ORIGINAL ARTICLE

Changes in the craniofacial complex from adolescence to midadulthood: A cephalometric study

Kristine S. West, DDS, MS,[a] and James A. McNamara, Jr, DDS, PhD[b]
Ann Arbor, Mich

The purpose of the present study was to evaluate cephalometrically the craniofacial growth changes and adjustments that occur from late adolescence to midadulthood in persons who had no previous history of orthodontic treatment. Serial lateral cephalograms from 58 subjects from the *University of Michigan Elementary and Secondary Growth Study* recalled on average in their late 40s were examined. Fifteen of the patients also had cephalograms taken in early adulthood (early 30s). Statistically significant growth changes occurred; mandibular and midfacial lengths as well as posterior and lower anterior facial heights had increased significantly for males and females over both time intervals. The pattern of expression of these changes was different in the two genders: males showed an anterior rotation of the mandible, whereas females demonstrated a posterior rotation of the mandible. Soft tissue changes also were somewhat different between genders. In males, the nose and chin grew downward and forward, with the lips generally moving straight downward. In contrast, females had nasal growth that progressed downward and forward, and there was a slight retrusion of the lips over time. Continued tooth eruption was noted in both genders as well. (Am J Orthod Dentofacial Orthop 1999;115:521-32)

With the increasing number of adults who seek esthetic and functional improvement of their teeth and facial structures through orthodontic treatment and sometimes through orthognathic surgery, an understanding of the normal changes that occur in the craniofacial complex with age is becoming increasingly important. Further, the growing popularity of endosteal implants in the treatment of the dentally compromised patient makes an understanding of craniofacial changes in the supposedly "nongrowing" adult of critical importance, because typically implant placement is recommended only after growth has ceased or is clinically insignificant.

Most previous cephalometric research into normal craniofacial growth has been directed toward early postnatal growth,[1-6] extending through the years of adolescence into the late second decade. Aside from the greater availability of complete orthodontic records of adolescents, the general assumption of cessation of growth by the late teens or early twenties has biased researchers to focus on this younger group. To date, relatively little effort has been spent analyzing craniofacial growth in adults.

One of the first attempts to examine craniofacial growth into early adulthood was a cross-sectional study by Björk[7] who used lateral headfilms to compare the facial profiles of 12-year-old boys to those of an approximately equal number of adult males. In a subsequent study, Björk[8] recalled the adolescents used in the previous study at the age of 20 and compared their cephalometric radiographs taken at both times. Björk[9,10] refined his technique for studying longitudinal cephalometric changes by inserting metallic implants into the bony structures of willing subjects for the purpose of more precise superimposition of the headfilms and used implant superimposition for a study of the growth of the mandible. Björk's studies showed that growth continued up through age 22; growth much beyond that age typically was not thought to be relevant by most clinicians.

Kendrick and Risinger[11] examined cephalometric radiographs taken over a 1-year interval on 71 subjects between the ages of 22 and 34 and found that all of the anteroposterior skull dimensions measured showed significant increases (eg, anterior and posterior cranial depth, upper, middle, and lower facial depth). In particular, the area of the chin (lower facial depth) showed significant anterior movement after the age of 22.

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[a]Adjunct Lecturer, Department of Orthodontics and Pediatric Dentistry, The University of Michigan, Ann Arbor Michigan; and in private practice of orthodontics, Ann Arbor and Okemos, Mich.
[b]Thomas M. and Doris Graber Endowed Professor of Dentistry, Department of Orthodontics and Pediatric Dentistry, School of Dentistry; Professor of Anatomy and Cell Biology, School of Medicine; Research Scientist, Center for Human Growth and Development, The University of Michigan, Ann Arbor; and in private practice of orthodontics, Ann Arbor.
Reprint requests to: Dr. Kristine S. West and Dr. James A. McNamara, Department of Orthodontics and Pediatric Dentistry, School of Dentistry, University of Michigan, Ann Arbor, MI 48109-1078.

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Sarnäs and Solow[12] also examined early adult craniofacial changes in a sample of 50 female and 101 male dental students. The mean age at the first cephalogram was 21 years, with the subsequent radiograph taken 5 years later. Overall, no sexual dimorphism was found with respect to the magnitude of change in linear dimensions. The largest changes noted were those in the vertical dimension, especially in total anterior facial height. Both sexes showed a larger increase in lower facial height than in upper facial height. Concurrent with the increase in lower facial height was an increase in both upper lip length and lower lip length, with a reduction of upper lip thickness found in males.

In 1973, Israel[13,14] published two studies of females, one longitudinal and the other mixed cross-sectional and longitudinal in design. In the longitudinal study,[13] the 26 females were 24 to 48 years of age at the time of the initial cephalogram and 13 to 28 years older when a final radiograph was taken. Thus, the age of each subject at the time of the final film was between 41 and 64 years. The results from Israel's study showed slight increases in several craniofacial dimensions, including cranial thickness, cranial base length, and upper anterior facial height. In the mandible, the length between the condyle and gnathion enlarged 4%, whereas the distance between menton and gonion showed a gain of 5%. The second study by Israel[14] reported similar findings on some of the females for whom longitudinal data was available. Israel[13,14] explained the changes in the craniofacial complex later in life as a "virtual magnification process." He was unable, however, to elucidate the mechanisms associated with the observed changes.

Forsberg and Odenrick[15] conducted a longitudinal cephalometric study that involved 25 males and 24 females, with the mean initial age of 24.5 years and a mean final age of 34.7 years. In contrast to the previously discussed studies of Israel,[13,14] all of the linear measurements in Forsberg's investigation were corrected for cephalometric enlargement. Forsberg and Odenrick found that there was a significant increase in total facial height, which they attributed to a slight increase in lower facial height (0.6 mm), as they found no noticeable increase in upper facial height. No change in the anteroposterior dimension of the maxilla was observed in either males or females, and no significant changes in the mandible were found in the subjects. There were some changes observed in the soft tissues: the apex of the nose moved anteriorly, the upper and lower lips retruded, and in females soft tissue pogonion demonstrated a posterior movement. Forsberg and Odenrick[15] suggested that because dimensional changes of individual bones such as the maxilla and mandible could not be shown, the changes measured probably were due to a posterior rotation of the mandible. The reasoning behind this lack of dimensional changes, particularly in the mandible, was that no change in the gonial angle was measured, but there was an increase in the inclination of the mandibular plane as compared with the sella-nasion line.

