

# Dynamic smile analysis: Changes with age

Shyam Desai,<sup>a</sup> Madhur Upadhyay,<sup>b</sup> and Ravindra Nanda<sup>c</sup>

Philadelphia, Pa, and Farmington, Conn

**Introduction:** The objective of this study was to define age-related changes in the smile. The areas of interest were upper lip length at smile and repose, upper lip thickness at smile and repose, maxillary incisal display at smile, interlabial gap height at smile, smile index, percentage of buccal corridors, intercommissural width at rest, smile height, and smile arc. A secondary objective was to study the perioral changes from rest to smile and compare them on the basis of age. **Methods:** Video equipment was used to capture images of 261 subjects, who were divided into 5 groups by age. Two frames for each subject were selected, 1 frame representing the lips at rest and the other representing the widest smile. After 40 subjects were excluded, the data for the remaining 221 were analyzed by using 1-way analysis of variance (ANOVA) with the Fisher LSD post-hoc test. **Results:** There was a decrease of 1.5 to 2 mm in maxillary incisor display during smile with increasing age, but the smile index showed a significant increase. In accordance with some other studies, most subjects (78%) had average smile height. No subject in the 50 and over age group had a high smile, and no subject in the 15-to-19 year group had a low smile. All dynamic measurements indicated a pattern of decreasing change from rest to smile, especially evident after ages 30 to 39 years. **Conclusions:** This study helps to establish age-related dynamic norms. As a person ages, the smile gets narrower vertically and wider transversely. The dynamic measures indicate that the muscles' ability to create a smile decreases with increasing age. (Am J Orthod Dentofacial Orthop 2009;136:310.e1-310.e10)

A primary objective of seeking orthodontic treatment is to improve dental esthetics. Although ideal occlusion should certainly remain the primary functional goal of orthodontics, the esthetic outcome is also critical for patient satisfaction and therefore essential to the overall treatment objectives.<sup>1</sup> The importance of an attractive smile is unquestionable. A pleasing smile involves a harmonious relationship among the teeth, the gingival scaffold, and the lip framework. The importance of physical and facial attractiveness, in which the smile arguably plays a major role, has been studied and related to job recruitment decisions, initial impressions, susceptibility to peer pressure, voting and juror decisions, and social interactions including dating decisions.<sup>2-5</sup> In a recent study involving self-evaluation, patients ranked the teeth and eyes as the most important features of an attractive face.<sup>6</sup> Ackerman et al<sup>7</sup> commented that an attractive smile is

a requisite for winning elections, and a beautiful smile sells products for companies whose subliminal message in an advertisement is "look better, feel younger."

The smile, along with the associated perioral tissues, most visibly displays the results of orthodontic treatment; therefore, it is not surprising that smile esthetics are a major goal of orthodontic mechanotherapy. It is important to have general guidelines to aid clinicians in optimizing dentofacial esthetics while satisfying other treatment goals. When developing the appropriate diagnosis and treatment plan for a patient, the hard and soft tissues are usually analyzed in 3 dimensions: sagittal, vertical, and transverse. Recently, time has been recognized as the fourth dimension.<sup>8,9</sup> With time, people undergo many skeletal and soft-tissue cellular changes that dramatically affect the overlying soft-tissue envelope, the related muscles, and their functions.<sup>10-26</sup> Although orthodontic retainers help the patient to maintain the posttreatment occlusion and ensure long-lasting function and esthetics, we believe that appropriate knowledge of smile changes with age can help orthodontists obtain healthy, long-lasting, and esthetically appealing treatment results.

Throughout the orthodontic literature, static profile photographs and lateral cephalograms have been the key diagnostic aids in analyzing a patient's profile and lips at rest.<sup>27-41</sup> However, to best study a smile and advance beyond static pictures, recent articles have established guidelines describing a new method of capturing a dynamic smile.<sup>8,9,42</sup> This method uses videography

<sup>a</sup> Private practice, Philadelphia, Pa.

<sup>b</sup> Resident, Division of Orthodontics, Department of Craniofacial Sciences, Health Center, University of Connecticut, Farmington.

<sup>c</sup> Professor and head, University of Connecticut Orthodontic Alumni Endowed Chair, Department of Craniofacial Sciences, Division of Orthodontics, Health Center, University of Connecticut, Farmington.

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Reprint requests to: Ravindra Nanda, Department of Craniofacial Sciences, Division of Orthodontics, University of Connecticut, Health Center, Farmington, CT 06030-1725; e-mail, [nanda@uchc.edu](mailto:nanda@uchc.edu).

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**Table I.** Exclusion criteria

<i>Reason for exclusion</i>	<i>Subjects (n)</i>
Anterior prosthodontics	26
Video error	1
Did not smile	6
Head position off	4
Lip enhancements	1
Lip irregularity	1
Lips not at rest	1
Total	40

(capturing images at 30 frames per second) and computer software to record a smile rather than a static picture. With this method, researchers can identify a more standardized smile (greatest width), thus minimizing the inherent error of a single snapshot.

