Determining the cessation of vertical growth of the craniofacial structures to facilitate placement of single-tooth implants

Piotr Fudalej,[a] Vincent G. Kokich,[b] and Brian Leroux[c]
Warsaw, Poland, and Seattle, Wash

Introduction: Single-tooth implants are commonly used to replace congenitally missing teeth in adolescent orthodontic patients. However, if implants are placed before cessation of facial growth, they will submerge relative to the adjacent erupting teeth. Therefore, it is important to know when facial growth is complete in postpubertal orthodontic patients. The purposes of this study were to determine and quantify the amount of vertical growth of the facial skeleton and the amount of eruption of the central incisors and the maxillary first molars after puberty. **Methods:** Two or 3 lateral cephalograms taken at pretreatment, posttreatment, and 10 years postretention of 142 males and 159 females were evaluated. Linear regression models were used to determine changes in the parameters with increasing age. **Results:** The findings indicate that (1) the growth of the facial skeleton continues after puberty; (2) there is a difference in the amount of growth between the sexes during the second decade of life, and after age 20 the intergender difference is substantially diminished; and (3) the rate of eruption of the maxillary central incisors in females seems to be greater than in males. Prediction tables are provided to help the clinician determine when to take cephalometric radiographs to assess the cessation of facial growth. **Conclusions:** The growth of the facial skeleton continues after puberty, but the amount of growth decreases steadily and after the second decade of life seems to be clinically insignificant. (Am J Orthod Dentofacial Orthop 2007;131:00)

Stability of orthodontic treatment has always been a concern of orthodontists.[1,2] Posttreatment mandibular growth permits continued tooth eruption and could adversely affect the alignment of teeth after orthodontic therapy. Now that dental implants have become a popular method of replacing congenitally missing teeth in orthodontic patients, it is important for orthodontists to determine when facial growth has been completed, so that an implant can be placed. A detailed picture of changes in facial structure is available from early childhood to puberty. Unfortunately, few studies have evaluated the amount of growth after puberty.[3-5] Most studies focused on changes after the second decade of life or in the late teens. Forsberg[6] followed 49 subjects from 24 to 34 years of age and reported that facial height increased, but the amount of increase was small (less than 0.6 mm over 10 years). In a 20-year follow-up of the same sample, he observed additional growth but of larger magnitude.[7]

Behrents[8] evaluated postadolescent growth of the Bolton sample and concluded that growth continued after adulthood. However, precise quantification of growth increments during specific periods of time are impossible to attain because of large time spans between initial and final records. Reports by Bishara et al[9] and Bondevik[10] confirmed postadolescent growth, although some details seem to be contradictory. Bishara et al observed growth in their sample but considered the amount insignificant. Bondevik reported increased anterior facial height, but the amount of growth in males was smaller than in females, and no linear change exceeded 1.35 mm over 11 years. Love et al[11] and Foley and Mamandras[12] studied growth of the facial skeleton during the late teens in both sexes and reported that anterior facial height (AFH) increased over the observation time, but the amount of increase was diminishing.

Because implants behave like ankylosed teeth,[13-15] early implantation could lead to submergence of the implant crown and produce an esthetic and periodontal disaster[16] Few studies are available to help the clinician determine the appropriate timing of implant placement relative to the cessation of craniofacial growth.[4] Therefore, the purposes of this study were to determine and quantify the amount of vertical growth of the facial skeleton and the amounts of eruption of the central incisors and the first molars after puberty.

[a]Assistant professor, National Research Institute for Mother and Child, Warsaw, Poland.
[b]Professor, Department of Orthodontics; University of Washington, Seattle.
[c]Associate professor, Department of Dental Public Health Sciences, University of Washington, Seattle.
Reprint requests to: Vincent G. Kokich, 1950 South Cedar St., Tacoma, WA 98466; e-mail, vgkokich@u.washington.edu.
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Table I. Demographic summary of male and female groups

	Males (*n* = *142*)	*Females* (*n* = *159*)	*P value*
Angle Class I	41	76	.001
Angle Class II Division 1	70	58	.033
Angle Class II Division 2	27	24	.453
Angle Class III	4	1	.303
Nonextraction treatment	38.7%	26.4%	.031
Age at T2 (y)	15.90 (2.27)	16.03 (2.47)	.620
Treatment time (y)	3.20 (1.62)	2.84 (1.56)	.048
Retention time (y)	2.30 (1.72)	2.52 (2.03)	.307
Postretention time (y)	13.87 (4.58)	13.33 (3.91)	.273

n = Subjets in sample.
Intergender differences tested with chi-square or *t* test.