In an effort to determine whether growth indeed continues into adulthood and to estimate the ages at which certain structures cease to grow, Lewis and Roche[16] selected 20 participants from the *Fels Longitudinal Study* to investigate. Each individual had one cephalogram taken during late adolescence with 3 to 8 succeeding radiographs taken, at least one of which was exposed when the subject was between 40 and 50 years of age. Focusing on cranial base length and mandibular length, Lewis and Roche found that the maximum lengths of these structures occurred between the ages of 29 and 39, followed by a very small but measurable decrease in the lengths of the cranial base and mandible.

Behrents[17] conducted the most indepth investigation into the changes in the aging craniofacial complex. The sample consisted of 113 individuals who had participated in the *Bolton-Brush Growth Study* of Case Western Reserve University as children and on whom an additional set of records had been obtained in adulthood (age range, 25 to 83). Changes in linear and angular measures of the craniofacial region were examined with a conventional cephalometric analysis. In the midface, there was general stability of the pterygomaxillary fissure, but the posterior aspect of the palate continued to move inferiorly while remodeling posteriorly. Point A maintained its angular relationship to the anterior cranial base, suggesting that the maxilla moved forward in concordance with nasion. The overall length of the mandible, as well as of the body and ramus, increased with age, and the gonial angle became more acute, particularly in males. In males, the chin landmarks moved downward and forward, but in females the landmarks moved straight downward.

Behrents[17] also noted that the soft tissues of the face undergo marked changes with time. Relative to cranial base structures, soft tissue glabella continued to move forward, the most anterior portion of the nose moved downward and forward, the upper lip elongated and flattened with age, whereas the lower lip prominence showed a relative increase. In addition to these changes, soft tissue pogonion became more prominent with age, especially in male subjects. Although this study was thorough and had a large sample size, the age range of those with final records was very broad; it therefore is difficult to conclude whether the morphologic changes that occurred took place in the late teens or early twenties or many years later into adulthood.

More recently, two studies have examined further the extent of adult growth as reflected by skeletal and dental changes. Bishara et al[18] longitudinally evaluated untreated normal individuals (15 males and 15 females) at ages 25 and 46. They reported that anteroposterior and vertical skeletal dimensions continued to change during adulthood in both sexes. The male skeletal profile tended to increase in convexity because of an increase in the prominence of the maxilla, whereas the female skeletal profile tended to increase in convexity because of a posterior rotation of the mandible. Formby et al[19] analyzed the longitudinal growth changes in 24 male and 23 female subjects from the age of 18 to 42 years. The subjects were divided into four groups on the basis of age: (1) 18 and 19 years, (2) 20 to 24 years, (3) 25 to 29 years, and (4) 30+ years. In the fourth group, only 15 males and 9 females remained. The authors concluded that females showed more changes in soft and hard tissue measurements after 25 years of age than before, whereas most hard tissue changes in males had been accomplished by the age of 25 but not soft tissue changes. The male profile generally was shown to straighten with age with a concomitant retrusion of the lips, whereas the female profile did not straighten nor did the lips retrude.

In summary, in comparison to cephalometric studies of juvenile and adolescent growth, relatively few studies have considered growth into midadulthood. The purpose of the present investigation is to evaluate new data derived from recalling subjects from one of the major longitudinal craniofacial growth studies to verify some of the male-female differences noted in previous investigations. In addition, a unique sample of films taken during early adulthood (early 30s) on 15 of the subjects are analyzed to determine whether growth is a continuous process that occurs throughout the third through fifth decades of life or rather mainly during the early adult period.

SUBJECTS AND METHODS

Sample

The longitudinal records examined in this investigation were from subjects of *The University of Michigan Elementary and Secondary School Growth Study (UMGS).* The subjects of this study originally were students (ages 3 to 18 years) who were enrolled in the University School, a laboratory school within the School of Education on the Ann Arbor campus. Cephalometric data were gathered annually beginning in 1953, and data collection continued until the school was closed in 1968. Based on these longitudinal cephalometric data, Riolo et al[1] published an atlas describing normal craniofacial growth in orthodontically untreated children and adolescents.

In total, the UMGS contains dental, psychometric and anthropometric data on approximately 700 individuals, including subjects who had dental casts and noncephalometric radiographs taken before 1953. Because subjects were included in the study only while they were in attendance at the University School, the cephalometric data are comprised of serial records of variable lengths beginning at varying ages.

For the purpose of the current study, the cephalometric records of the UMGS were examined to determine the number of subjects who had a lateral cephalogram at the end of adolescence (minimum age 15 years for females, 16 years for males) and who had not undergone orthodontic treatment during childhood or adolescence. A sample of 82 individuals in the UMGS was identified to recall for an additional set of orthodontic records. A total of 60 subjects were located who agreed to participate in the cephalometric portion of the recall study. An additional 19 members of the target group could not be located or had schedules that prevented their participation; three others chose not to participate in the recall study. Furthermore, three of the original target group were dropped from the study because the latest adolescent cephalogram was found to be untraceable and the prior year's cephalogram would have been at an age younger than the minimum required. One additional subject was excluded from the study after gathering the records because of obvious physical growth abnormalities. All subjects except four had an Angle Class I molar relationship. The remainder were Class II; Class III malocclusion was not represented in the recall sample, although one subject had a strong Class III tendency. A description of the dental casts of the subjects in the recall study is provided in a companion publication.[20]

The final sample size for the cephalometric portion of the recall study was 56. None of these subjects had undergone orthodontic treatment in adulthood. The mean age of the last available cephalogram taken during adolescence (T_1) on the female subjects was 17 years, 2 months ± 8 months, and the mean age for the male subjects was 17 years, 6 months ± 7 months. The mean age of the females at the time of their recall cephalogram (T_3) was 48 years, 4 months ± 3 years, 8 months, whereas that of the males was 47 years, 4 months ± 4 years, 2 month.

