ORIGINAL ARTICLE

The aging craniofacial complex: A longitudinal cephalometric study from late adolescence to late adulthood

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Introduction: The purpose of this investigation was to evaluate craniofacial growth changes from late adolescence through late adulthood in participants from the University of Michigan Elementary and Secondary School Growth Study. **Methods:** This was a recall study with 39 subjects (19 male, 20 female). Their lateral cephalograms taken during late adolescence (T1; mean age, about 17 years), midadulthood (T2; mean age, about 47 years), and late adulthood (T3; mean age, about 57 years) were evaluated. To test for significant differences between times, sexes, and the sex and time interaction, repeated measures analysis of variance was used. For the comparisons of time (T1 vs T2, T2 vs T3), the nominal α level was set at 0.01. **Results:** Skeletal changes were significant only from late adolescence to midadulthood; soft-tissue changes were significant from late adolescence to midadulthood, and mid- to late adulthood. Changes in skeletal tissues consisted of increases in sella-nasion length, midfacial length, and lower anterior facial height. Sex differences were apparent in the mandible. The women had downward and backward mandibular rotation; the men, on the other hand, had more forward rotation of the mandible and increased chin prominence. Mandibular growth was greater in the men. Changes in the soft tissues were the most remarkable and included significant thinning and elongation of the upper lip. Significant changes in the nose took place, including drooping of the nasal tip and columella, the latter leading to more acute nasolabial angles. **Conclusions:** Our findings in this longitudinal study provide insights on several significant changes in the aging craniofacial complex. (Am J Orthod Dentofacial Orthop 2008;134:496-505)

Longitudinal growth studies historically have focused on the first 2 decades of life. In the United States and Canada, 12 growth studies were compiled from annual data collection, most of which included standardized cephalograms. Among the larger and most used studies are the Bolton-Brush Growth Study (Cleveland, Ohio), the Burlington Growth Study (Toronto, Ontario, Canada), the Denver Growth Study (Denver, Colo), the Fels Research Institute Study (Yellow Springs, Ohio), the Iowa Child Welfare Study (Iowa City, Iowa), and the University of Michigan Elementary and Secondary School Growth Study (Ann Arbor, Mich). The prevailing belief during the early to mid 20th century, when these longitudinal growth studies began, was that growth stopped soon after puberty. In addition, the abundance of orthodontic records of younger patients compared with adults reinforced the lack of information available on mature people, in spite of evidence supporting the continuation of craniofacial changes well into adulthood.[1-3]

Several of the studies mentioned above described growth in untreated adults by analyzing lateral cephalograms of subjects taken after adolescence. Among these investigations, the comprehensive growth study by Behrents[1,4] was conducted with 113 untreated subjects from the Bolton-Brush Growth Study at Case Western Reserve University in Cleveland, Ohio. The early examinations took place when the subjects were between 17 and 19 years of age. The later examinations occurred from 65 to 83 years, with an age range of 25 to 83 years at the final records. An additional longitudinal cephalometric study analyzed 20 subjects from the Fels Longitudinal Study.[5] The participants' initial lateral cephalograms were taken at age 17 or 18 years, and the final cephalograms between 40 and 50 years.

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Other longitudinal studies of adult growth were performed on cephalograms from the Denver Growth Study[6] and from the Iowa Child Welfare Society.[2]

West and McNamara[3] conducted a longitudinal cephalometric study focusing on craniofacial changes from adolescence to midadulthood. Fifty-six subjects from the University of Michigan growth study were included, with a lateral cephalogram originally available at age 17 years; they were on average in their fifth decade of life when recalled for the additional orthodontic records. In the meantime, several studies evaluated growth and remodeling changes in the craniofacial region of young Scandinavian adults (Swedish dental students[7,8] and Norwegians[9]). Most of these studies agreed that most adults have significant increases in skeletal facial linear dimensions and decreases in the cranial base angle and mandibular prominence, and the lower lip becomes more retruded relative to the nose (especially in men) combined with flattening and elongation of the upper lip.

With increased emphasis on esthetics, more adults are now seeking orthodontic treatment.[10] To keep pace with the demands of the changing orthodontic population, the skeletal and integumental tissues must be examined in detail so that health professionals can gain a comprehensive understanding of the normal aging process. The purpose of this study was to evaluate craniofacial skeletal and soft-tissue changes in adulthood by using longitudinal cephalograms from late adolescence to midadulthood, and from midadulthood to late adulthood.

MATERIAL AND METHODS

Our subjects previously participated in the University of Michigan Elementary and Secondary School Growth Study. The 56 subjects who contributed to the 1995 recall investigation were targeted for this study, after we obtained approval from the Health Sciences Institutional Review Board.[3] Of the 56 subjects, 5 subjects could not be located, 3 were unwilling to participate, 2 had undergone surgery in the facial region, and 7 were excluded because of lateral cephalometric radiographs obtained from sources that were not of diagnostic quality. Therefore, we had 39 subjects (19 men, 20 women) in this recall study. Their lateral cephalograms were evaluated in late adolescence (T1), midadulthood (T2), and late adulthood (T3). Their mean ages at each time are given in Table I. Thirty-four of the 39 subjects had a Class I molar relationship, 4 had a Class II molar relationship, and 1 had a strong Class III tendency. All subjects were postpubertal at T1; however, although all the female subjects were at CS6 in cervical vertebral maturation, 4 of the 19 male subjects were at CS5, and 1 male subject was still at CS4 in skeletal maturation.[11]

Table I. Mean age in years at each time point

Time	*Mean age (men)*	*Mean age (women)*
T1	17.4 ± 0.7	17.2 ± 0.8
T2	46.0 ± 3.3	47.5 ± 3.4
T3	57.2 ± 3.5	58.5 ± 3.7

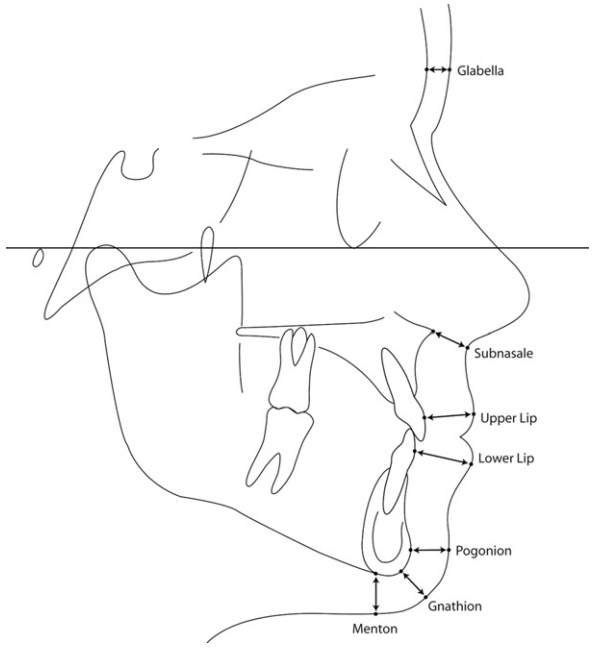

Fig 1. Measurements of soft-tissue thicknesses.