Therefore, the objective of this study was to use videography to study the anatomic and physiologic perioral age-related changes of the smile related to upper lip length, upper lip thickness, maxillary incisal display, interlabial gap at smile, smile index, percent buccal corridors, intercommissural width, smile height, and smile arc. Additionally, we analyzed perioral changes from rest to smile in various subjects and compared them on the basis of age.

## MATERIAL AND METHODS

Approval was obtained from the University of Connecticut Institutional Review Board (IRB number: 07-045-1) for this study and the subject selection process. The subjects were students, residents, staff, faculty, patients, parents, and guardians at the University of Connecticut Health Center. It was explained to potential subjects that this was a study on lip movements involving a short questionnaire followed by a 5-second video clip capturing only a small part of the face (chin to nose). Initial data were collected sequentially on 261 subjects; 40 were not included in the data analysis for the reasons shown in Table I. The remaining 221 subjects were separated into 5 groups with the following age ranges: group (G) 1 (15-19 years), G2 (20-29 year), G3 (30-39 years), G4 (40-49 years), and G5 (50 years and above). The sample is described in Table II. The ages ranged from 15 to 70 years; 59.7% (132 subjects) were female, and 40.3% (89 subjects) were male. Furthermore, 59.3% (131 subjects) of the total had a history of orthodontic treatment.

The inclusion criteria were (1) over 15 years of age, (2) no active orthodontic treatment, (3) voluntary involvement in the study, and (4) ability to answer questions on the questionnaire. The exclusion criteria were (1) missing teeth that could have been visible on

**Table II.** Description of study sample (age groups)

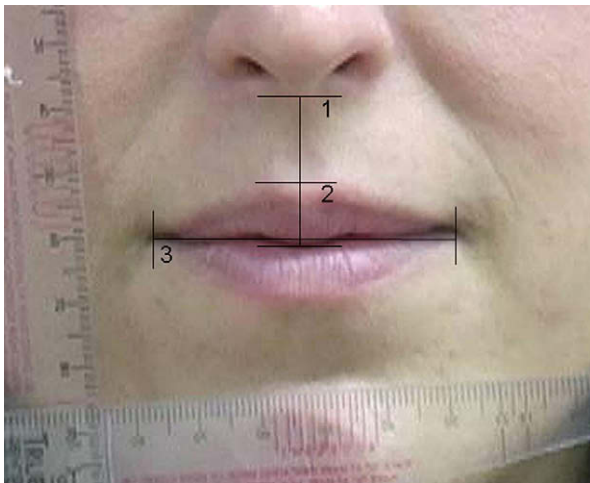
<i>Age (y)</i>	<i>Total (%)</i>
15-19	49 (22.2)
20-29	64 (29.0)
30-39	35 (15.8)
40-49	42 (19.0)
50+	31 (14.0)
Total (%)	221 (100)

smile, (2) prosthodontic work on teeth visible in smile, (3) gross facial asymmetries, (4) excessive dental attrition, (5) lip irregularities, (6) history of lip surgery or enhancements, (7) inability to determine natural head position, and (8) inability to hold the millimeter ruler parallel to the lens. If a potential subject met all inclusion criteria, he or she was initially included in the study. Later, if any exclusion criteria were noticed in the video or the resulting JPEG file, the subject was excluded (Table I).

A miniDV video camera (GL-2, Canon, Tokyo, Japan) was set on a tripod approximately 4 feet from the standing subject. The subjects were instructed to hold the head in natural head position by looking straight into an imaginary mirror. If head position required correction, the researcher (S.D.) helped the subject into natural head orientation.<sup>43</sup> The camera lens was adjusted to be parallel to the apparent occlusal plane and the camera focused only on the mouth (from nose to chin) so that the person could not be identified. Included in the capture area (frame) were 2 rulers with millimeter markings. The rulers were secured in a cross configuration so that if the subject accidentally rotated 1 ruler, the other could be used to analyze the frame. The subjects were instructed to hold the ruler to their chin, say "Subject number \_\_\_\_\_. Chester eats cheesecake by the Chesapeake," relax, and then smile. Recording started about 1 second before the subject began speaking and ended after the smile.

The video clip was downloaded to a computer (E2000 P04, Gateway, Irvine, Calif) and uploaded to ScenalyzerLive (version 4.0, Andreas Winter, Vienna, Austria), a video-editing software program. Each frame was analyzed, and 2 frames were captured for the study. The first frame represented the subjects' lips at rest, and the second showed the subjects' widest commissure-to-commissure posed smile. These frames were converted into a JPEG file in ScenalyzerLive and renamed in Windows XP Professional (Microsoft, Redmond, Wash) with the subject's number and the rest and smile frames.