A small number of subjects (N = 15) had an additional set of orthodontic records taken in 1981 (T_2) as part of a recall pilot study. Because of the uniqueness of this sample, this set of cephalograms was included in the analysis as well. The mean age of the female subjects at T_2 was 31 years, 0 months ± 2 years, 6 months, and the mean age of the males was 31 years, 5 months ± 2 years, 9 months. Therefore, not only was growth assessed from late adolescence to adulthood, but also growth was assessed from what we define as "early adulthood" (early 30s) to "mid adulthood" (late 40s).

In the *University of Michigan Elementary and Secondary School Growth Study*, all cephalograms were taken at a standardized subject-to-film distance that produced 12.92% enlargement.[21] The recall cephalograms were taken at an object-film distance (19.7 cm) that produced the same enlargement as that of the T_1 film, thus minimizing the enlargement error in the measurements. For radiographs that would not be taken in Ann Arbor, a radiographic test object was constructed. It consisted of a 2-mm thick piece of splint Biocryl with four small spheres of lead shot implanted exactly 100 mm apart at each corner forming a square. The design allowed the test object to be fixed in the midsagittal plane, suspended between the ear rods with the aid of polyvinyl chloride piping. One template was sent to each of the out-of-town cooperating orthodontists, and an exposure of the template was made just before taking the cephalogram of the subject at the same subject-to-film distance. Thus, the specific enlargement factor for each T_3 film was known, a critical factor in the analysis of adult growth changes. During the analysis, all linear cephalometric measurements were converted to a standardized enlargement of 8% to facilitate comparison to the enlargement factor typically found in routine clinical practice.[22]

Cephalometric Analysis

A conventional cephalometric approach was used to examine the data, with specific variables derived from the analyses of Steiner,[23,24] Riedel,[25] Ricketts,[26-28] and McNamara et al.[29,30] These data will be analyzed with the methods of Bookstein[31-33] in a subsequent study.

The sets of lateral cephalograms were selected in a random order and were traced on 0.003 inch frosted acetate by one investigator (K.S.W.) and then checked for landmark location by a second (J.A.M.). Disagreements in landmark position were resolved mutually. Regional superimpositions at the cranial base, midface, and mandible were performed by hand, using the basion-nasion line with superimposition on the pterygomaxillary fissure or the internal structures of the maxilla or mandible, according to the protocol described by Ricketts[34] and McNamara.[29] All cephalometric measurements were generated through the use of a customized digitization package. The cephalometric tracings were digitized with the aid of Dentofacial Planner (Richard Walker, Dentofacial Planner 5.32, Toronto, Ontario, Canada) with a standard 71-point regimen. "Average" faces were generated for comparison of profiles, using an averaging program, modified by L. E. Johnston, Jr, that is available through Dentofacial Planner. McNamara et al[35] have described the error of the method previously.

In all of the tracings, fixed fiducial points were transferred from the T_1 cephalometric tracing to the subsequent tracing or tracings in the individual's series to record the superimposition of the craniofacial structures. Cranial base superimposition, maxillary regional superimposition, and mandibular regional superimposition were recorded with the appropriate fiducial (registration) points. Dentoalveolar measures included the movement of the upper and lower incisors and molars relative to the maxillary fiducial points (for upper teeth) or mandibular fiducial points (for lower teeth) or to the Frankfort plane (for upper teeth) and mandibular plane (for lower teeth).

STATISTICAL EVALUATION OF THE SAMPLE

To evaluate the sample data, the following statistical analyses were performed.

Descriptive statistics. Means and standard deviations were calculated for all of the variables at the three times: late adolescence (T_1), early adulthood (T_2), and midadulthood (T_3). Mean differences and standard deviations also were calculated for the changes between T_1 and T_3, as well as between T_2 and T_3 in all of the variables measured.

Inferential statistics. To analyze the changes that occurred from T_1 to T_3 and from T_2 to T_3, *t* tests were performed. The level of significance ($P \leq .001$) was selected based on the Bonferroni correction that states for multiple comparisons the alpha level should be calculated by the original alpha level (.05) divided by the number of comparisons. In each individual, 43 comparisons were calculated; therefore, by the Bonferroni correction, .05 divided by 43 equals .001.

RESULTS

Adolescence to Adulthood

Descriptive statistics were calculated for all of the measurements taken at T_1, T_2, and T_3. The means and standard deviations of the measurements are presented in Tables I, II, and III. A comparison of the cephalometric measurements taken at T_1 and T_3 was conducted by means of *t* tests. The results of the *t* tests for males and females between T_1 and T_3 are presented in Tables I and II.

Several of the linear measurements changed significantly over time in the males, but none of the angular measurements changed significantly (Table I). For