The cephalograms taken at T3 were traced on matte acetate by 1 examiner (N.G.P.) and checked for accuracy by another (J.A.M.). The examiners were blinded to the identity of the subjects. The original T1 and T2 tracings from the 1995 recall study were rechecked thoroughly for accuracy of landmark placement and adjusted if necessary. All tracings from T1 through T3 were digitized with Dentofacial Planner (Dentofacial Software, Toronto, Ontario, Canada). The cephalometric hard- and soft-tissue measurements and "average" profiles were generated with Dentofacial Planner. Figures 1 and 2 illustrate the soft-tissue measurements used in this study. Fiducial landmarks in the T1 and T2 films were transferred to the T3 films to allow for regional superimpositions. All linear measurements were configured to a standardized 8% enlargement factor. The error of the method was previously described by McNamara et al[12] and Levin et al.[13]

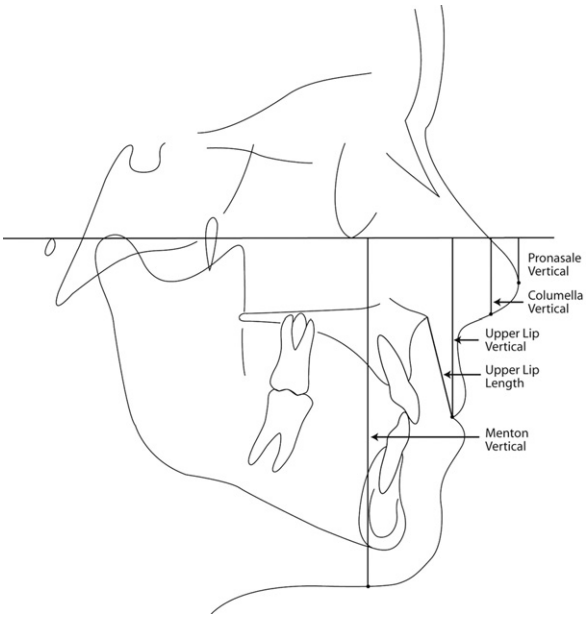

Fig 2. Soft-tissue vertical measurements.

Statistical analysis

The following statistical analyses were performed to evaluate the sample data.

Descriptive statistics—means and standard deviations—were computed for all variables at T1, T2, and T3. Mean differences and standard deviations were calculated for the changes from T1 to T2, and T2 to T3.

Inferential statistics were also computed. An exploratory Shapiro-Wilks test assessed normal distribution of the cephalometric variables in the total group of subjects, and in the 2 sexes separately. To test for significant differences between times and sexes, and in the sex and time interaction, repeated measures analysis of variance (RMANOVA) was used, with time as a within-subjects effect and sex as a between-subjects effect. If there was a significant sex and time interaction, the effect of time was investigated separately by using RMANOVA for each sex. If the sex and time interaction effect was not significant, the sexes were evaluated together. For the comparisons of time (T1 vs T2, T2 vs T3), the nominal α level was set at 0.01 (the T1 vs T3 comparison, not reported here, was included in the initial evaluation and was therefore accounted for in the established α level).

RESULTS

Descriptive statistics including means and standard deviations for the 3 times are shown in Tables II through IV. RMANOVA was conducted to compare the changes

Table II. Descriptive statistics of cephalometric variables at T1

	Men (n = 19)		*Women (n = 20)*	
Measurement	*Mean*	*SD*	*Mean*	*SD*
Cranial base				
SN-FH (°)	8.5	2.3	9.1	2.9
S-N (mm)	77.5	5.0	72.7	3.0
Ba-S-N (°)	129.7	4.8	133.0	4.2
Maxillary anteroposterior skeletal				
SNA (°)	80.9	4.2	79.9	4.1
Point A-Na perp (mm)	−0.9	4.1	−1.1	3.6
Co-Point A (mm)	96.9	5.9	91.2	4.3
Mandibular anteroposterior skeletal				
SNB (°)	77.4	3.7	75.8	3.6
Pg-Na perp (mm)	−5.9	6.8	−7.3	7.4
Co-Gn (mm)	126.9	6.6	117.3	5.1
Intermaxillary				
ANB (°)	3.5	1.9	4.1	1.9
Wits (mm)	1.2	2.5	0.4	3.0
Maxillomandibular differential (mm)	30.1	4.1	26.	4.1
Vertical skeletal				
FH-PP (°)	0.2	3.3	0.3	4.0
FH-FOP (°)	7.6	3.7	10.	3.7
FMA (°)	24.2	5.3	25.6	6.0
Gonial angle (°)	122.3	8.1	122.7	4.7
UFH (mm)	57.6	3.8	53.3	4.1
LAFH (mm)	73.2	6.7	67.7	6.4
UFH:LAFH	79.2	8.1	79.5	10.3
PFH (mm)	65.6	5.3	58.0	3.8
PFH:LAFH	89.9	8.0	86.5	10.4
Maxillary dentoalveolar				
U1-SN (°)	103.3	5.3	99.7	5.8
U1-Pt A vert (mm)	5.3	1.7	4.6	2.5
Mandibular dentoalveolar				
IMPA (°)	95.9	6.7	97.1	7.0
L1-APg (mm)	2.8	2.5	2.9	2.5
Interdental				
Overjet (mm)	3.8	2.5	3.8	1.6
Overbite (mm)	3.8	1.8	3.5	1.4
1/1 (°)	128.0	8.8	128.4	10.7
Soft-tissue profile				
Upper lip to E-plane (mm)	−3.5	2.2	−4.5	2.6
Lower lip to E-plane (mm)	−2.1	2.6	−1.2	2.0
NL angle (°)	123.5	11.2	113.2	10.5
Upper lip cant (°)	−0.3	10.3	2.8	9.0
Thicknesses				
Glabella (mm)	7.0	1.5	6.2	0.8
Subnasale (mm)	14.2	1.4	12.4	2.2
Upper lip (mm)	17.1	2.3	15.9	2.1
Lower lip (mm)	16.5	1.7	14.9	1.7
Pogonion (mm)	14.4	3.6	12.3	2.4
Gnathion (mm)	9.5	2.5	7.9	1.5
Menton (mm)	11.0	5.6	8.0	1.3
Vertical				
Pronasale vertical (mm)	15.1	3.4	15.9	4.6
Columella vertical (mm)	27.0	4.5	25.1	3.9
Upper lip vertical (mm)	53.8	3.5	50.2	3.2
Menton vertical (mm)	105.8	7.0	97.1	5.8
Upper lip length (mm)	27.7	2.8	26.1	3.3