MATERIAL AND METHODS

The sample was selected from the postretention records in the Department of Orthodontics at the University of Washington. All subjects were treated by faculty or graduate students of the University of Washington, and each subject had pretreatment (T1), end of treatment (T2), and at least 10-year postretention (T3) records. Some had additional records taken 20 years postretention (T4).

A total of 301 of 645 subjects were selected for this study. The inclusion criteria were (1) T2 at age 12 or later; (2) orthodontic treatment without surgery; (3) no additional orthodontic treatment during the observation period; (4) between T2 and T3, no more than 2 teeth lost, and no extensive prosthodontic treatment (ie, 4-unit or larger bridge, multiple crowns); (5) satisfactory orthodontic treatment (normal overbite and overjet at T2); and (6) good quality lateral cephalometric radiographs at T2, T3, and T4 (if available). Only lateral headfilms of a subject that were taken on the same x-ray machine or could be adjusted for magnification were used. Angle classification at pretreatment was not used to select the sample. The subjects underwent either extraction or nonextraction orthodontic therapy that routinely included fixed edgewise appliances. The subjects were predominantly of European descent living in western Washington (Table I).

The sample was subsequently divided into 2 subsamples: males and females, consisting of 142 and 159 subjects, respectively. Two or 3 lateral cephalometric radiographs were evaluated on each subject (Table II).

The following landmarks were identified on each cephalogram and marked on 0.003 acetate tracing paper: nasion (N), menton (Me), gonion (Go), anterior nasal spine (ANS), posterior nasal spine (PNS), incisal edge of maxillary central incisor (U1e), mesial cusp of maxillary first molar (U6c), and incisal edge of mandibular central incisor (L1e). Based on these landmarks, 2 planes and 1 point were constructed: palatal plane (PP), line running through ANS and PNS; mandibular plane (MP), line running through Me and Go; and ANS´, point at intersection of PP and line connecting N and Me (Fig 1). From these landmarks, various linear measurements were derived: AFH-N/Me; lower AFH (LAFH), ANS´/Me; eruption of maxillary teeth, U1e/PP and U6c/PP; and eruption of mandibular teeth,

Table II. Characteristics of sample

Lateral cephalograms at	*Males*	*Females*
T2 and T3 only	125	141
T2, T3, and T4	13	17
T3 and T4 only	4	1
	142	159

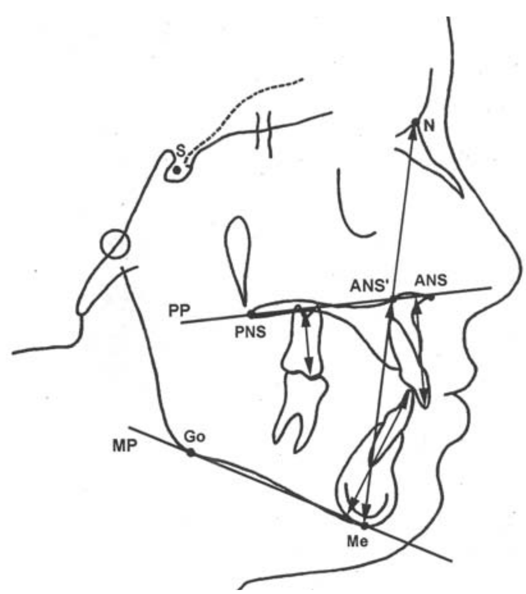

Fig 1. Landmarks and measurements: *N,* nasion; *Me,* menton; *Go,* gonion; *ANS* and *ANS´,* anterior nasal spine; *PNS,* posterior nasal spine; *MP,* mandibular plane; *PP,* palatal plane.

Table III. Error of measurement of variables (mm)

	Measurement				
	N/Me	*ANS'/Me*	*U1e/PP*	*L1e/MP*	*U6c/MP*
Error	0.52	0.40	0.36	0.39	0.35

L1e/MP, The distances were measured with a digital caliper in millimeters.

Total change in AFH was assessed by measuring the change in the distance from N to Me over the observation period. The amounts of eruption of the maxillary and mandibular central incisors were assessed by measuring the distances from the incisal edges to the PP or the MP, respectively. Similarly, the amount of eruption of the maxillary molars was assessed by measuring the change in position of the mesial cusp in relation to the PP.

The reproducibility of the measurements was assessed by statistically analyzing the difference between double measurements taken 6 weeks apart on 28 cephalograms selected at random. The error of the method (s_i) was calculated from the equation:

$$s_i = \text{square root of } (Sd^2/2N),$$

where *d* represents the difference between the first and second measurements, and *N* is the number of double determinations. The mean error for the cephalometric measurements was 0.40 mm and ranged from 0.36 mm (U1e/PP) to 0.52 mm (N/Me) (Table III).