Table I. Cephalometric measures for males between T_1 and T_3

	T_1 (N = 27)		T_3 (N = 30)		ΔT_1-T_3 (N = 27)		
Measure	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Sig*
Maxillary skeletal							
Midfacial length (Co-PtA)	97.4	5.4	100.4	5.2	2.8	1.2	*
SNA	81.0	3.9	81.0	4.4	0.2	1.3	
Point A to Nasion perpendicular	–0.9	3.8	–0.9	4.1	0.2	1.1	
Condylion to ANS	100.7	5.1	103.5	5.0	2.6	1.1	*
Palatal plane	–0.1	3.3	–0.6	3.6	–0.4	1.0	
Mandibular skeletal							
Mandibular length (Co-Gn)	128.6	7.1	133.4	7.5	4.8	2.2	*
SNB	77.8	3.8	77.9	4.2	0.3	1.3	
Pogonion to Nas perpendicular	–5.7	6.3	–5.4	6.7	0.8	2.1	
Condylion to Gonion	64.6	5.5	68.4	5.5	3.9	2.0	*
Gonion to Pogonion	82.4	4.6	84.0	5.0	1.9	1.4	*
Articulare to Gnathion	119.0	6.7	123.7	7.2	4.8	4.8	*
Articulare to PTM	34.5	2.9	35.6	4.0	0.8	2.8	
Mandibular plane to Frankfort (MPA)	24.5	5.1	23.9	4.9	–0.9	1.4	
Facial plane	87.4	2.9	87.6	3.0	0.3	1.1	
Maxillary/mandibular							
WITS	1.6	2.6	1.3	3.2	–0.1	2.4	
Maxillary/mandibular difference	31.1	4.5	33.0	5.2	2.1	2.2	*
Overbite	3.5	1.6	3.6	2.1	0.3	1.3	
Overjet	4.0	1.4	3.9	1.5	0.0	0.9	
ANB	3.3	2.1	3.1	2.4	–0.1	1.3	
Occlusal plane	7.7	3.5	7.9	3.0	0.0	2.8	
Upper 1 to lower 1	127.2	8.7	128.2	8.3	0.8	6.8	
Facial axis	–1.4	5.2	–1.2	5.0	0.5	1.1	
Vertical							
Nasion to Menton	131.0	9.0	135.6	8.8	4.3	2.3	*
Sella to Gonion	85.0	6.5	89.3	7.0	4.3	2.5	*
Nasion to ANS	58.2	3.6	60.1	4.0	1.6	1.1	*
ANS to Menton	74.8	7.0	77.4	6.9	2.5	2.0	*
Maxillary dentoalveolar							
Upper 1 to Point A perpendicular	5.6	1.8	5.5	2.2	0.1	1.4	
Upper 1 to maxilla (horizontal)	7.4	2.9	7.3	3.2	0.3	1.4	
Upper 1 to maxilla (vertical)	29.3	3.4	30.3	3.2	1.0	1.4	*
Upper 6 to maxilla (horizontal)	19.9	4.1	19.6	4.4	0.6	1.6	
Upper 6 to maxilla (vertical)	25.5	3.2	26.9	3.8	1.1	1.7	*
Upper 1 to S-N	104.3	5.5	103.7	7.6	–0.3	4.5	
Mandibular dentoalveolar							
Lower 1 to A-Pogonion	3.2	2.3	3.1	2.6	0.0	1.0	
Lower 1 to mandible (horizontal)	3.1	3.2	3.5	3.1	0.3	1.1	
Lower 1 to mandible (vertical)	34.3	3.4	35.9	3.7	1.6	1.1	*
Lower 6 to mandible (horizontal)	38.0	4.6	38.0	4.6	0.4	1.1	
Lower 6 to mandible (vertical)	28.8	3.0	30.9	3.3	1.8	1.5	*
IMPA	95.9	6.3	95.9	5.7	0.4	4.3	
FMIA	59.7	6.9	60.2	6.1	0.4	4.2	
Soft Tissue							
Upper lip to E plane	–2.3	2.5	–6.4	2.7	–3.2	1.7	*
Lower lip to E plane	–1.2	2.1	–4.2	2.6	–2.7	2.4	
Upper lip length	24.3	2.7	27.2	3.7	2.6	3.1	*
Nasolabial angle	124.0	9.8	124.5	9.6	1.8	5.4	

*$P \leq .001$.
SD, Standard deviation.

example, midfacial and mandibular lengths increased 2.8 ± 1.2 mm and 4.8 ± 2.2 mm, respectively. Lower anterior facial height increased by 2.5 ± 2.0 mm, but the mandibular plane angle remained relatively constant, decreasing by only 0.9 ± 1.4°, a change that was not statistically significant (Table I).

TABLE II. Cephalometric measures for females between T_1 and T_3

Measure	T_1 (N = 29) Mean	SD	T_3 (N = 30) Mean	SD	ΔT_1-T_3 (N = 29) Mean	SD	Sig
Maxillary skeletal							
Midfacial length (co-PtA)	91.7	4.8	93.9	4.7	2.1	1.3	*
SNA	80.2	3.6	79.9	3.4	–0.3	0.9	
Point A to Nasion perpendicular	–1.3	3.3	–1.5	3.3	–0.3	0.9	
Condylion to ANS	94.4	4.7	96.5	4.6	2.1	1.4	*
Palatal plane	–0.2	3.6	–0.3	3.1	0.1	1.5	
Mandibular skeletal							
Mandibular length (Co-Gn)	118.9	6.3	121.1	6.4	2.3	1.5	*
SNB	76.5	3.3	75.5	3.3	–1.0	0.9	*
Pogonion to Na perpendicular	–7.0	7.9	–9.1	8.1	–2.2	1.7	*
Condylion to Gonion	57.2	5.1	58.5	5.1	1.4	1.4	*
Gonion to Pogonion	78.0	4.1	78.8	4.1	1.0	1.0	*
Articulare to Gnathion	109.7	5.2	111.7	5.7	2.2	2.2	*
Articulare to PTM	32.2	2.7	32.5	3.1	0.2	0.2	
Mandibular plane to Frankfort (MPA)	26.0	6.3	27.1	6.5	1.0	1.4	*
Facial plane	86.5	4.0	85.5	4.0	–0.9	0.9	*
Maxillary/mandibular							
WITS	1.0	3.2	1.9	3.3	0.9	1.7	
Maxillary/mandibular difference	27.1	4.2	27.2	4.6	0.2	1.2	
Overbite	3.5	1.5	3.9	1.7	0.3	1.0	
Overjet	3.7	1.6	4.0	1.7	0.2	1.1	
ANB	3.7	2.7	4.4	2.7	0.6	0.8	*
Occlusal plane	10.0	4.1	10.9	4.1	0.8	2.4	
Upper 1 to lower 1	128.9	10.8	128.5	10.7	–0.9	5.5	
Facial axis	–0.8	4.8	–1.9	5.1	–1.1	1.2	*
Vertical							
Nasion to Menton	120.5	5.7	124.7	7.1	4.5	2.0	*
Sella to Gonion	74.8	8.0	76.9	5.1	2.2	1.8	*
Nasion to ANS	53.7	9.9	55.3	3.7	1.5	1.5	*
ANS to Menton	68.7	7.9	71.6	6.0	3.2	1.6	*
Maxillary dentoalveolar							
Upper 1 to Point A perpendicular	4.7	2.4	4.5	2.4	0.2	1.2	
Upper 1 to maxilla (horizontal)	6.1	3.0	6.0	2.8	–0.1	1.1	
Upper 1 to maxilla (vertical)	28.2	2.8	29.8	3.0	1.8	1.1	*
Upper 6 to maxilla (horizontal)	17.6	3.8	18.0	4.0	0.6	1.1	
Upper 6 to maxilla (vertical)	22.7	2.6	23.7	2.9	1.1	1.1	*
Upper 1 to S-N	100.8	6.0	98.8	6.3	–2.0	4.1	
Mandibular dentoalveolar							
Lower 1 to A-Pogonion	2.8	2.5	3.1	2.7	0.3	0.9	
Lower 1 to mandible (horizontal)	3.1	3.2	2.8	3.4	–0.3	1.0	
Lower 1 to mandible (vertical)	31.0	3.4	32.7	3.5	1.8	1.0	*
Lower 6 to mandible (horizontal)	35.4	3.7	36.4	4.2	1.2	0.8	*
Lower 6 to mandible (vertical)	27.4	2.8	29.2	3.0	2.0	0.7	*
IMPA	95.6	6.6	97.0	8.5	1.8	3.2	
FMIA	58.5	4.9	55.9	10.3	–2.4	3.6	*
Soft tissue							
Upper lip to E plane	–3.4	2.8	–5.5	3.4	–1.8	1.3	*
Lower lip to E plane	–0.9	3.1	–2.8	3.3	–1.7	1.4	*
Upper lip length	22.4	1.9	24.2	2.4	1.8	1.7	*
Nasolabial angle	119.0	9.0	121.5	9.7	3.1	8.7	

