA Jr, Gerstner GE. Esthetic evaluation of dynamic smiles with attention to facial muscle activity. Am J Orthod Dentofacial Orthop 2013;143:819-27.
21. Miron H, Calderon S, Allon D. Upper lip changes and gingival exposure on smiling: vertical dimension analysis. Am J Orthod Dentofacial Orthop 2012;141:87-93.