Each file was opened in Adobe Photoshop CS2 (Adobe Systems, San Jose, Calif) and adjusted by using

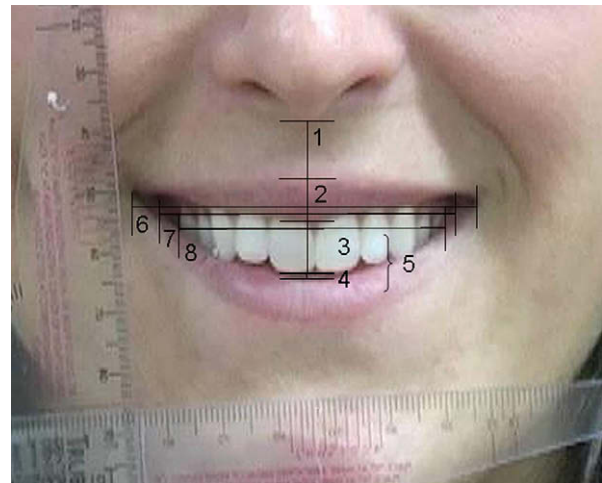


**Fig 1.** Measurements on the rest frame: 1, upper lip length; 2, upper lip thickness; 3, intercommissural width.

the millimeter ruler in the frame. The following procedure was used to adjust each picture. First, the resolution was changed to 300 pixels per inch by going to “image>image size.” Then, the ruler function was chosen and set to millimeter. It was determined which cross configuration millimeter ruler was most parallel to the camera lens. If neither ruler was parallel, the subject was excluded from the study. On the parallel end of the ruler, a 10-mm area, close to the smile, was measured. That number was divided into 10 (10/measurement on JPEG file) and multiplied by the width value found in image size screen (image>image size). The resulting number was copied and pasted in place of the width reading, and the changes were applied to the JPEG file. To check the accuracy of these steps, the 10-mm area on the ruler was measured again. If done correctly, this measurement would read 10 mm, and thus direct measurements could be recorded from that JPEG file. In Photoshop, the following data were measured and entered into Excel (Microsoft).

In the rest frame (Fig 1), (1) upper lip length, from subnasale to stomion superius; (2) upper lip thickness, vertical distance from the most superior point of the cupid's bow to the most inferior portion of the tubercle of the upper lip; and (3) intercommissural width.

In the smile frame (Figs 2-4), (1) upper lip length, subnasale to stomion superius; (2) upper lip thickness, vertical distance from the most superior point of the cupid's bow to the most inferior portion of the tubercle of the upper lip; (3) maxillary incisor display, stomion superius to maxillary incisor edge (if the central incisors were not at the same levels, 2 measurements were taken, and the average used for that subject); (4) maxillary incisal edge to upper part of lower lip, stomion inferius



**Fig 2.** Measurements on the smile frame: 1, upper lip length; 2, upper lip thickness; 3, maxillary incisal display; 4, maxillary incisal edge to lower lip; 5, interlabial gap height; 6, outer intercommissural width; 7, inner intercommissural width; 8, widest maxillary dental display.

to maxillary incisor edge; (5) interlabial gap at smile, direct measurement taken only if the lower lip covered the maxillary incisal edge, otherwise measurement 3 plus 4 was used; (6) outer intercommissural width; (7) inner intercommissural width; (8) visible maxillary dental width; (9) the anterior smile height was entered as high, average, low, or n/a (no dental display); (10) the curvature of the maxillary incisal edges and canine-premolar relationship to the lower lip line was entered as parallel, flat, reverse, or n/a (lower lip covering the maxillary incisor edge).

Although many definitions used in this study have variations in the literature, those outlined below were used.

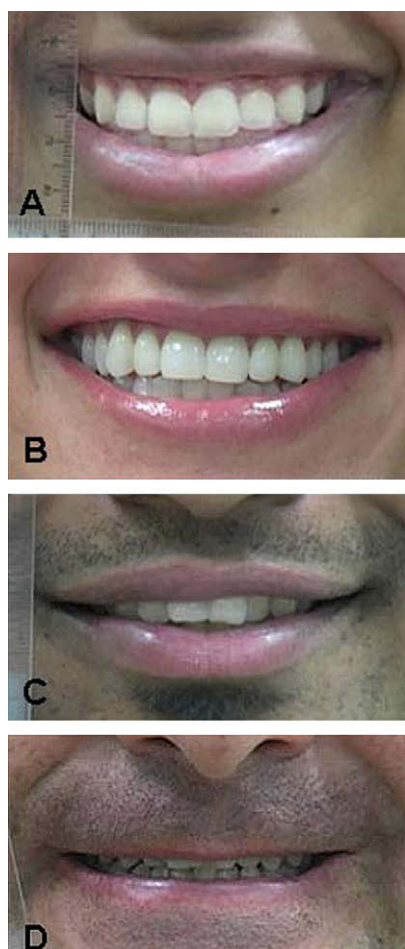
Buccal corridor was the difference between the visible maxillary dentition width and the inner commissure width divided by the inner commissure width stated as a percentage. This is the amount of inner commissure width occupied by the buccal corridor.