*$P \leq .001$.

The females presented a slightly different result: many of the linear measurements as well as several of the angular measurements changed significantly over time (Table II). For instance, midfacial and mandibular lengths increased 2.2 ± 1.3 mm and 2.3 ± 1.5 mm in females, respectively, with the mandibular length increase about half that of males. Lower anterior facial height increased by 3.2 ± 1.6 mm, and the mandibular plane angle (MPA)

Table III. Cephalometric measures for pooled males and females between T_2 and T_3

	T_2 (N = 15)		*T_3 (N = 15)*		*ΔT_2-T_3 (N = 15)*		
Measure	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Sig*
Maxillary skeletal							
Midfacial length (co-PtA)	96.8	4.5	98.2	4.7	1.4	1.2	*
SNA	81.7	4.0	81.4	4.1	–0.3	0.7	
Point A to Nasion perpendicular	0.0	3.5	–0.3	3.8	–0.3	0.7	
Condylion to ANS	99.9	4.6	101.2	4.7	1.3	1.0	*
Palatal plane	–2.0	3.3	–1.6	3.4	0.3	1.1	
Mandibular skeletal							
Mandibular length (Co-Gn)	126.6	5.6	128.9	6.4	2.3	1.5	*
SNB	78.0	3.5	77.8	3.6	–0.2	0.8	
Pogonion to Nas perpendicular	–4.9	6.2	–5.3	6.7	–0.4	1.4	
Condylion to Gonion	63.1	6.0	64.4	6.2	1.2	1.1	*
Gonion to Pogonion	80.5	3.8	81.6	4.2	1.0	0.9	*
Articulare to Gnathion	117.8	5.6	119.7	6.5	1.9	1.8	*
Articulare to PTM	34.1	3.0	34.4	3.3	0.4	0.9	
Mandibular plane to Frankfort (MPA)	24.9	5.6	25.4	5.5	0.5	0.7	
Facial plane	87.7	3.0	87.6	3.1	–0.1	0.6	
Maxillary/mandibular							
WITS	1.1	3.2	1.4	3.2	0.3	1.4	
Maxillary/mandibular difference	29.7	3.2	30.7	3.7	0.9	1.2	
Overbite	3.2	1.6	3.5	1.6	0.3	0.4	
Overjet	3.7	1.1	4.1	1.4	0.4	0.6	
ANB	3.6	1.9	3.6	1.9	–0.1	0.6	
Occlusal Plane	9.0	3.5	8.5	3.2	–0.4	1.6	
Upper 1 to lower 1	127.8	11.0	128.6	10.1	0.9	4.4	
Facial axis	–0.3	4.8	–0.7	5.0	–0.4	0.7	
Vertical							
Nasion to Menton	127.7	8.2	130.4	8.3	2.7	2.0	*
Sella to Gonion	82.3	8.1	83.8	8.4	1.5	1.0	*
Nasion to ANS	57.4	3.1	58.5	3.3	1.0	1.1	
ANS to Menton	72.3	6.9	74.0	6.7	1.7	1.2	*
Maxillary dentoalveolar							
Upper 1 to Point A perpendicular	4.8	2.5	5.2	2.3	0.4	0.6	
Upper 1 to maxilla (horizontal)	6.4	2.8	6.7	2.6	0.4	0.6	
Upper 1 to maxilla (vertical)	28.7	2.8	29.4	2.8	0.7	0.8	
Upper 6 to maxilla (horizontal)	18.4	4.1	18.5	4.1	0.1	0.7	
Upper 6 to maxilla (vertical)	25.2	3.0	26.1	3.7	0.9	1.3	
Upper 1 to S-N	103.1	7.4	102.8	6.5	–0.3	3.1	
Mandibular dentoalveolar							
Lower 1 to A-Pogonion	2.6	2.6	2.6	2.7	0.0	0.6	
Lower 1 to mandible (horizontal)	3.6	1.3	4.0	1.5	0.4	0.6	
Lower 1 to mandible (vertical)	33.2	3.4	34.1	3.6	0.9	0.7	*
Lower 6 to mandible (horizontal)	36.0	4.7	36.2	4.5	0.2	0.8	
Lower 6 to mandible (vertical)	29.7	3.9	30.4	3.5	0.7	1.1	
IMPA	95.9	5.6	94.7	6.0	–1.2	2.7	
FMIA	59.2	6.2	59.9	6.3	0.6	2.7	
Soft tissue							
Upper lip to E plane	–5.0	2.0	–6.1	2.2	–1.0	1.7	
Lower lip to E plane	–3.4	2.3	–4.2	2.0	–0.7	1.4	*
Upper lip length	24.9	3.4	25.8	3.1	0.9	1.3	
Nasolabial angle	125.8	6.8	126.2	10.5	–0.1	6.5	

*$P \leq .001$.

increased 1.0 ± 1.4°. The slight opening of the MPA in females was opposite to the slight closure of the MPA in males. Similarly, the facial axis closed in males and opened in females (Tables I and II).

The averaged T_1 and T_3 tracings of the males and females analyzed in this study were superimposed and are presented in Figs 1 through 6. Males and females grow differently over this time period.