Table III. Descriptive statistics for cephalometric variables at T2

	Men (n = 19)		Women (n = 20)	
Measurement	*Mean*	*SD*	*Mean*	*SD*
Cranial base				
SN-FH (°)	8.7	2.6	9.2	2.8
S-N (mm)	78.9	4.7	74.6	3.0
Ba-S-N (°)	130.4	5.3	132.8	4.5
Maxillary anteroposterior skeletal				
SNA (°)	81.0	4.8	79.5	4.0
Pt A-Na perp (mm)	−0.6	4.4	−1.5	3.7
Co-Pt A (mm)	99.4	5.7	92.9	3.9
Mandibular anteroposterior skeletal				
SNB (°)	77.6	4.1	74.7	3.4
Pg-Na perp (mm)	−5.5	7.1	−9.4	7.7
Co-Gn (mm)	131.0	6.9	119.0	4.8
Intermaxillary				
ANB (°)	3.5	2.3	4.7	2.1
Wits (mm)	1.0	2.8	1.7	3.4
Maxillomandibular differential (mm)	31.6	4.9	26.1	4.5
Vertical skeletal				
FH-PP (°)	0.4	3.9	0.0	3.2
FH-FOP (°)	7.6	3.0	10.6	3.5
FMA (°)	23.2	5.5	26.7	5.5
Gonial angle (°)	121.5	8.0	122.8	4.6
UFH (mm)	58.9	4.6	54.3	3.8
LAFH (mm)	75.8	7.2	70.8	6.0
UFH:LAFH	78.3	9.2	77.3	8.6
PFH (mm)	69.2	5.7	59.3	3.5
PFH:LAFH	91.7	8.6	84.3	8.8
Maxillary dentoalveolar				
U1-SN (°)	101.8	6.9	98.0	6.1
U1-Pt A vert (mm)	5.0	1.7	4.4	2.4
Mandibular dentoalveolar				
IMPA (°)	96.1	6.0	98.8	8.1
L1-APg (mm)	2.3	2.5	3.1	2.5
Interdental				
Overjet (mm)	3.8	2.6	4.2	1.6
Overbite (mm)	4.3	2.3	4.0	1.6
1/1 (°)	130.3	7.8	127.4	11.0
Soft-tissue profile				
Upper lip to E-plane (mm)	−6.8	3.3	−5.8	3.3
Lower lip to E-plane (mm)	−5.6	3.1	−2.3	2.8
NL angle (°)	119.8	11.2	111.7	13.1
Upper lip cant (°)	−7.3	11.2	−0.9	10.2
Thicknesses				
Glabella (mm)	7.1	1.7	6.5	1.5
Subnasale (mm)	14.6	2.6	11.2	2.1
Upper lip (mm)	13.7	1.8	12.1	2.1
Lower lip (mm)	16.2	2.5	13.8	1.6
Pogonion (mm)	15.6	3.0	12.8	2.7
Gnathion (mm)	13.2	4.2	9.1	2.1
Menton (mm)	14.0	5.6	9.0	3.2
Vertical				
Pronasale vertical (mm)	18.9	3.6	17.9	4.4
Columella vertical (mm)	29.9	4.4	27.6	3.8
Upper lip vertical (mm)	58.1	3.8	54.0	3.3
Menton vertical (mm)	111.5	6.9	100.4	6.8
Upper lip length (mm)	30.9	3.0	29.3	2.8

Table IV. Descriptive statistics of cephalometric variables at T3

	Men (n = 19)		Women (n = 20)	
Measurement	*Mean*	*SD*	*Mean*	*SD*
Cranial base				
SN-FH (°)	8.5	2.4	9.4	2.7
S-N (mm)	78.9	4.6	74.3	3.0
Ba-S-N (°)	130.4	5.0	133.3	4.5
Maxillary anteroposterior skeletal				
SNA (°)	81.2	4.9	79.5	3.8
Pt A-Na perp (mm)	−0.6	4.5	−1.2	3.7
Co-Pt A (mm)	99.4	6.1	93.3	3.9
Mandibular anteroposterior skeletal				
SNB (°)	77.5	4.0	74.4	3.3
Pg-Na perp (mm)	−5.7	7.2	−9.5	7.5
Co-Gn (mm)	131.0	7.0	119.3	4.9
Intermaxillary				
ANB (°)	3.7	2.5	5.0	1.9
Wits (mm)	1.6	3.2	2.1	3.1
Maxillomandibular differential (mm)	31.7	5.1	26.0	4.3
Vertical skeletal				
FH-PP (°)	0.2	3.7	−0.1	3.1
FH-FOP (°)	7.1	3.2	10.6	3.8
FMA (°)	23.2	5.6	26.6	5.7
Gonial angle (°)	121.6	7.7	122.6	5.5
UFH (mm)	58.8	4.4	54.4	3.7
LAFH (mm)	76.3	7.8	71.2	6.2
UFH:LAFH	77.8	9.7	77.1	8.5
PFH (mm)	69.6	6.1	59.6	4.0
PFH:LAFH	91.8	9.2	84.3	9.1
Maxillary dentoalveolar				
U1-SN (°)	101.6	6.9	98.4	6.9
U1-Pt A vert (mm)	5.0	1.6	4.4	2.5
Mandibular dentoalveolar				
IMPA (°)	95.2	5.5	98.6	9.0
L1-APg (mm)	2.2	2.7	3.1	2.6
Interdental				
Overjet (mm)	3.8	3.3	4.3	1.6
Overbite (mm)	4.2	2.0	3.9	1.8
1/1 (°)	131.5	8.0	127.0	12.5
Soft-tissue profile				
Upper lip to E-plane (mm)	−6.9	2.9	−5.7	3.4
Lower lip to E-plane (mm)	−6.4	2.2	−2.8	2.7
NL angle (°)	113.8	11.1	109.6	12.8
Upper lip cant (°)	−5.7	11.8	−0.3	9.7
Thicknesses				
Glabella (mm)	7.4	1.4	6.8	1.1
Subnasale (mm)	14.1	2.4	11.4	2.2
Upper lip (mm)	12.4	1.9	10.7	1.8
Lower lip (mm)	15.8	2.2	13.8	2.0
Pogonion (mm)	16.3	2.9	12.7	2.0
Gnathion (mm)	13.2	4.6	9.0	1.3
Menton (mm)	13.4	6.3	8.6	1.7
Vertical				
Pronasale vertical (mm)	19.0	3.2	18.9	4.6
Columella vertical (mm)	31.0	3.7	28.7	4.2
Upper lip vertical (mm)	59.0	3.4	55.1	3.6
Menton vertical (mm)	109.8	6.0	99.4	6.6
Upper lip length (mm)	32.2	3.2	30.8	2.8