Statistical analysis

Chi-square tests were performed to evaluate differences in distribution of Angle classification and extraction treatment alternative. Intergender difference in age at T2, treatment time, retention time, and postretention time were tested with independent *t* tests .

Linear regression models were used to determine changes in the parameters with increasing age. Polynomials involving inverse age were used in the regression models to allow accurate modeling of a rapidly increasing curve at the younger ages and an asymptote as age increases (ie, slope becoming close to 0 at older ages). Only first order (linear) and second order (quadratic) terms were included in the final models because third order (cubic) terms were not statistically significant. The following model was used:

$$Y = A + B*(25/AGE) + C*(25/AGE)^2 + ERROR$$

where *Y* is the dependent variable (NMe and so on). Multiplication of the first and second order inverse age terms by 25 (the approximate mean age) was done for ease of interpretation of the regression coefficients (B and C). The models were fitted by using the generalized estimating equations method and robust standard errors to account for the correlation between multiple observations per patient. The fitted models were compared with fitted curves obtained by using a nonparametric regression approach (the Loess method in the S-plus statistical package) to verify that the results were not overly sensitive to the particular mathematical form of the model. The results were reported by using plots of fitted curves and 95% confidence intervals as well as changes in the fitted curve over various age intervals (12–15, 15–18, and so on).

Prediction tables

For each measured parameter, changes over the various age intervals were calculated by subtraction of the fitted values obtained by substituting the 2 age values into the fitted regression equation. The 95% confidence intervals for these changes were determined by adding and subtracting 1.96 times the standard error (SE) of the change. This SE was computed as the square root of the variance, which was found by using the formula for the variance of a difference between 2 random variables—$var(Y1-Y2) = var(Y1) - 2cov(Y1,Y2) + var(Y2)$; the components of this formula were the robust variance and covariance estimates obtained from the generalized estimating equations method. These confidence intervals indicated a range of plausible values for the change in the mean for the population and should not be interpreted as a predicted range of values for the change in a single patient.

RESULTS

Anterior facial height

The changes in AFH were calculated by comparing the difference in the N/Me distances for males and females and are shown in Tables IV and V and Figure 2.

In the males, AFH (N/Me) increased 9.4 mm (SE = 0.7) during the observation period from ages 12 to 50. Over half of the increase (4.9 mm, SE = 0.8) took place before age 15. After age 15, the rate of growth decreased: between ages 15 and 18, AFH (N/Me) increased 2.3 mm (SE = 0.3); from 18 to 50 years, AFH increased 2.2 mm (SE = 0.6).

In the females, the total change in AFH (N/Me) over the entire observation period was 4.3 mm (SE = 0.4). About 40% of the growth in facial height (1.7 mm, SE = 0.4) occurred before age 15. From 15 to 18 years, the N/Me distance increased only 0.9 mm (SE = 0.1). After 18 years, AFH increased 1.8 mm (SE = 0.4). The increments of growth for both sexes seemed to be similar after age 18.

Lower anterior facial height

The change of LAFH was used to calculate the proportion of growth of AFH occurring in the LAFH. The

Table IV. Prediction of change of NMe distance in males (mm) with SE in parentheses (mm)

Age (y)	12							
12	0.0 (0.0)	15						
15	4.9 (0.8)	0.0 (0.0)	18					
18	7.2 (1.0)	2.3 (0.3)	0.0 (0.0)	21				
21	8.4 (1.1)	3.5 (0.4)	1.2 (0.1)	0.0 (0.0)	24			
24	9.0 (1.1)	4.1 (0.4)	1.8 (0.1)	0.6 (0.1)	0.0 (0.0)	27		
27	9.4 (1.1)	4.4 (0.4)	2.1 (0.2)	1.0 (0.1)	0.3 (0.1)	0.0 (0.0)	30	
30	9.5 (1.0)	4.6 (0.3)	2.3 (0.2)	1.1 (0.2)	0.5 (0.1)	0.2 (0.1)	0.0 (0.0)	40
40	9.6 (0.8)	4.7 (0.4)	2.4 (0.4)	1.2 (0.4)	0.6 (0.4)	0.2 (0.3)	0.1 (0.2)	0.0 (0.0)
50	9.4 (0.7)	4.5 (0.5)	2.2 (0.6)	1.0 (0.6)	0.4 (0.6)	0.1 (0.5)	–0.1 (0.4)	–0.2 (0.2)

Table V. Prediction of the change of NMe distance in females (mm) with SE in parentheses (mm).