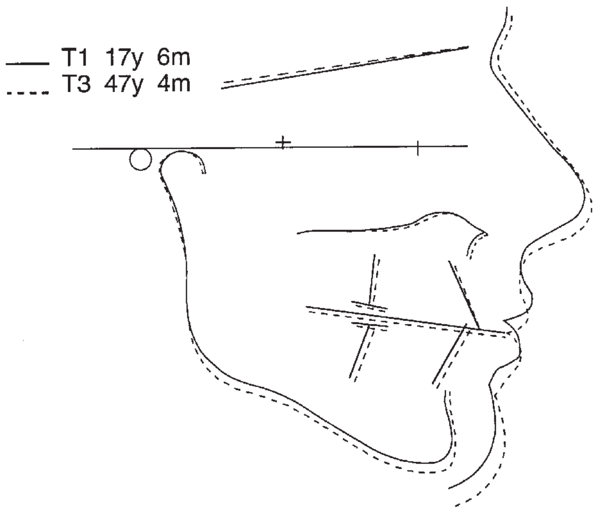

Fig 1. Superimposition of averaged male tracings at T_1 and T_3.

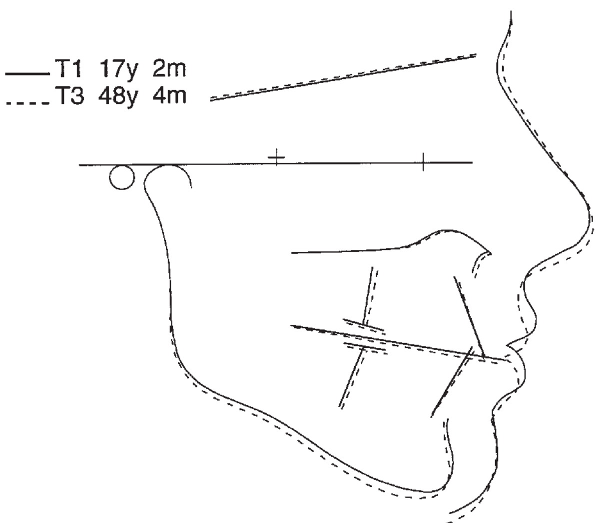

Fig 2. Superimposition of averaged female tracings at T_1 and T_3.

Early Adulthood to Midadulthood

Because of the small sample size (N = 15), males and females were analyzed together, and *t* tests were executed for all of the cephalometric variables (Table III). At the significance level of $P \leq .001$, many of the linear measurements increased significantly during the adult years, indicating continued craniofacial growth, whereas none of the angular measurements showed significant results. For example, midfacial and mandibular lengths increased 1.4 ± 1.2 mm and 2.3 ± 1.5 mm, respectively. Lower anterior facial height increased by 1.7 ± 1.2 mm, but the mandibular plane angle remained relatively constant (0.5° ± 0.7°).

The averaged superimposed tracings of males and females from early to late adulthood are presented in Figs 7 and 8. Again, it can be seen that there are gender differences in some of the linear and angular variables considered.

DISCUSSION

The present study examined three types of changes in interrelated regions in the craniofacial complex: skeletal, soft tissue, and dentoalveolar changes occurring from late adolescence to midadulthood. The authors fully realize the limitations of including our so-called "early adulthood" (early 30s) sample of films in this discussion, but the lack of gender specification and modest number of cephalograms available (N = 15) are outweighed by the unique nature of this sample. No previous study has examined craniofacial growth and adaptations from early to midadulthood. Any conclusions based in part on data derived from the T_2 films, of course, must be made with caution; such conclusions must be verified in subsequent recall studies of untreated individuals involving larger sample sizes.

Skeletal Changes

As can be seen in Figs 1 and 2, the skeletal and soft tissue profiles of averaged males and females are different at T_1 and T_3. Growth changes obviously have occurred, indicating that facial growth continued into adulthood. The question arises as to when exactly did this growth occur? Did the growth occur shortly after the teenage cephalogram was taken (perhaps late in the second or early in the third decade of life), or did growth occur as a gradual continuum that culminated in the profile presented at T_3? An examination of the data by craniofacial region will reveal the underlying changes that occurred in these individuals.

Midface. Statistical analysis shows that the midfacial region increased in length an amount that is statistically significant (Table I and II). Relative to condylion, the maxilla (point A and ANS) moved anteriorly a statistically significant amount during both time intervals studied. This effective midfacial growth could be the result of a combination of anterior movement of the maxillary landmarks resulting from bodily displacement of the maxilla as a whole, in addition to a posterior movement of condylion.

The anterior bodily movement of the maxilla as a result of growth in length was documented by Björk and Skieller[36] examining individuals who had intrabony metallic implants in their craniofacial region.

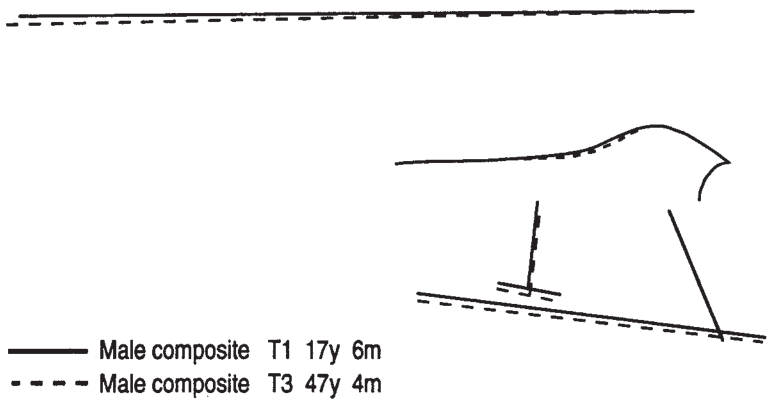

Fig 3. Regional superimposition of averaged male maxillary tracings at T_1 and T_3.