Smile index was determined by dividing the outer intercommissural width by the interlabial gap height during smile.

Vertical lip thickness was the vertical distance from the most superior point of the peak of the lip to the most inferior portion of the tubercle of the upper lip.<sup>44</sup>

### Statistical analysis

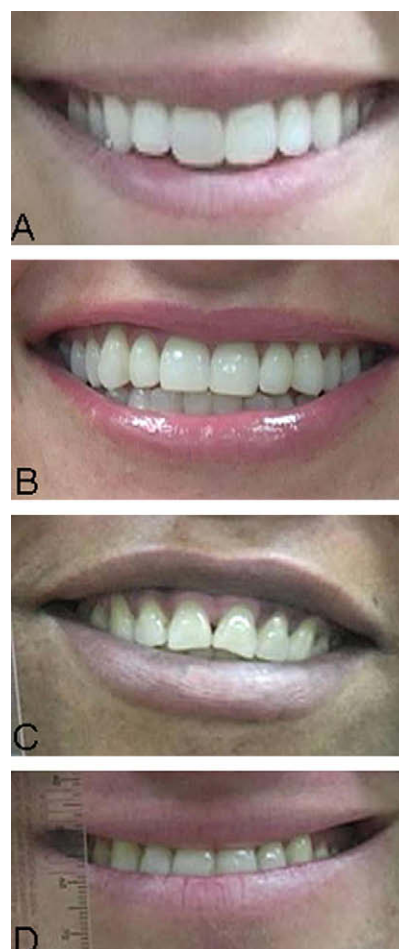
To examine the reliability, 2 sets of analyses were conducted. One set was conducted to obtain the Pearson correlation for numeric measures at times 1 and 2 (1 month apart) recorded by the same rater. A second



**Fig 3.** Smile height: **A**, high; **B**, average; **C**, low; **D**, no dental display.

reliability analysis was performed to obtain interrater reliabilities for 3 independent raters on measurements of smile height and smile arc. For all analyses of the main hypothesis, an alpha level of 0.05 was used. A series of analyses of variance (ANOVA) tests was conducted for the numeric measurements by using age group (G1-G5) as the between-groups factor with the dependent variables. If the ANOVA showed statistical significance, the Fisher LSD post-hoc test was used to determine which groups were significant from the others. To examine whether there were age differences in smile height and smile arc, chi-square analyses were conducted. Smile height and smile arc were measured on a categorical scale with 4 levels, whereas age represented an interval-level variable.

One examiner (S.D.) scored the first 10 subjects twice (1 month apart). The Pearson correlations for the measurements were highly acceptable, from 0.84 to 0.99 (Table III). The reliability across the 3 raters



**Fig 4.** Smile arc: **A**, parallel; **B**, flat; **C**, reverse; **D**, lower lip covering maxillary incisal edge.

for smile height was 0.86, and the reliability for smile arc was 0.68. Reliability analyses of the results indicate that the measurements ranged from substantial to outstanding.<sup>45</sup> For the other measurements (Table III), the commissural measurements had the least reliability because often there was wrinkling at the commissure, especially in older subjects.

## RESULTS

The results are shown in Tables IV through VIII. Table IX gives the overall means for the various perioral measurements.

With increasing age, there was a tendency for upper lip length at rest to increase from 21.58 to 22.69 mm, but it was not significant ( $P = 0.477$ ) (Table IV).

Overall, there were significant age-related differences in upper lip thickness at rest ( $P < 0.001$ ). Post-hoc tests showed that G1, G2, and G3 exhibited



**Table III.** Reliability of smile features measured twice by the same rater

Smile measurement	Pearson's <i>r</i>
Upper lip length at rest	0.99
Upper lip thickness at rest	0.99
Intercommissural width at rest	0.98
Upper lip length at smile	0.98
Upper lip thickness at smile	0.99
Maxillary incisal display	0.99
Outer intercommissural width at smile	0.99
Interlabial gap height at smile	0.99
Smile index (width/height)	0.99
Inner commissural width at smile	0.84
Widest dental display at smile	0.97
Percentage of buccal corridors	0.88
Change in upper lip thickness	0.98
Change in intercommissural width	0.98
Change in upper lip length	0.96

All correlations are statistically significant beyond the 0.001 level.

significantly longer lip thicknesses at rest than G4 ( $P < 0.001$ ) and G5 ( $P < 0.001$ ). There were no significant differences in lip thickness at rest between G1, G2, and G3, or between G4 and G5.