Age (y)	12							
12	0.0 (0.0)	15						
15	1.7 (0.4)	0.0 (0.0)	18					
18	2.6 (0.6)	0.9 (0.1)	0.0 (0.0)	21				
21	3.1 (0.6)	1.4 (0.2)	0.5 (0.0)	0.0 (0.0)	24			
24	3.5 (0.6)	1.8 (0.2)	0.9 (0.1)	0.4 (0.0)	0.0 (0.0)	27		
27	3.7 (0.6)	2.0 (0.2)	1.1 (0.1)	0.6 (0.1)	0.2 (0.0)	0.0 (0.0)	30	
30	3.9 (0.6)	2.2 (0.2)	1.3 (0.1)	0.8 (0.1)	0.4 (0.1)	0.2 (0.0)	0.0 (0.0)	40
40	4.2 (0.4)	2.5 (0.2)	1.6 (0.3)	1.1 (0.3)	0.7 (0.2)	0.5 (0.2)	0.3 (0.2)	0.0 (0.0)
50	4.3 (0.4)	2.7 (0.3)	1.8 (0.4)	1.2 (0.4)	0.9 (0.4)	0.6 (0.3)	0.5 (0.3)	0.1 (0.1)

formula used for calculation was as follows: (LAFH/AFH) × 100%. For both sexes, about 60% to 70% of the increase in AFH occurred in the LAFH.

Incisors

The amounts of eruption of the central incisors in males and females are presented in Tables VI through IX and Figure 2.

In males, the total eruption of the maxillary incisors (U1e/PP) was 2.0 mm (SE = 0.3). Half of that (1 mm, SE = 0.3) occurred before age 15. From ages 15 to 18, the maxillary incisors erupted 0.5 mm (SE = 0.1). After age 18, the maxillary central incisors erupted 0.5 mm (SE = 0.2). The total eruption of the mandibular central incisors (L1e/MP) was 5.0 mm (SE = 0.4). About 46% of the change occurred before age 15 (2.3 mm, SE = 0.4). Between 15 and 18 years, the mandibular incisors erupted 1.1 mm (SE = 0.1). After age 18, they continued to erupt an additional 1.5 mm (SE = 0.3).

In the females, the total eruption of the maxillary incisors (U1e/PP) was 2.7 mm (SE = 0.2). About 44% of the change (1.2 mm, SE = 0.3) occurred before age 15. From ages 15 to 18, the maxillary incisors erupted 0.6 mm (SE = 0.1). After age 18, they erupted 0.8 mm (SE = 0.3). The total eruption of the mandibular incisors (L1e/MP) was 2.4 mm (SE = 0.2). About 30% of the change occurred before age 15 (0.8 mm, SE = 0.2). Between 15 and 18 years, the mandibular incisors erupted 0.5 mm (SE = 0.1). After age 18, they continued to erupt an additional 1.1 mm (SE = 0.2).

Molars

The eruption values of the maxillary molars (U6c/PP) are given in Tables X and XI and Figure 2.

In the males, the maxillary molars erupted 4.0 mm (SE = 0.3) during the observation period (ages 12 to 50). About 2.5 mm (SE = 0.3) occurred before age 15. After age 15, the amount of eruption diminished. Between ages 15 and 18, the maxillary molars erupted 1.1 mm (SE = 0.1). From 18 to 50 years of age, they erupted 0.5 mm (SE = 0.3).

In the females, the total eruption of the maxillary molars was 1.7 mm (SE = 0.3). About 65% of the eruption (1.1 mm, SE = 0.2) occurred before age 15. From