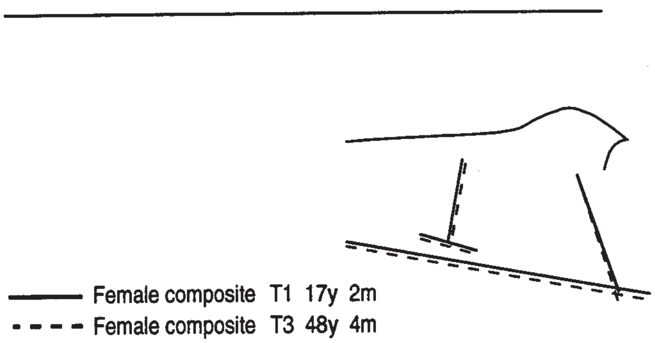

Fig 4. Regional superimposition of averaged female maxillary tracings at T_1 and T_3.

This growth in length of the maxilla was directed toward the palatine bone with the effect of translating the maxilla anteriorly. Similar findings also were reported by Kendrick and Risinger,[11] Behrents[17] and Bishara et al[18]; however, Israel[13] and Forsberg and Odenrick[15] found no significant increase in maxillary length in the adults they studied.

Mandible. The mandible in both genders increased in overall length from T_1 to T_3, as assessed from the measures condylion-gnathion, gonion-pogonion, and articulare-gnathion (Tables I and II). The mandible also grew a significant amount from early to midadulthood (Table III), both in overall length (condylion-gnathion, gonion-pogonion, articulare-gnathion) and in ramal height (condylion-gonion). In females, the mandible can be seen rotating posteriorly as it increases in length (Fig 2), as described by the measures pogonion-nasion perpendicular, SNB angle, mandibular plane to Frankfort, and the facial plane angle. The mandibles in males, on the other hand, tend to rotate anteriorly as they increase in length, as can be seen in the averaged tracings in Fig 1. Similar results also were noted by Behrents. [17]

Forsberg and Odenrick[15] reported a posterior mandibular rotation in their subjects, both in males and in females. They did not note a significant change in mandibular length, but rather explained that the changes in profile likely were a result of mandibular rotation, apparently as a result of continued tooth eruption. A significant increase in mandibular length in males and females was reported by Bishara et al,[18] again finding an apparent posterior rotation of the mandible in females that contributed to an increase in profile convexity. In addition, Kendrick and Risinger[11] observed anterior movement of the chin in adult males over a period of 1 year.

In the present study, a greater increase in the length of the mandible was observed in males than females (Table I and II), but this increase in length alone does not explain the different directions of rotation of the mandible in males and females. One possible explanation for this difference in rotation is the interaction of the growth in mandibular length with the increase in the vertical dimension. For example, an increase in a vertical measure or combination of measures that is greater than the increase in mandibular length will produce a net pos-

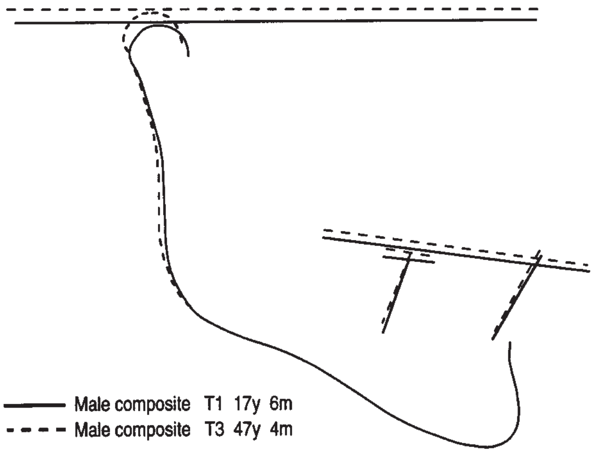

Fig 5. Regional superimposition of averaged male mandibular tracings at T_1 and T_3.

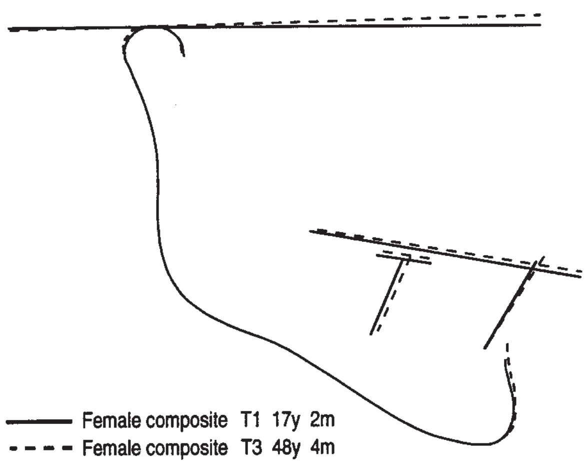

Fig 6. Regional superimposition of averaged female mandibular tracings at T_1 and T_3.

terior rotation of the mandible,[29] as was found in the female profile. If the maxilla descends or the teeth erupt a greater amount than the mandible increases in length, posterior rotation of the mandible will result, producing an increased mandibular plane angle and increased total anterior facial height (nasion-menton).

Intermaxillary measures. All four of the maxillary/mandibular measures that were based on skeletal landmarks (WITS appraisal, maxillomandibular difference, ANB angle, and facial axis angle) showed some gender difference from T_1 to T_3; however, none of the four measures showed significant change from early to midadulthood (T_2 to T_3). Males and females differed in which measurements were significant from T_1 to T_3. Only the maxillomandibular difference was significant in males, but both the ANB angle and the facial axis angle showed significant change in the females. These findings coincide with the observation of posterior mandibular rotation in the females. Two previous studies found the ANB angle to change significantly in both males and females.[15,18]

Vertical measures. All of the vertical skeletal measures increased significantly over the T_1 to T_3 and the T_2 to T_3 time intervals examined for both males and females, with the exception of the upper facial height during the latter time interval. These findings are in agreement with those of other studies.[13,15,18] Upper facial height (nasion-anterior nasal spine), lower facial height (anterior nasal spine-menton), posterior facial height (sella-gonion), and total anterior facial height (nasion-menton) all increased significant amounts from T_1 to T_3, thereby describing the accumulation of individual changes in the cranial base, the maxilla, and the mandible in the vertical plane. In addition, the vertical dentoalveolar changes (eg, the eruption of the posterior teeth) contributed to increased anterior facial heights (lower and total).