Table V. Statistical analysis (RMANOVA) of the T1-T2 changes without significant sex differences (combined male and female data [n = 39])

Measurement	*Mean difference*	*SE*	P *value*
Cranial base			
S-N-FH (°)	0.1	0.1	0.90
S-N (mm)	1.6	0.2	0.01*
Ba-S-N (°)	0.3	0.2	0.58
Maxillary anteroposterior skeletal			
SNA (°)	−0.1	0.2	1.00
Pt A-Na perp (mm)	−0.1	0.2	1.00
Co-Pt A (mm)	2.1	0.2	0.01*
Vertical skeletal			
FH-PP (°)	−0.1	0.2	1.00
FH-FOP (°)	0.1	0.4	1.00
Gonial angle (°)	−0.4	0.3	0.58
UFH (mm)	1.1	0.3	0.01*
LAFH (mm)	2.9	0.3	0.01*
UFH:LAFH	−1.6	0.5	0.02
Maxillary dentoalveolar			
U1-SN (°)	−1.6	0.7	0.08
U1-Pt A vert (mm)	−0.3	0.2	0.18
Mandibular dentoalveolar			
IMPA (°)	0.9	0.6	0.53
Interdental			
Overjet (mm)	0.2	0.2	0.66
Overbite (mm)	0.5	0.2	0.08
1/1 (°)	0.6	1.1	1.00
Soft-tissue profile			
NL angle (°)	2.6	1.5	0.26
Upper lip cant (°)	−5.3	1.0	0.01*
Thicknesses			
Glabella (mm)	0.2	0.2	1.00
Upper lip (mm)	−3.6	0.3	0.01*
Lower lip (mm)	−0.6	0.3	0.11
Pogonion (mm)	0.9	0.3	0.01*
Menton (mm)	2.0	0.9	0.12
Vertical			
Pronasale vertical (mm)	2.9	0.4	0.01*
Columella vertical (mm)	2.7	0.3	0.01*
Upper lip vertical (mm)	4.0	0.3	0.01*
Menton vertical (mm)	4.5	0.6	0.01*
Upper lip length (mm)	3.2	0.3	0.01*

*$P < 0.01$.

Table VI. Statistical analysis (RMANOVA) of the T2-T3 changes without significant sex differences (combined male and female data [n = 39])

Measurement	*Mean difference*	*SE*	P *value*
Cranial base			
SN-FH (°)	0.0	0.1	1.00
S-N (mm)	−0.1	0.1	0.92
Ba-S-N (°)	0.2	0.2	1.00
Maxillary anteroposterior skeletal			
SNA (°)	0.1	0.2	1.00
Pt A-Na perp (mm)	0.1	0.1	1.00
Co-Pt A (mm)	0.2	0.1	0.53
Vertical skeletal			
FH-PP (°)	−0.1	0.2	1.00
FH-FOP (°)	−0.2	0.3	1.00
Gonial angle (°)	0.0	0.3	1.00
UFH (mm)	0.0	0.1	1.00
LAFH (mm)	0.4	0.2	0.04
UFH:LAFH	−0.3	0.3	0.75
Maxillary dentoalveolar			
U1-SN (°)	0.1	0.4	1.00
U1-Pt A vert (mm)	0.0	0.1	1.00
Mandibular dentoalveolar			
IMPA (°)	−0.5	0.6	1.00
Interdental			
Overjet (mm)	0.0	0.4	1.00
Overbite (mm)	0.1	0.1	1.00
1/1 (°)	0.4	0.8	1.00
Soft-tissue profile			
NL angle (°)	−4.0	1.2	0.01*
Upper lip cant (°)	1.1	0.7	0.41
Thicknesses			
Glabella (mm)	0.3	0.2	0.49
Upper lip (mm)	−1.4	0.2	0.01*
Lower lip (mm)	−0.2	0.2	0.60
Pogonion (mm)	0.3	0.3	0.89
Menton (mm)	−0.4	0.6	1.00
Vertical			
Pronasale vertical (mm)	0.6	0.3	0.16
Columella vertical (mm)	1.1	0.2	0.01*
Upper lip vertical (mm)	1.0	0.2	0.01*
Menton vertical (mm)	−1.2	0.6	0.10
Upper lip length (mm)	1.4	0.2	0.01*

*$P < 0.01$.

from T1 to T2 and T2 to T3; for variables that did not show a significant time and sex interaction, the combined male and female data are reported in Tables V and VI. For variables with a significant time and sex interaction, a separate RMANOVA was carried out for the sexes. These results are shown in Tables VII through X. The average changes in craniofacial configurations of the subjects from T1 to T2 and T2 to T3 are illustrated in Figures 3 through 6.