Overall, differences in intercommissural width at rest across the age groups were significant ( $P = 0.015$ ). Post-hoc analyses indicated that G1 had significantly smaller intercommissural width at rest (Table IV) than G2 ( $P = 0.028$ ), G3 ( $P = 0.025$ ), and G5 ( $P = 0.004$ ). G2, G3, and G5 did not significantly differ from each other. Furthermore, G4 showed significantly smaller intercommissural width at rest than G5 ( $P = 0.017$ ). No other differences were significant.

There were marginally significant differences ( $P = 0.061$ ) in upper lip length at smile between the 5 groups (Table V). Post-hoc analyses indicated that G5 had significantly higher upper lip length at smile measurements than did G1 ( $P = 0.018$ ) and G2 ( $P = 0.012$ ), and were marginally higher than G3 ( $P = 0.061$ ). No other differences were significant.

Overall, age differences in upper lip thickness at smile were significant ( $P = 0.002$ ). Post-hoc tests showed that G1 had significantly more lip thickness (Table V) than G5 ( $P = 0.041$ ), G2 had more than G4 ( $P = 0.003$ ) or G5 ( $P = 0.001$ ), and G3 had more than either G4 ( $P = 0.019$ ) or G5 ( $P = 0.008$ ).

Maxillary incisor display differed significantly as a function of age (Table V). Post-hoc analysis confirmed that G1 had higher maxillary incisor display than either G4 ( $P = 0.029$ ) or G5 ( $P = 0.004$ ), G2 was higher than G4 ( $P = 0.007$ ) or G5 ( $P = 0.001$ ), and G3 was higher than G4 ( $P = 0.005$ ) and G5 ( $P = 0.001$ ). G1, G2, and G3 did not differ significantly from each other

**Table IV.** Rest frame analysis results for measurements by age group

Smile measurement	Group (y)	Mean (mm)	SD	P value	Post-hoc
Upper lip length at rest	1 (15-19)	21.58	3.16	0.477	n/a
	2 (20-29)	21.7	2.87		
	3 (30-39)	22.25	1.92		
	4 (40-49)	22.02	3.47		
	5 (50 and over)	22.69	3.12		
Upper lip thickness at rest	1 (15-19)	7.87	1.94	<0.001	A
	2 (20-29)	8.28	1.84		
	3 (30-39)	8.38	1.59		
	4 (40-49)	6.51	1.67		
	5 (50 and over)	6.25	2.15		
Intercommissural width at rest	1 (15-19)	49.53	4.3	0.015	A/C
	2 (20-29)	51.24	3.78		
	3 (30-39)	51.56	3.84		
	4 (40-49)	49.92	4.09		
	5 (50 and over)	52.24	4.43		

Means with the same letter are not statistically different at the 0.05 level of significance.

( $P < 0.05$ ). The difference between G4 and G5 was not significant.

Interlabial gap height showed significant differences between the age groups (Table V). Post-hoc analysis indicated that G1 was significantly higher in interlabial gap height than the other groups. Furthermore, G2 was significantly higher than either G4 ( $P = 0.001$ ) or G5 ( $P = 0.028$ ). G3 was also significantly higher than G4 ( $P = 0.001$ ) or G5 ( $P = 0.020$ ), but the differences between G2 and G3 and between G4 and G5 were not significant.

Post-hoc tests (Table V) indicated that G1 had a significantly lower average smile index than either G2 ( $P = 0.037$ ), G4 ( $P < 0.001$ ), or G5 ( $P < 0.001$ ). G2 also had a significantly lower smile index than either G4 ( $P = 0.003$ ) or G5 ( $P = 0.034$ ). G3's average smile index was also significantly lower than that of G4 ( $P = .005$ ) or G5 ( $P = 0.032$ ). However, the differences between G1 and G3, G2 and G3, and G4 and G5 were not significant.

Post-hoc tests (Table V) showed that G1's average percentage of buccal corridor was significantly lower than that of G4 ( $P = 0.015$ ) or G5 ( $P = 0.009$ ). Similarly, G2 had a lower percentage of buccal corridor than either G4 ( $P = 0.030$ ) or G5 ( $P = 0.018$ ). No other differences were significant.

Post-hoc analysis showed no statistically significant difference ( $P = 0.188$ ) between the age groups in change in upper lip length (Table VI).