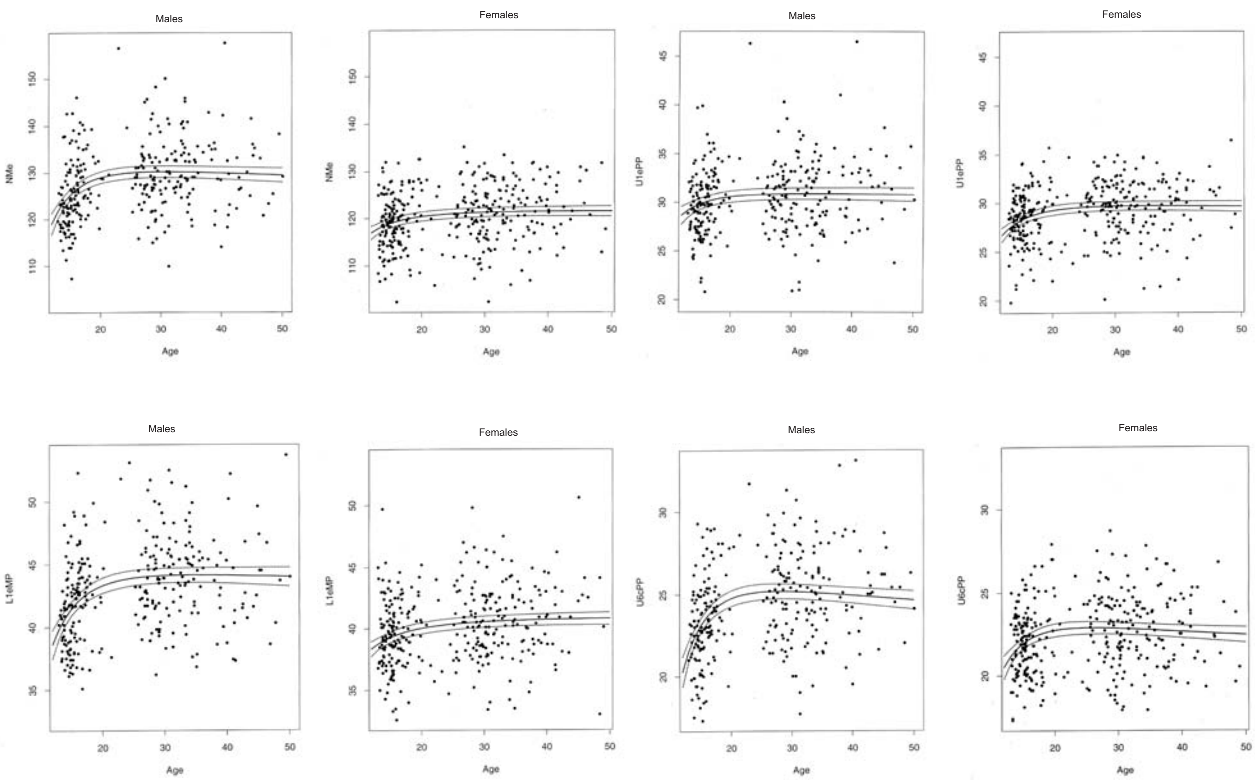

Fig 2. Observed values of measurements (mm) vs age (y) for 142 male subjects and 159 female subjects measured on 2 or 3 occasions. Each point represents measurement at given age for 1 subject. *Solid curve* represents estimated mean value as function of age (estimated growth curve) based on fitted linear regression model. *Dashed curves* represent 95% confidence band for growth curve.

15 to 18 years, the amount of eruption was 0.5 mm (SE = 0.1). After 18 years, the maxillary first molars continued to erupt an additional 0.1 mm (SE = 0.2).

DISCUSSION

Implants are a popular treatment alternative for replacing congenitally missing lateral incisors. The ability to predict future growth and tooth eruption is critical. Although a correlation exists between facial growth and growth in stature, the correlation is not perfect.[17-20] Despite cessation of statural growth, vertical growth of the face and the resulting eruption of teeth continue past puberty.[8] Dental age is also not a good predictor. A full complement of permanent teeth does not indicate completion of facial growth.[21,22] If an implant is placed too early (before growth and eruption are complete), the implant crown will become submerged. Brugnolo et al[16] described 3 patients (11.5–13 years of age) who received implants in the anterior regions of the maxilla. After 2.5 to 4.5 years, all patients had implant crowns in infraocclusion. Thilander et al[23] reported that, when implants were placed in adolescents (at ages 13.2–19.3), most of the implant crowns were found in infraocclusion. Experimental studies in growing pigs showed that implants behave like ankylosed teeth and remain at the same location, in spite of constant remodeling of surrounding bone as the adjacent teeth erupt.[13,14,24]

Various study designs can be used to measure growth. If the goal is to determine the amount of growth from 15 to 20 years of age, an ideal design would be to gather longitudinal data from subjects measured at age 15 and again at age 20. Such a balanced longitudinal design avoids the biases that might be present in average growth estimates obtained from cross-sectional studies or from studies in which either the number of measurements or the measurement times vary. We used a sample of subjects whose measurements were available on 2 to 3 occasions from adolescence to middle age. This design had the advantage of providing a descriptive growth chart on a yearly basis over a wide range. The measurement times typically spanned the age range of most interest in this study: the typical age at the first measurement was 15 to 16 years, and the typical interval between the first and last measurements was also 15 to 16 years. Because of the nature of the sample (treated

Table VI. Prediction of change of U1e/PP distance in males (mm) with SE in parentheses (mm).