From T1 to T2, several significant changes were apparent in the soft-tissue measurements, showing that men and women changed similarly with time. Specifically, the cant of the upper lip decreased by 5.3°, upper lip thickness decreased 3.6 mm, upper lip length increased 3.2 mm, and upper lip vertical increased 4.0 mm. Soft-tissue thickness at pogonion increased by 0.9 mm, and menton vertical increased by 4.5 mm. Both vertical nasal measurements increased significantly; columella vertical and pronasale vertical increased by 2.7 and 2.9 mm, respectively.

From T2 to T3, a significant decrease in the nasolabial angle was noted (resulting in a more acute nasolabial angle). Similar changes were significant with respect to the upper lip, as were described in the

Table VII. Statistical analysis (RMANOVA) of the T1-T2 changes with significant sex differences (male subjects' data [n = 19])

Measurement	*Mean difference*	*SE*	P *value*
Mandibular anteroposterior skeletal			
SNB (°)	0.2	0.2	1.00
Pg-Na perp (mm)	0.4	0.3	0.63
Co-Gn (mm)	4.1	0.4	0.01*
Intermaxillary			
ANB (°)	0.0	0.2	1.00
Wits (mm)	−0.2	0.4	1.00
Maxillomandibular differential (mm)	−1.5	0.4	0.01*
Vertical skeletal			
FMA (°)	−1.0	0.3	0.01*
PFH (mm)	3.6	0.4	0.01*
Mandibular dentoalveolar			
L1-APg (mm)	−0.4	0.2	0.10
Soft-tissue profile			
Upper lip to E-plane (mm)	−3.3	0.7	0.01*
Lower lip to E-plane (mm)	−3.5	0.7	0.01*
Thicknesses			
Subnasale (mm)	0.4	0.5	1.00
Gnathion (mm)	3.6	0.7	0.01*

*$P < 0.01$.

Table VIII. Statistical analysis (RMANOVA) of the T1-T2 changes with significant sex differences (female subjects' data [n = 20])

Measurement	*Mean difference*	*SE*	P *value*
Mandibular anteroposterior skeletal			
SNB (°)	−1.1	0.2	0.01*
Pg-Na perp (mm)	−2.2	0.4	0.01*
Co-Gn (mm)	1.8	0.3	0.01*
Intermaxillary			
ANB (°)	0.7	0.2	0.01*
Wits (mm)	1.3	0.4	0.01*
Maxillomandibular differential (mm)	0.0	0.3	1.00
Vertical skeletal			
FMA (°)	1.0	0.3	0.01*
PFH (mm)	1.3	0.3	0.01*
Mandibular dentoalveolar			
L1-APg (mm)	0.2	0.2	1.00
Soft-tissue profile			
Upper lip to E-plane (mm)	−1.3	0.3	0.01*
Lower lip to E-plane (mm)	−1.1	0.4	0.01*
Thicknesses			
Subnasale (mm)	−1.3	0.2	0.01*
Gnathion (mm)	1.1	0.5	0.11

*$P \leq 0.01$.

Table IX. Statistical analysis (RMANOVA) of the T2-T3 changes with significant sex differences (male subjects' data [n = 19])

Measurement	*Mean difference*	*SE*	P *value*
Mandibular anteriorposterior skeletal			
SNB (°)	−0.1	0.2	1.00
Pg-Na perp (mm)	−0.1	0.2	1.00
Co-Gn (mm)	0.0	0.2	1.00
Intermaxillary			
ANB (°)	0.2	0.2	0.48
Wits (mm)	0.6	0.3	0.25
Maxillomandibular differential (mm)	0.1	0.2	1.00
Vertical skeletal			
FMA (°)	0.0	0.2	1.00
PFH (mm)	0.5	0.3	0.47
Mandibular dentoalveolar			
L1-APg (mm)	−0.2	0.2	0.86
Soft-tissue profile			
Upper lip to E-plane (mm)	−0.1	0.4	1.00
Lower lip to E-plane (mm)	−0.7	0.5	0.54
Thicknesses			
Subnasale (mm)	−0.5	0.3	0.42
Gnathion (mm)	0.1	0.4	1.00

Table X. Statistical analysis (RMANOVA) of the T2-T3 changes with significant sex differences (female subjects' data [n = 20])

Measurement	*Mean difference*	*SE*	P *value*
Mandibular anteroposterior skeletal			
SNB (°)	−0.3	0.1	0.20
Pg-Na perp (mm)	−0.1	0.2	1.00
Co-Gn (mm)	0.3	0.2	0.48
Intermaxillary			
ANB (°)	0.3	0.2	0.25
Wits (mm)	0.4	0.4	1.00
Maxillomandibular differential (mm)	−0.1	0.2	1.00
Vertical skeletal			
FMA (°)	−0.1	0.2	1.00
PFH (mm)	0.3	0.3	0.99
Mandibular dentoalveolar			
L1-APg (mm)	0.0	0.1	1.00
Soft-tissue profile			
Upper lip to E-plane (mm)	0.1	0.3	1.00
Lower lip to E-plane (mm)	−0.5	0.3	0.18
Thicknesses			
Subnasale (mm)	0.2	0.2	1.00
Gnathion (mm)	0.0	0.5	1.00

previous time span: the upper lip decreased in thickness (1.4 mm) and increased in length (1.4 and 1.0 mm for upper lip length and upper lip vertical, respectively). Soft-tissue thickness at pogonion continued to increase from T2 to T3, but this change was not statistically significant.

Other soft-tissue measurements were evaluated separately for the sexes. Of these measurements,

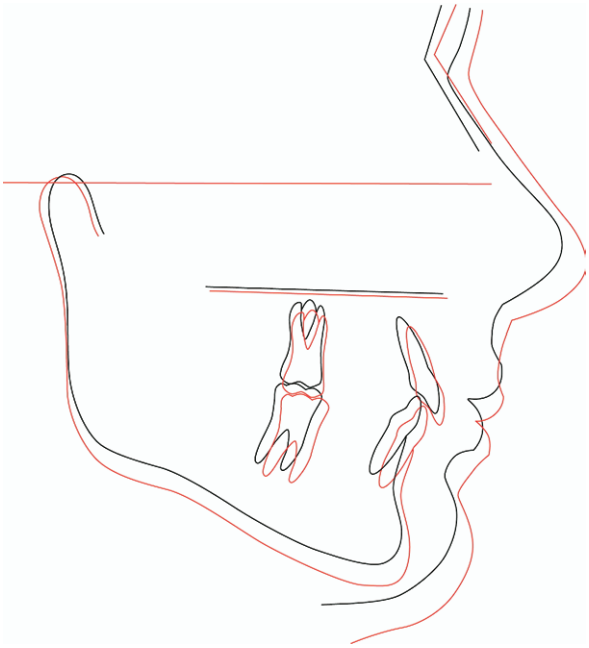

Fig 3. Superimposition of average male profiles from T1 to T2 (*black line,* T1; *red line,* T2).