**Table V.** Smile frame analysis results for measurements by age group

Smile measurement	Group (y)	Mean (mm)	SD	P value	Post-hoc
Upper lip length at smile	1 (15-19)	16.84	2.94	0.061*	A
	2 (20-29)	16.83	2.53		A
	3 (30-39)	17.06	2.16		A*
	4 (40-49)	17.74	2.83		B
	5 (50 and over)	18.3	2.78		B/C
Upper lip thickness at smile	1 (15-19)	6.26	1.81	0.002	A/B
	2 (20-29)	6.72	1.89		B
	3 (30-39)	6.61	1.74		B
	4 (40-49)	5.61	1.71		A/C
	5 (50 and over)	5.39	2.09		C/D
Maxillary incisor display at smile	1 (15-19)	8.76	1.9	0.001	A
	2 (20-29)	9.02	2.12		A
	3 (30-39)	9.29	2.28		A
	4 (40-49)	7.62	2.27		B
	5 (50 and over)	7.14	2.55		B
Interlabial gap height at smile	1 (15-19)	12	2.83	<0.001	A
	2 (20-29)	10.42	2.77		B
	3 (30-39)	10.7	2.85		B
	4 (40-49)	8.5	2.86		B/C
	5 (50 and over)	9.01	3.03		B/C
Smile index	1 (15-19)	5.63	1.67	<0.001	A
	2 (20-29)	6.73	2.09		B
	3 (30-39)	6.55	2.19		A/B
	4 (40-49)	8.39	3.9		C
	5 (50 and over)	8.05	3.98		C
Percentage of buccal corridor	1 (15-19)	10.82	4.77	0.02	A/C
	2 (20-29)	11.25	5.4		A/C
	3 (30-39)	11.77	4.56		C
	4 (40-49)	13.53	5.69		B/C
	5 (50 and over)	14.04	5.39		B/C

Means with the same letter are not statistically different at the 0.05 level of significance.

\*Marginal significance ( $P = 0.061$ ).

Overall, the age differences for change in upper lip thickness from rest to smile were significant ( $P = 0.002$ ) for all age groups. However, post-hoc tests showed that G1, G2, and G3 had significantly larger changes in lip thickness from rest to smile than did G4 and G5 (all  $P$  values  $<0.05$ ). Differences between G1, G2, and G3 and between G4 and G5 were not significant ( $P >0.05$ ).

Significant differences in changes of intercommissural width were evident among the age groups (Table VI). Post-hoc analysis showed that G1, G2, and G3 had significantly greater changes of intercommissural width compared with G4 and G5. There were no signif-

**Table VI.** Analysis results for dynamic measurements by age group

Smile measurement	Group (y)	Mean (mm)	SD	P value	Post-hoc
Change in upper lip length	1 (15-19)	4.74	1.84	0.188	n/a
	2 (20-29)	4.88	1.72		
	3 (30-39)	5.2	1.92		
	4 (40-49)	4.28	1.97		
	5 (50 and over)	4.4	1.83		
Change in upper lip thickness	1 (15-19)	1.61	1.1	0.002	A
	2 (20-29)	1.56	1.51		A
	3 (30-39)	1.77	1.49		A
	4 (40-49)	0.9	1.02		B
	5 (50 and over)	0.86	1.03		B
Change in intercommissural width	1 (15-19)	13.86	4.43	<0.001	A
	2 (20-29)	13.63	3.41		A
	3 (30-39)	12.88	4.81		A
	4 (40-49)	11.01	3.09		B
	5 (50 and over)	10.68	3.75		B

Means with the same letter are not statistically different at the 0.05 level of significance.

**Table VII.** Smile height: percentages of subjects in the 5 groups at various measurements ( $P = 0.001$ )

Smile height	Group (y)					Total % (n)
	1 (15-19)	2 (20-29)	3 (30-39)	4 (40-49)	5 (50 and over)	
High	20.4	25	26.5	10	0	17.6 (39)
Average	79.6	71.9	70.6	77.5	79.3	73.8 (163)
Low	0	3.1	2.9	12.5	20.7	6.3 (14)
No dental display	0	0	2.9	4.8	6.5	2.3 (5)

icant differences between G1, G2, and G3 or between G4 and G5.

Age was found to be significantly associated with smile height ( $P = .001$ ). Younger subjects (G1, 20.4%; G2, 25.0%; G3, 26.5%) were more likely to have higher smile height than older ones (G4, 10.0%; G5, 0%) (Table VII). No dental display was observed in G3, G4, and G5.

Smile arc and age were associated (chi-square [12] = 28.40;  $P = 0.005$ ); generally, about the same percentages of parallel, flat, and reverse smile arcs were noted in each age category. However, there were higher percentages of subjects in G4 and G5 having the maxillary incisor edge covered by the lower lip than in the other 3 groups; there was none in G1 (Table VIII).

**Table VIII.** Smile arc: percentages of subjects in the 5 groups at various measurements ( $P = 0.005$ )

Smile arc	Group (y)					Total % (n)
	1 (15-19)	2 (20-29)	3 (30-39)	4 (40-49)	5 (50 and over)	
Parallel	57.1	69.8	55.2	56.7	37.5	48.4 (107)
Flat	42.9	22.6	41.4	36.7	58.3	31.7 (70)
Reverse	0	7.5	3.4	6.7	4.2	3.6 (8)
Lower lip covers MIE	0	17.2	17.1	28.6	22.6	16.3 (36)

MIE, Maxillary incisal edge.