Age (y)	*12*	*15*	*18*	*21*	*24*	*27*	*30*	*40*
12	0.0 (0.0)							
15	1.0 (0.3)	0.0 (0.0)						
18	1.4 (0.4)	0.5 (0.1)	0.0 (0.0)					
21	1.7 (0.4)	0.7 (0.1)	0.2 (0.0)	0.0 (0.0)				
24	1.8 (0.4)	0.8 (0.1)	0.4 (0.1)	0.1 (0.0)	0.0 (0.0)			
27	1.9 (0.4)	0.9 (0.1)	0.5 (0.1)	0.2 (0.0)	0.1 (0.0)	0.0 (0.0)		
30	1.9 (0.4)	1.0 (0.1)	0.5 (0.1)	0.3 (0.1)	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	
40	2.0 (0.3)	1.0 (0.2)	0.6 (0.2)	0.3 (0.2)	0.2 (0.1)	0.1 (0.1)	0.0 (0.1)	0.0 (0.0)
50	2.0 (0.3)	1.0 (0.2)	0.5 (0.2)	0.3 (0.2)	0.2 (0.2)	0.1 (0.2)	0.0 (0.2)	0.0 (0.1)

Table VII. Prediction of change of U1e/PP distance in females (mm) with SE in parentheses (mm).

Age (y)	*12*	*15*	*18*	*21*	*24*	*27*	*30*	*40*
12	0.0 (0.0)							
15	1.2 (0.3)	0.0 (0.0)						
18	1.8 (0.4)	0.6 (0.1)	0.0 (0.0)					
21	2.2 (0.4)	0.9 (0.1)	0.3 (0.0)	0.0 (0.0)				
24	2.4 (0.4)	1.1 (0.1)	0.5 (0.0)	0.2 (0.0)	0.0 (0.0)			
27	2.5 (0.4)	1.3 (0.1)	0.6 (0.1)	0.3 (0.1)	0.1 (0.0)	0.0 (0.0)		
30	2.5 (0.3)	1.3 (0.1)	0.7 (0.1)	0.4 (0.1)	0.2 (0.1)	0.1 (0.0)	0.0 (0.0)	
40	2.6 (0.3)	1.4 (0.1)	0.8 (0.2)	0.5 (0.2)	0.3 (0.2)	0.2 (0.1)	0.1 (0.1)	0.0 (0.0)
50	2.7 (0.2)	1.4 (0.2)	0.8 (0.3)	0.5 (0.3)	0.3 (0.2)	0.2 (0.2)	0.1 (0.2)	0.0 (0.1)

orthodontic patients), the timing of the measurements was not likely to be related to the size of the measurements themselves. Therefore, biases due to the imbalanced study design were considered negligible. Statistical methods appropriate for longitudinal data were used to account for the correlation between measurements on the same subject.

Our findings indicate that growth of the craniofacial skeleton is a continuous process. However, the amount of growth decreases with time, especially after age 20. Increase in AFH due to vertical growth of the craniofacial skeleton is especially rapid during the early teenage years. Between the ages of 12 and 15 years, the AFH increases 4.9 (SE = 0.8) and 1.7 (SE = 0.4) mm in males and females, respectively. These changes correspond with the onset of puberty and are consistent with other studies.[17] During the late teenage years, the amount of growth is considerably less. Our results show 50% more increase in AFH in boys between the ages of 15 and 18 than that documented by Love et al.[11] However, the observation period in their investigation started 1 year later. They also did not report the variation of the change.

The increase in AFH in females between 15 and 18 years of age observed in this study agrees with the findings of Foley and Mamandras.[12] In addition, the amount of vertical growth in the third decade of life found in this study is consistent with reports by Forsberg[6,7] and Behrents.[8] Both investigators showed that growth in the third decade is about 1 mm over 10 years. Sarnas and Solow,[18] Bondevik,[10] and Bishara et al[9] reported slightly larger amounts of vertical growth, from 1.55 mm (age 21–26 years) to 2.0 mm (age 25–46 years). However, the magnitude of the vertical changes after age 20 seems to have little clinical importance.

In this investigation, the increase in LAFH was 60% to 70% of the increase in AFH for males and females. This finding is consistent with studies by Love et al,[11] Foley and Mamandras,[12] Forsberg,[7] and Bishara et al.[9] Therefore, not all changes in total facial height (AFH) result in concomitant eruption of the maxillary and mandibular teeth.