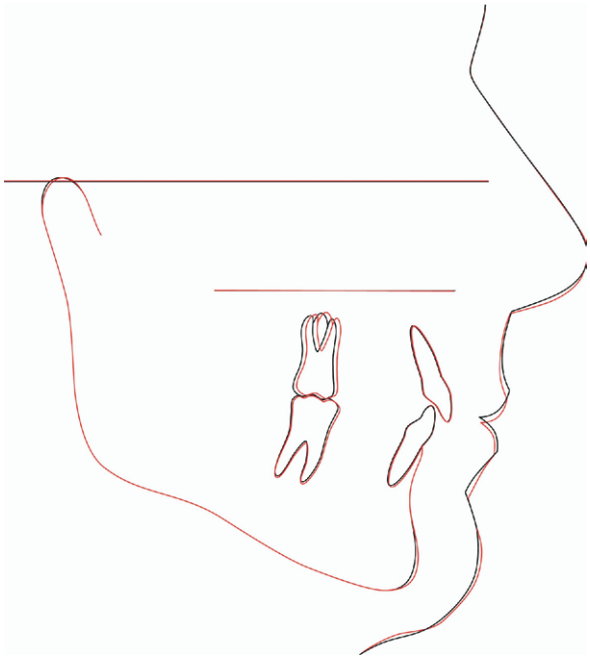

Fig 5. Superimposition of average male profiles from T2 to T3 (*black line,* T2; *red line,* T3).

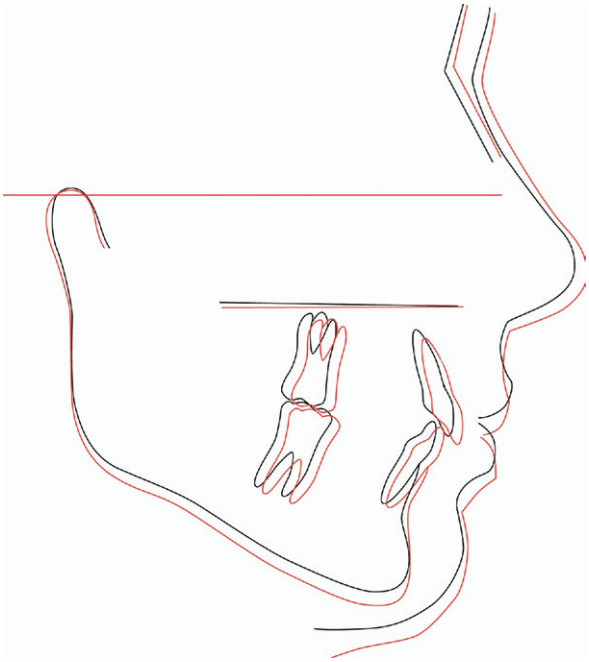

Fig 4. Superimposition of average female profiles from T1 to T2 (*black line,* T1; *red line,* T2).

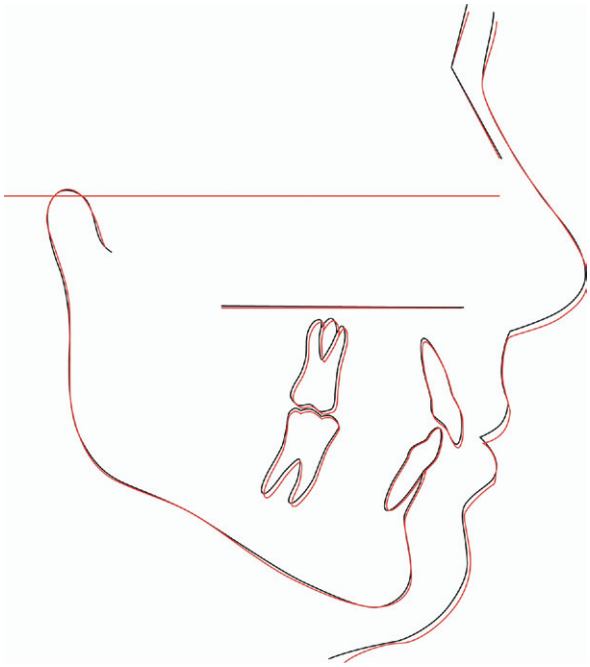

Fig 6. Superimposition of average female profiles from T2 to T3 (*black line,* T2; *red line,* T3).

none was significant from T2 to T3, but several were from T1 to T2. Upper and lower lip to E-plane decreased significantly for both sexes. Only the men, however, had significant increases in soft-tissue thickness at gnathion. In contrast, only the women had a significant change in soft-tissue thickness at subnasale, which decreased significantly from T1 to T2.

For the skeletal measurements without sex differences over time that were evaluated together, significant changes in the anteroposterior and vertical dimensions were observed from T1 to T2. These changes were apparent in anterior cranial base length, midfacial length, lower anterior facial height, and upper facial height to lower facial height ratio. No significant changes were observed from T2 to T3.

Anterior cranial base length was measured from sella to nasion. Although no significant change was noted from mid- to late adulthood, this measurement increased significantly (1.6 mm) from late adolescence to midadulthood. No significant changes were apparent for either angular measurement examined: sella-nasion to Frankfort horizontal and cranial base angle.

Midfacial length was measured from condylion to Point A. This measurement increased significantly by 2.1 mm from late adolescence to midadulthood. Other maxillary measures evaluated (midfacial length, SNA angle, Point A-nasion perpendicular) did not change significantly in either time period.