**Table IX.** Overall means for various perioral measurements

Smile measurement	Mean (mm)	SD
Upper lip length at rest	21.96	2.97
Upper lip thickness at rest	7.58	2.01
Intercommissural width at rest	50.8	4.14
Upper lip length at smile	17.25	2.7
Upper lip thickness at smile	6.2	1.9
Maxillary incisal display	8.52	2.28
Interlabial gap height at smile	10.27	3.08
Smile index (width/height)	6.94	2.91
Percentage of buccal corridors	12.04	5.29
Change in upper lip length	4.72	1.85
Change in upper lip thickness	1.38	1.31
Change in intercommissural width	12.65	4.07

## DISCUSSION

Although there are many studies on smile, anterior dental display, and smile esthetics in the literature, almost all used static pictures or direct measurements.<sup>27-29,33-41,46-48</sup> A major drawback of static pictures is the inability to know whether the researcher has captured the intended frame in that 1 snapshot. To overcome this difficulty, digital video has been introduced.<sup>8,9,42</sup>

Researchers have studied age-related changes in lip length<sup>38</sup> and maxillary incisor exposure,<sup>41,46</sup> but, to our knowledge, this is the first study to examine a comprehensive list of smile parameters with respect to age. Age-related perioral changes are called senile lip changes. With age, the lips undergo several predictable changes that affect the dental display. For example, atrophy of muscles results in decreased lip volume, loss of lip architecture, and lip lengthening. These changes highlight the importance of having age-related norms as references so that more objective and specific treatment can be rendered to older patients.

Relaxed lip position is primarily determined by the muscles; therefore, it cannot have the reproducibility that is associated with measurements of hard-tissue structures. The recording of lip posture is further complicated because we are dealing with muscles innervated by the seventh cranial nerve. This nerve is closely associated with the autonomic nervous system and has connections at a higher level with the hypothalamus; this means that emotional state can strongly influence the contraction or lack of contraction of the muscle fibers of the lip. With care, the investigator or clinician can obtain records of relaxed lip positions that are relatively reproducible.<sup>49</sup> Therefore, every attempt was made to ensure that both frames for each subject were not affected by emotional input.

For upper lip length at rest, our results (Table IV) indicated an increasing trend from the youngest to the oldest age groups by 1.11 mm, although it was not statistically significant. Similarly, Formby et al<sup>31</sup> found a small increase of 0.83 mm from 18 to 42 years of age. On the other hand, for maxillary incisor display at smile, our results (Table V) showed a significant decrease after 40 years of age. Similar results were obtained by Vig and Brundo,<sup>46</sup> who noted a decrease in maxillary incisor exposure of about 3.41 mm from less than 29 years to over 60 years of age. Dong et al<sup>41</sup> examined both maxillary incisor display at rest and smile. They described decreases in maxillary incisor display of about 2.5 mm at rest and 2 mm at smile between the 20-to-29 year and the 60-to-69 year age groups. However, we found no correlation between upper lip length at rest and maxillary incisor display at smile ( $P = 0.738$ ). Peck et al<sup>38</sup> also found no correlation when they compared lip length at rest between those with a gingival smile and a reference group. However in separate studies, Singer<sup>50</sup> and Peck and Peck<sup>40</sup> reported that those with gingival smiles had slightly longer lips at rest. Since upper lip length at rest was not related to maxillary incisal display at smile, this leads to an obvious question: what causes the decreased maxillary incisal display on smiling?

Change in upper lip length, intercommissural width, and upper lip thickness are novel concepts introduced in this study that shed some light on this question by relating lip measurements at rest and smiling. These measurements give insight into the inherent activity of the facial muscles involved in raising and widening the smile. The data in Table VI show that the change in upper lip length from rest to smile tends to increase on average from G1 through G3 by 0.46 mm (Table VI) followed by decreases of 0.92 mm at G4 compared with G3 and 0.46 mm compared with G1, suggesting that, about 40 years of age, there is a decrease in the

muscles' ability to raise the upper lip by approximately 2 mm. By combining upper lip length at rest and at smiling, we get an average of 1.57 to 2.03 mm less display of the incisors on smiling with advancing age. This contributes greatly to a person's aged look when the maxillary anterior teeth are hidden by the upper lip during smiling. In addition, lip thickness at rest (Table IV) and at smile (Table V) also decreased by 1.62 and 0.87 mm, respectively, from G1 to G5, thereby giving some credibility to the empirical observations of thinner lips with age.