Table VIII. Prediction of L1e/MP distance in males (mm) with SE in parentheses (mm)

Age (y)	*12*							
12	0.0 (0.0)	*15*						
15	2.5 (0.3)	0.0 (0.0)	*18*					
18	3.5 (0.4)	1.1 (0.1)	0.0 (0.0)	*21*				
21	4.0 (0.5)	1.6 (0.1)	0.5 (0.0)	0.0 (0.0)	*24*			
24	4.3 (0.5)	1.8 (0.2)	0.7 (0.1)	0.2 (0.0)	0.0 (0.0)	*27*		
27	4.4 (0.4)	1.9 (0.1)	0.8 (0.1)	0.3 (0.1)	0.1 (0.0)	0.0 (0.0)	*30*	
30	4.4 (0.4)	1.9 (0.1)	0.8 (0.1)	0.3 (0.1)	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	*40*
40	4.2 (0.4)	1.8 (0.2)	0.7 (0.2)	0.2 (0.2)	0.0 (0.2)	–0.1 (0.1)	–0.1 (0.1)	0.0 (0.0)
50	4.0 (0.3)	1.6 (0.2)	0.5 (0.3)	0.0 (0.3)	–0.3 (0.2)	–0.3 (0.2)	–0.4 (0.2)	–0.2 (0.1)

Table IX. Prediction of change of L1e/MP distance in females (mm) with SE in parentheses (mm)

Age (y)	*12*							
12	0.0 (0.0)	*15*						
15	1.1 (0.2)	0.0 (0.0)	*18*					
18	1.6 (0.4)	0.5 (0.1)	0.0 (0.0)	*21*				
21	1.8 (0.4)	0.7 (0.1)	0.2 (0.0)	0.0 (0.0)	*24*			
24	1.9 (0.4)	0.8 (0.1)	0.3 (0.0)	0.1 (0.0)	0.0 (0.0)	*27*		
27	1.9 (0.4)	0.8 (0.1)	0.3 (0.1)	0.1 (0.0)	0.0 (0.0)	0.0 (0.0)	*30*	
30	1.9 (0.4)	0.8 (0.1)	0.3 (0.1)	0.1 (0.1)	0.0 (0.1)	0.0 (0.0)	0.0 (0.0)	*40*
40	1.8 (0.3)	0.7 (0.1)	0.2 (0.2)	0.0 (0.2)	–0.1 (0.2)	–0.1 (0.1)	–0.1 (0.1)	0.0 (0.0)
50	1.7 (0.3)	0.6 (0.2)	0.1 (0.2)	-0.1 (0.3)	–0.2 (0.2)	–0.2 (0.2)	–0.2 (0.2)	–0.1 (0.1)

Our findings showed a difference in growth between the sexes. Overall, growth of facial structures was greater in males. Between ages 12 and 50 years, the increase of AFH was about 120% greater in males than in females. This is partially due to the time frame of this investigation: ie, only subjects age 12 or older were included. Most girls undergo their pubertal growth spurts about 2 years earlier than boys.[25] Therefore, some girls who were undergoing pubertal growth spurts were excluded. The second reason for the difference in the amount of growth between the sexes is that the male body attains an overall larger size, including the size of the craniofacial skeleton.[25]

The difference between the sexes decreased gradually with time. Between ages 18 and 50, the AFH increased in males about 22% more than in females (2.2 and 1.8 mm, respectively). This finding agrees with studies by Behrents,[8] Foley and Mamandras,[12] and Love et al.[11] All other measurements except 1 showed a similar trend: the difference in growth between the sexes was largest at the outset of the observation period and gradually tapered off.

The most surprising finding of this study was the greater amount of eruption of the maxillary central incisors in females than in males. Between ages 12 and 18, the maxillary central incisors erupted 1.4 mm (SE = 0.4) and 1.8 mm (SE = 0.4) in males and females, respectively. Although the variation in each group was substantial, this is especially significant when contrasted with the increase in AFH over the same time: 7.2 mm (SE = 1.0) and 2.6 mm (SE = 0.6) in males and females, respectively. Unfortunately, there is little information on the amount of eruption of the central incisors beyond age 15. Riolo et al[17] reported that the rate of eruption of the maxillary central incisors in relation to the PP was about the same in both sexes between ages 11 and 16. Simultaneously, there are considerable intergender differences in the amounts of eruption of the mandibular incisors, and the maxillary and mandibular first molars. Our results generally agree with those of Riolo et al.[17]

One may only speculate about the underlying cause of this unusual difference in incisor eruption. The imperfection of the statistical analysis might have resulted

Table X. Prediction of change of U6c/PP distance in males (mm) with SE in parentheses (mm).