Because of sex differences over time, mandibular length, SNB angle, and pogonion-nasion perpendicular were evaluated separately for the sexes. From late adolescence to midadulthood, mandibular length increased 4.1 and 1.8 mm for men and women, respectively. No significant changes in mandibular length were observed from mid- to late adulthood.

The position of the mandible in relation to the cranial base (SNB angle) remained fairly stable in the men from T1 to T2 and T2 to T3. The women, on the other hand, had significant decreases in SNB angle and pogonion-nasion perpendicular from T1 to T2. No significant change in the angle was observed in the women from T2 to T3.

Because of differences between the sexes, all intermaxillary measurements were evaluated separately. The Wits appraisal was significant for the women from T1 to T2, with an increase of 1.3 mm. The change in the ANB angle also was significant for the women over the same time period; neither measurement was significant in the men. The men, on the other hand, had a significant change in the maxillomandibular differential, which increased by 1.5 mm from T1 to T2.

Lower anterior facial height increased significantly from T1 to T2. From late adolescence to midadulthood, it increased 2.9 mm. The increase from mid- to late adulthood (0.4 mm) was not significant. Additionally, upper facial height increased significantly from T1 to T2 but to a lesser extent. Coinciding with these changes in facial height, the ratio of upper facial height to lower facial height decreased from T1 to T2.

An additional measure of vertical dimension—posterior facial height—was evaluated separately for the sexes. From T1 to T2, both sexes both had significant increases in posterior facial height of 3.6 and 1.3 mm, respectively. Increases in posterior facial height in either sex from T2 to T3 were not statistically significant. The mandibular plane angle also was evaluated separately for the sexes. Distinct differences were noted from T1 to T2; the men had a significant decrease of 1°, and the women had a significant increase of the same magnitude.

The relationship of the maxillary central incisors to the mandibular central incisors showed no significant change at either time point. The angle between the incisors increased (ie, became more obtuse) from T1 to T2 and T2 to T3, but these changes were not statistically significant.

DISCUSSION

We evaluated changes in the craniofacial complex over more than 40 years, from late adolescence to late adulthood. Emphasis was placed on the changes from mid- to late adulthood, specifically the soft-tissue changes. Thirty-nine subjects were included in the study, a 69% success rate in relation to the previous recall effort when 56 subjects were evaluated. These data demonstrated that several soft-tissue and skeletal changes occur in the craniofacial complex throughout adulthood. As one would expect, changes in the soft-tissue integument provide the most dramatic evidence of postadolescent craniofacial changes, whereas skeletal measurements did not show significant changes from mid- to late adulthood.

Soft-tissue changes

Several upper-lip measures changed significantly over the 2 time periods. Upper-lip length increased 3.2 and 1.4 mm from T1 to T2 and T2 to T3, respectively. Coinciding with this increase in length was thinning of the upper lip, again significant in both time periods (decreasing 3.6 mm from T1 to T2 and 1.4 mm from T2 to T3). These findings agree with the data of Behrents[1,4] and Nanda et al,[14] and they are most likely due to the natural aging process in which the skin becomes less consistent and inelastic over time, in addition to the effect of gravity. Other changes in the integument with age include thinning of the epidermis and loss of subcutaneous fat.[1] The cant of the upper lip also changed significantly from T1 to T2, decreasing as a logical consequence of the flattening of the upper lip.

Soft-tissue thickness at pogonion showed a significant increase of 0.9 mm from T1 to T2 and continued to increase (0.3 mm) from mid- to late adulthood. Also supporting Behrents' data[1] on the differences between sexes in the region of the soft-tissue chin was the observation that, in the men, soft-tissue gnathion increased more than 3 times the amount in the women (3.6 vs 1.1 mm in men and women, respectively).

The 2 linear nasal measurements (columella vertical and pronasale vertical) are unique to this investigation. These measurements were chosen not only because of the stability of Frankfort horizontal but also to describe the vertical changes with age. Columella and pronasale vertical increased significantly by 2.7 and 2.9 mm, respectively, from T1 to T2. These measurements also continued to increase from mid- to late adulthood, but only columella vertical was significant. Several previous researchers noted similar findings with regard to the downward and forward movement of the nose with advancing age.[1,3,6,7]

The downward movement of columella led to a significant decrease in the nasolabial angle from T2 to T3. Although the thickness of the upper lip decreased, the effect of columella moving inferiorly overrode the change in lip thickness, resulting in a more acute nasolabial angle.

Upper and lower lip to E-plane measurements were evaluated separately for the sexes. Retrusion of the upper and lower lips to the E-plane were apparent from T1 to T2. This agrees with the findings of Bishara et al,[15] who described progressive retrusion of the lips along with a decrease of the Holdaway soft-tissue angle from adolescence through 45 years of age in both sexes. In the women, the upper and lower lips to the E-plane retruded 1.3 and 1.1 mm, respectively. The men had much greater lip retrusion: 3.3 mm in the upper lip and 3.5 mm in the lower lip. This was a consistent finding in previous research.[1-3,16] The changes in the lips in relation to the E-plane were due to a combination of decreased lip thickness and anterior movement of the nose and chin landmarks.

Skeletal changes

The increase in sella-nasion length was significant from T1 to T2, but no change was noted in the 11-year period of T2 to T3. Behrents[1] found a similar increase in the length of sella-nasion with a consistent anterior movement of nasion. He also reported on the continued development of the frontal sinus that then would displace nasion in a more anterior position. Similarly, Sarnäs and Solow[8] noted an increase in anterior cranial base length in their adult growth study and noted that the changes might be due to a combination of the anterior movement of nasion and the posterior movement of sella.