Similarly, our findings for interlabial gap height showed significant decreases with age from 12 mm (G1) to 9.01 mm (G5), causing an increase in the smile index between the same age groups (Table V). These data provide evidence that, as a person ages, the smile tends to get relatively wider transversely and narrower vertically. This assumption is further supported by the increase in buccal corridor space of almost 4% with age (Table V). In a recent study that evaluated smile esthetics in digitally altered smile images, a broader smile with minimal buccal corridors was rated as most attractive by laypeople.<sup>47</sup> Similarly, in another study, it was found that excessive buccal corridors were rated as less attractive by both orthodontists and laypersons.<sup>48</sup> However, there are also contrary viewpoints.<sup>51,52</sup>

The data in Table IV show that intercommissural width at rest increases with age by 2.71 mm from G1 to G5. These results were consistent with the idea that activity and function of the muscles involved in smile decrease with age. Loss of skin elasticity and volume can also contribute to increased wrinkles at the corners of the lip, making it difficult to identify the commissures. In these situations, the anatomic information from the smiling picture proves useful. Also, the lighting while taking images can affect a researcher's ability to differentiate between the inner and outer commissures.<sup>42</sup> In this study, every attempt was made to keep the ambient lighting constant.

For smile height, the most interesting finding was inversion of the data from G1 to G5 as seen in Table VII. This is evidence that, as one ages, the upper lip displays less maxillary incisor on smile. Specifically, with time, some people with high smiles in youth developed average smiles, whereas some with average smile heights became low smiles. With regard to the esthetics of anterior smile height, Hulsey<sup>35</sup> found that the most attractive smile had the upper lip at the height of the gingival margin of the maxillary central incisors (defined as average smile height in this study). In addition, Table VII shows that 73.8% of the subjects had average anterior smile height. This is higher than reported by Tjan et al,<sup>37</sup> Dong et al,<sup>41</sup> and Maulik and Nanda<sup>53</sup> (68.9%, 56%,

and 56.9%, respectively); however, it does support our data that average anterior smile height is the most common.

Of all the different kinds of smile arc, the parallel one was the most common at 48.4% (Table VIII); this agrees with other studies measuring smile arc (Tjan et al,<sup>37</sup> Dong et al,<sup>41</sup> and Owens et al<sup>34</sup>). In comparison, a previous study by Maulik and Nanda<sup>53</sup> showed that a flat smile arc is the most common at 49%. This difference could be attributed to the subjectiveness of the smile-arc measurement. In addition, the smile arc highly depends on conversational distance and head posture (angle of elevation).<sup>54,55</sup> Therefore, every effort should be made to keep the subject's apparent occlusal plane parallel to the camera. Our finding that 3.6% of the subjects had a reverse smile arc is consistent with the studies mentioned above (Tjan et al, 1.32%; Dong et al, 5%; and Maulik and Nanda, 10%). An interesting observation in this study was that, with age, people are more likely to smile with the lower lip covering the maxillary anterior incisal edges (Table VIII). This can be perhaps explained by the fact that, as people age, they become more self-conscious of their dentition and do not want to show their teeth, so that smile arc and height cannot be determined. In our sample, 13.3% of the subjects had the lower lip covering the maxillary incisal edges during their smile frame; this is similar to other studies in which more than 10% of the subjects covered the incisal portions of their anterior teeth with the lower lip.<sup>37,41</sup>

Most orthodontic treatment is during late childhood and early adolescence. Since time has been introduced as the fourth dimension of treatment planning, long-term knowledge of dentofacial changes are paramount for clinical success.<sup>8,9</sup> If the results of this study are judiciously applied for accurate diagnosis and treatment planning, we believe that treatment results will be esthetically more appealing, healthier, and longer-lasting. Overall, this study broadens our knowledge and understanding of how the perioral soft tissues change with age and helps clinicians to optimize dentofacial esthetics while satisfying other treatment goals. Clinicians must work within these changes. Although our results indicate that expansion of the maxillary arch might help to reduce buccal corridors, we do not recommend this approach in patients without a skeletal crossbite because of stability considerations. Since our study shows that incisor display changes with age, we think that treatment should be age specific. For example, intrusion of the maxillary incisors in deepbite patients needs careful consideration of the amount of gingival display with age. Orthodontic treatment planning and execution demand a holistic approach for the problem. It cannot



be based on just 1 parameter. Other factors such as functional and structural considerations and issues related to stability of the resulting occlusion must also be considered; at times, these are more important than esthetics, especially in older patients. Clinicians must consider all these factors before active intervention. In this study, we have tried to quantify many aspects of smile changes that were simply assumed in the past.

## CONCLUSIONS

1. A significant decrease of 1.5 to 2 mm in maxillary incisal display at smile was found with increasing age. Similarly, with age, upper lip thickness also decreases by 1.5 mm at rest and at smile.
2. The smile index significantly increased, indicating that the smile gets narrower vertically and wider transversely as a person ages.
3. No subject in the 50 and over age group had a high smile, and no subject in the 15-to-19 year group had a low smile. Most (78%) subjects had average smile height.
4. Taking into account all dynamic measurements in this study, it can be said that the muscles' ability to create a smile decreases with increasing age.

To obtain more accurate information of age-related changes on the perioral tissues, a long-term prospective longitudinal study would be ideal. Additionally, future studies could evaluate the attractiveness of measurements that have not been widely studied including, but not limited to, smile index, lip thickness, and the lower lip covering the maxillary incisor edges.

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