Soft tissue. In the male and female composite tracings from T_1 to T_3 (Figs 1 and 2), the nose, lips, and chin moved downward over time, with the male nose and chin moving anteriorly as well. Similar changes are noted from early to midadulthood (Figs 7 and 8). The nose appears to have grown more in the vertical direction than in the horizontal direction, a finding that is consistent with the results of Subtelny.[37] The lips appear to "flatten" slightly, and this observation is supported statistically (Tables I and II). The measures of upper and lower lip to "E" plane are relative, given that a significant change could result from the retrusion of the lips, the advancement of the nose and/or chin, or a combination of the two. The upper lip grew significantly in length over time, but the cant of the upper lip, measured by the nasolabial angle, did not demonstrate a significant change. Similar findings are reported by Behrents [17] who found the upper lip in males and females to become less prominent as it elongates with time.

Dentoalveolar Changes

Maxillary dentoalveolar region. From Tables I and II it can be seen that only two of the maxillary dentoalveolar measurements showed statistically significant changes from adolescence to adulthood: the upper incisor (U1) relative to the maxilla and the upper first molar (U6) relative to the maxilla. Although these same measurements also increased from early to midadulthood, the changes were not statistically significant (Table III). These findings support the observations from Figs 3 and 4 that the maxillary teeth continue to erupt over time into adulthood.

From the regional superimposition of the maxilla (Figs 3 and 4), it is apparent that in males the incisors erupt a small amount while maintaining their faciopalatal position, but in the females the incisors erupt and the crowns tip toward the palate. The uprighting of the incisors in the females is consistent with the findings of Behrents,[17] although he found incisor uprighting to occur in both males and females. Behrents found the behavior of the upper molars to be a bit more complex: in males there was a significant uprighting of the molars relative to the palatal plane, but in females the molars tend to become distally inclined.[17] He showed a significant gender difference in the molar configuration, but in the present study the molars in both genders erupted and moved mesially during adulthood. Forsberg and Odenrick[15] found that the distance from the upper incisal edge to nasion increased significantly in both males and females during the adult years.

Mandibular dentoalveolar region. There were four measurements that changed significantly from adolescence to adulthood in females: vertical movement of the lower molars and incisors relative to a fixed point on the mandibular plane, horizontal movement of the lower first molars, and FMIA (Table II). The males (Table I) showed significant change only in the vertical dentoalveolar measurements. Only the lower incisors, however, showed significant vertical change from early to midadulthood (Table III). Again, the main movement of the teeth is eruption. This vertical movement probably is compensatory, resulting from either continued dental eruption, continued alveolar growth, or both, to balance the occlusion with the skeletal growth that is occurring.

From Fig 5, it appears that in the males the mandibular teeth are erupting and moving posteriorly (or distally). This distal movement of the teeth is an unexpected finding, as it is believed that all teeth tend to migrate mesially with age. Behrents,[17] however, also found that in males the mandibular molars erupted and tipped distally with age. Björk et al[9,38] also noted this type of movement in certain types of faces. The females show a different situation (Fig 6); their teeth erupt and move anteriorly (or mesially). These movements may compensate for the type of differential mandibular growth that occurred previously (females down and backward, males down and forward) and may be the combined result of actual eruption of the teeth and increase in the height of the alveolus.

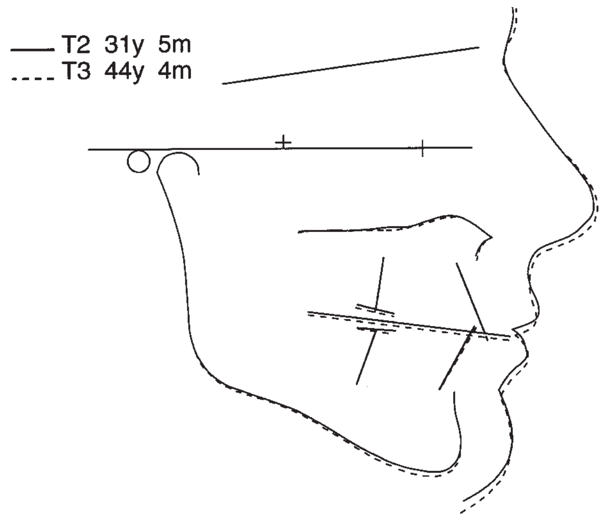

Fig 7. Superimposition of averaged male tracings at T_2 and T_3.

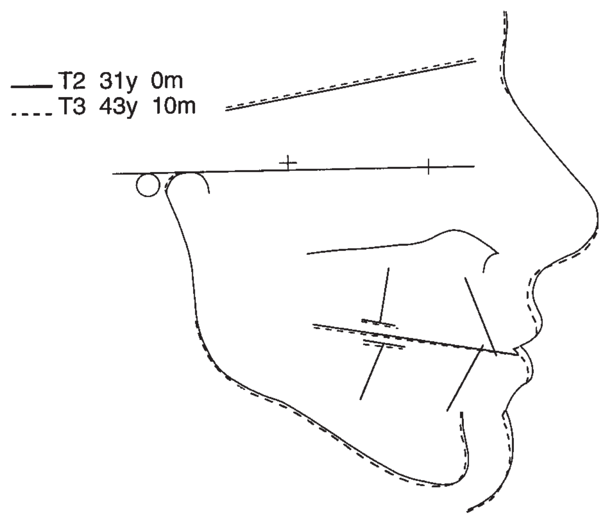

Fig 8. Superimposition of averaged female tracings at T_2 and T_3.

SUMMARY AND CONCLUSIONS

The purpose of the present study was to evaluate cephalometrically the craniofacial growth changes and adjustments from adolescence to midadulthood. Statistically significant growth changes occurred between late adolescence to midadulthood. Further analysis of the data that included a modest sample of films taken in midadulthood indicated that some of the changes in craniofacial size might have occurred in the fourth and fifth decades of life. Mandibular and midfacial lengths, in addition to posterior and lower anterior facial heights, increased significantly for males and females over both time intervals. The pattern of expression of these changes was different in the two genders; the males showed an anterior rotation of the mandible, whereas the females demonstrated a posterior rotation of the mandible. The soft tissue changes also were somewhat different for the males and females. In the males, the nose and chin grew downward and forward, with the lips generally moving straight downward. The females, on the other hand, had nasal growth that progressed downward and forward, and there was a slight retrusion of the lips over time. The teeth erupted in the maxilla and mandible from late adolescence to adulthood, but only the lower incisor continued that movement from early to midadulthood.

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