Midfacial length as measured from condylion to Point A increased significantly from T1 to T2. It continued to increase from T2 to T3, but the increase was not significant. Previous research reported similar findings: forward movement of the maxilla consistent with the movement of nasion.[1,3]

Mandibular length (condylion to anatomic gnathion) was evaluated separately for the sexes. Both showed significant increases in mandibular length from T1 to T2, with men having greater increases than women (4.1 and 1.8 mm, respectively). However, several men had not completed their circumpubertal active growth at T1. In spite of their chronologic age (beyond 16 years) at T1, 4 of the 19 male subjects were at CS5, and 1 was still at CS4 in skeletal maturation. On the contrary, all 20 female subjects had an adult CS6 at T1. This difference in individual skeletal maturation between the sexes at T1 could well account for the discrepancy in the amount of mandibular growth of the men vs the women from T1 to T2. Small increases were noted in the men from mid- to late adulthood, and these changes were not statistically significant. Similar findings of increases in mandibular length after adolescence were noted in previous studies.[2,3,17]

The direction of mandibular growth showed some between-sex differences also. The women had more change in the vertical dimension than the sagittal, with posterior rotation of the mandible. In contrast, the men had more anterior rotation of the mandible. These observations were described by the changes in mandibular plane angle, pogonion-nasion perpendicular, and SNB angle. For example, the posterior rotation of the mandible in the women was associated with a decrease in SNB, an increase in the distance from pogonion to nasion perpendicular, and an increase in the mandibular plane angle. These results confirm previous observations by West and McNamara.[3]

Intermaxillary measurements (Wits appraisal, ANB angle, and maxillomandibular differential) were analyzed separately for the sexes. Differences were apparent: ANB and Wits increased significantly in the women from T1 to T2, whereas neither was significant for the men. These changes provide further evidence of the posterior mandibular rotation visualized in the superimpositions. The men had a significant increase in maxillomandibular differential, but the women did not. No intermaxillary measure was significant for either sex from T2 to T3.

Upper facial height increased significantly from T1 to T2. Lower anterior facial height showed an even

more dramatic increase in the same age range. These data agree with those of Sarnäs and Solow,[8] who noted significant changes in total facial height, increasing 1.5 mm in 5 years, most of which was attributed to the increase in lower anterior facial height. West and McNamara[3] found similar increases in facial height after adolescence. The increase in facial height is most likely due to a combination of the continued eruption of the dentition along with downward movement of the maxilla and thus the anterior nasal spine, as noted previously.[1]

Posterior facial height was analyzed separately for the sexes and increased in both from T1 to T2 and T2 to T3. Only the increase in the former period, however, was significant. Most of the literature on postadolescent growth supports this finding.[1,3,6]

CONCLUSIONS

The purpose of this study was to examine the hard- and soft-tissue changes during adulthood. The subjects were recalled from the University of Michigan Elementary and Secondary School Growth Study for additional orthodontic records. Cephalometric radiographs were examined at 3 times: late adolescence, midadulthood, and late adulthood.

Overall, this investigation provided further evidence for the continuation of changes in the craniofacial complex with age, and it did not corroborate the hypothesis that growth stops soon after puberty. Although the changes after adolescence are smaller than those in adolescence, the culmination of these changes throughout life results in the facial features that one associates with increased age.

Statistically significant changes occurred from late adolescence to midadulthood and from mid- to late adulthood. Changes in the skeletal tissues consisted of increases in sella-nasion length, midfacial length, and lower anterior facial height. These changes were significant only from late adolescence to midadulthood. Sex differences were apparent in the mandible. Women had more vertical movement of the mandible, rotating downward and backward. The men, on the other hand, had more forward rotation of the mandible and increased chin prominence. From late adolescence through late adulthood, skeletal changes included on average a 2-mm increase in maxillary length, about a 3-mm increase in mandibular length, and about a 3.5-mm increase in lower anterior facial height. Changes in the soft tissues were the most remarkable during both age periods, and they included thinning and elongation of the upper lip. Additionally, significant changes in the nose took place, including drooping of the nasal tip and columella, the latter leading to a more acute nasolabial angle.

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REFERENCES

1. Behrents RG. Growth in the aging craniofacial skeleton. Monograph 17. Craniofacial Growth Series. Ann Arbor: Center for Human Growth and Development; University of Michigan; 1985.
2. Bishara SE, Treder JE, Jakobsen JR. Facial and dental changes in adulthood. Am J Orthod Dentofacial Orthop 1994;106:175-86.
3. West KS, McNamara JA Jr. Changes in the craniofacial complex from adolescence to adulthood: a cephalometric study. Am J Orthod Dentofacial Orthop 1999;115:521-32.
4. Behrents RG. An atlas of growth in the aging craniofacial complex. Monograph 18. Craniofacial Growth Series. Ann Arbor: Center for Human Growth and Development; University of Michigan; 1985.
5. Lewis AB, Roche AF. Late growth changes in the craniofacial skeleton. Angle Orthod 1988;58:127-35.
6. Formby WA, Nanda RS, Currier GF. Longitudinal changes in the adult facial profile. Am J Orthod Dentofacial Orthop 1994;105: 464-76.
7. Forsberg CM. Facial morphology and ageing: a longitudinal cephalometric investigation of young adults. Eur J Orthod 1979;1:15-23.
8. Sarnäs KV, Solow B. Early adult changes in the skeletal and soft-tissue profile. Eur J Orthod 1980;2:1-12.
9. Bondevik O. Growth changes in the cranial base and the face: a longitudinal cephalometric study of linear and angular changes in adult Norwegians. Eur J Orthod 1995;17:525-32.
10. Proffit W, Fields HW. Contemporary orthodontics. 3rd ed. St Louis: Mosby Year Book; 2000.
11. Baccetti T, Franchi L, McNamara JA Jr. The cervical vertebral maturation (CVM) method for the assessment of optimal treatment timing in dentofacial orthopedics. Semin Orthod 2005;11: 119-29.
12. McNamara JA Jr, Howe RP, Dischinger TG. A comparison of the Herbst and Fränkel appliances in the treatment of Class II malocclusion. Am J Orthod Dentofacial Orthop 1990;98:134-44.
13. Levin AS, McNamara JA Jr, Franchi L, Baccetti T, Fränkel C. Short-term and long-term treatment outcomes with the FR-3 appliance of Fränkel. Am J Orthod Dentofacial Orthop 2008 (in press).
14. Nanda RS, Meng H, Kapila S, Goorhuis J. Growth changes in the soft tissue facial profile. Angle Orthod 1990;60:177-90.
15. Bishara SE, Jakobsen JR, Hession TJ, Treder JE. Soft tissue profile changes from 5 to 45 years of age. Am J Orthod Dentofacial Orthop 1998;114:698-706.
16. Zylinski CG, Nanda RS, Kapila S. Analysis of soft tissue facial profile in white males. Am J Orthod Dentofacial Orthop 1992; 101:514-8.
17. Israel H. Recent knowledge concerning craniofacial aging. Angle Orthod 1973;43:176-84.