Age (y)	*12*							
12	0.0 (0.0)	*15*						
15	2.5 (0.3)	0.0 (0.0)	*18*					
18	3.5 (0.4)	1.1 (0.1)	0.0 (0.0)	*21*				
21	4.0 (0.5)	1.6 (0.1)	0.5 (0.0)	0.0 (0.0)	*24*			
24	4.3 (0.5)	1.8 (0.2)	0.7 (0.1)	0.2 (0.0)	0.0 (0.0)	*27*		
27	4.4 (0.4)	1.9 (0.1)	0.8 (0.1)	0.3 (0.1)	0.1 (0.0)	0.0 (0.0)	*30*	
30	4.4 (0.4)	1.9 (0.1)	0.8 (0.1)	0.3 (0.1)	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	*40*
40	4.2 (0.4)	1.8 (0.2)	0.7 (0.2)	0.2 (0.2)	0.0 (0.2)	–0.1 (0.1)	–0.1 (0.1)	0.0 (0.0)
50	4.0 (0.3)	1.6 (0.2)	0.5 (0.3)	0.0 (0.3)	–0.3 (0.2)	–0.3 (0.2)	–0.4 (0.2)	–0.2 (0.1)

Table XI. Prediction of change of U6c/PP distance in females (mm) with SE in parentheses (mm).

Age (y)	*12*							
12	0.0 (0.0)	*15*						
15	1.1 (0.2)	0.0 (0.0)	*18*					
18	1.6 (0.4)	0.5 (0.1)	0.0 (0.0)	*21*				
21	1.8 (0.4)	0.7 (0.1)	0.2 (0.0)	0.0 (0.0)	*24*			
24	1.9 (0.4)	0.8 (0.1)	0.3 (0.0)	0.1 (0.0)	0.0 (0.0)	*27*		
27	1.9 (0.4)	0.8 (0.1)	0.3 (0.1)	0.1 (0.0)	0.0 (0.0)	0.0 (0.0)	*30*	
30	1.9 (0.4)	0.8 (0.1)	0.3 (0.1)	0.1 (0.1)	0.0 (0.1)	0.0 (0.0)	0.0 (0.0)	*40*
40	1.8 (0.3)	0.7 (0.1)	0.2 (0.2)	0.0 (0.2)	–0.1 (0.2)	–0.1 (0.1)	–0.1 (0.1)	0.0 (0.0)
50	1.7 (0.3)	0.6 (0.2)	0.1 (0.2)	–0.1 (0.3)	–0.2 (0.2)	–0.2 (0.2)	–0.2 (0.2)	–0.1 (0.1)

in a distorted picture of eruption. Certainly, the ideal method to assess growth is with a longitudinal follow-up of growth of a single subject. For ethical reasons, this methodology is impossible. The regression analysis used in this study gives an approximate picture of the changes. It is possible that the sample was biased and included a disproportionate number of girls having more eruption of the maxillary incisors.

The difference in angulation (tipping) of the maxillary incisors might have affected the eruption pattern. The amount of eruption was measured as the shortest distance from the incisal edge to PP. If the central incisors had proclined excessively during eruption, this would lead to underestimation of the amount of eruption. However, there does not seem to be any reason that the maxillary incisors would have tipped forward more in males than in females.

The clockwise rotation of the PP might also explain the intergender difference. Unfortunately, the detailed depiction of changes in the maxillary anterior teeth exceeds the scope of this study. Certainly, this phenomenon should be researched further. This is particularly important because the maxillary anterior region is a frequent site for dental implants.

The error of the measurement in this study was between 0.35 and 0.52 mm. For landmarks that are easy to identify, the error tends to be small. Despite that, the change of AFH was measured between relatively easy to locate N and Me. The error equaled 0.52 mm. The magnitude of error has some implication for the accuracy of prediction. After age 24, the increase of AFH in both sexes is small, and the error of measurement is larger than growth between successive time intervals. This makes the estimation of growth relatively inaccurate in later years.

This study had some limitations. The facial growth pattern was not considered during the selection process. Patients with vertical growth patterns might have had a prolonged period of facial growth in the vertical plane. Therefore, a single-tooth implant in a subject with a vertical facial growth pattern could be placed later than in a person with a horizontal growth pattern. The design of his study did not permit distinguishing subjects with prolonged vertical growth.

The change of incisor angulation was not measured in this investigation. However, circumpubertal facial growth in the horizontal plane is completed substantially sooner than growth in the vertical plane.[26] Therefore, the cessation of vertical facial growth is of clinical interest.

CONCLUSIONS

Our findings indicate the following:

1. The growth of the facial skeleton continues after puberty, but the amount of growth decreases steadily and, after the second decade of life, seems to be clinically insignificant.
2. About 60% to 70% of the increase of AFH (N/Me) occurs in LAFH (ANS´/Me).
3. There is a difference in the amount of growth between the sexes during the second decade of life; after age 20, the intergender difference is substantially diminished.
4. The rate of eruption of the maxillary central incisors in females seems to be greater than in males despite more growth of AFH in males over the same time period.

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