Longitudinal dental arch changes in adults

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This study examined changes in the dental arches that occur in untreated persons between late adolescence and the fifth or sixth decade of life. Longitudinal dental casts from 82 subjects were obtained as part of a recall study of subjects from the University of Michigan Elementary and Secondary School Growth Study. From the parent sample, three groups were identified. The untreated sample comprised 53 subjects (27 males and 26 females). A midadult sample of 10 persons, who had an additional set of records taken on average during their fourth decade of life also was analyzed, as was a sample of 13 subjects who received orthodontic treatment as adolescents and were about 30 years posttreatment. Measures of dental arch width, arch depth, and arch perimeter were evaluated with the aid of digital-imaging hardware and software. Incisor irregularity, curve of Spee, overjet, and overbite were measured directly from the dental casts. Statistically significant decrements occurred in arch width, depth, and perimeter. The mean decrement in any one dimension was less than 3 mm. At all times, males displayed significantly more mandibular incisor irregularity than females. In addition, the increase in mandibular incisor irregularity that occurred in male and female subjects was the same. However, irregularity did not increase in all subjects; it decreased in 3% of the males and 7% of the females. In general, overbite, overjet, and curve of Spee were stable during adulthood. Statistically significant correlations between the changes in dental arch measures could not be established. (Am J Orthod Dentofacial Orthop 1998;114:88-99)

The human craniofacial skeleton and its associated dental arches undergo visible alterations as they grow, adapt, and age. Relatively rapid changes occur during the transitional dentition, and once a functional permanent dentition is established, smaller changes continue to be observed. An understanding of the mechanisms underlying these slowly occurring changes in supposedly "nongrowing" adults, however, remains elusive.

There is substantial literature describing the development of the dentition. Given that there is relatively rapid growth during the first two decades of life, the study of the growth changes occurring during the juvenile and adolescent periods has consumed the vast majority of previous research efforts.[1-21] These naturally occurring changes in untreated dentitions often are used as comparative "gold standards," against which the dental changes produced by orthodontic treatment are evaluated.

It has been only recently that adult growth and development has been studied in detail. Although there was some information in the literature that indicated that the adult craniofacial skeleton continues to increase in size,[22-28] the findings from the cephalometric recall study of Behrents[27,28] that involved subjects from the Bolton-Brush Growth Study at Case Western Reserve University provided indisputable evidence that craniofacial growth continues into adulthood.

Given these findings, which have been replicated recently by West[29] on another sample of untreated persons, it is reasonable to assume that changes also occur in the associated dental arches. These changes presumably influence the duration and success of orthodontic retention procedures, especially if the arch changes continue to occur into the fifth and sixth decades of life. In addition, the increasing interest in adult orthodontics and the broadened scope of treatment possibilities, including the increasing popularity of dental implants, makes an understanding of the dentoalveolar changes in the adult of even greater importance.

Because of the time interval involved in gathering such longitudinal data on human beings, however, there have been relatively few descriptions of the longitudinal dental arch changes that occur in persons beyond the age of 20 years.[25,30-33] To date,

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Table I. Descriptive statistics of the untreated sample

	Females				Males				Pooled			
Age group	*N*	*Mean Age**	*Age Range**	*SD**	*N*	*Mean Age**	*Age Range**	*SD**	*N*	*Mean Age**	*Age Range**	*SD**
T_1	22	14.0	11.5–16.1	1.4	24	13.8	11.0–17.0	1.3	46	13.9	11.0–17.0	1.6
T_2	26	16.7	14.8–19.3	1.0	27	17.2	15.8–18.0	1.0	53	16.9	14.8–19.3	0.9
T_3	26	47.8	40.1–60.7	4.8	27	48.6	40.0–61.9	5.0	53	48.2	40.0–61.9	4.9

*In years.

only one investigation has been conducted specifically to examine certain dental arch changes into midadulthood.[32] Furthermore, longitudinal changes in arch depth have been examined in subjects only to 26 years of age,[30] and gender changes in arch perimeter and incisor irregularity have not been analyzed in subjects beyond the age of 20 years.

The present investigation was designed to describe the dental arch changes from adolescence to the fifth decade of life. Adult subjects in the University of Michigan Elementary and Secondary School Growth Study (UMGS) were selected and recalled for routine orthodontic records. Subsequently, the serial dental casts from these subjects were analyzed. The null hypotheses tested in the present investigation were that: (1) there are no changes in dental arch parameters in UMGS subjects; (2) there are no differences in dental arch parameters between females and males; and (3) any changes in dental arch parameters in males and females are the same regardless of time.

SUBJECTS AND METHODS

Patient samples

The University of Michigan Elementary and Secondary School Growth Study[17,34] was started in the early 1930s and consists of 714 subjects, primarily of Northern European ancestry, on whom anthropometric, psychometric, and craniofacial growth data were obtained on an annual basis while they were enrolled as students in the University School, a laboratory school located within the School of Education on the Ann Arbor campus. The number of annual records was variable among subjects and depended on the number of years that each student attended the University School.

One hundred and twenty-eight subjects who had had preexisting postpubertal dental casts were targeted for recall. Eighty-two subjects participated, and these subjects made up the recall parent sample. Each recall subject had study models made from standard alginate impressions as part of the long-term records obtained. Three study samples then were identified.

Untreated sample. The major thrust of this study was to investigate the long-term changes in the untreated dentition. Subjects were included in the untreated sample if they had: (1) no history of previous orthodontic treatment; (2) existing postpubertal dental casts; (3) no more than one missing tooth that broke arch continuity; and (4) no extensive prosthodontic reconstruction. All angle dental classifications were eligible for inclusion in the untreated sample, but Class III malocclusion was not represented.

The above inclusion criteria limited the number of subjects with intact acceptable dentitions to 27 males and 26 females. Casts were selected and measured at three different stages of dental development: T_1, after the exfoliation of all deciduous teeth and closure of the "E" spaces; T_2, an age that, on average, was just beyond or near the end of puberty[35]; and T_3, the recall age. Table I lists the untreated sample statistics.

Midadult sample. The recall of UMGS subjects offered a unique opportunity to evaluate other aspects of age-related dental change, and two smaller samples also were identified. The midadult sample comprised 10 subjects (5 females, 5 males) who also had participated in a pilot recall project of the Michigan Growth Study in 1981. At this time, orthodontic records were taken, including dental casts (T_{mid}), when the subjects were, on average, 31.9 ± 3.8 (range, 24.9 to 36.3 years) of age. The average age at recall (T_3) was 45.3 ± 3.3 years of age (range, 41.2 to 50.6 years). Dental casts from these subjects were analyzed for changes between T_{mid} and T_3, *i.e.,* on average between the early fourth and midfifth decades of life. Although this sample is small, no previous investigation has considered this time interval.

Postorthodontic sample. The third group of subjects consisted of 13 additional persons (9 females, 4 males) who were not included in the untreated sample because they underwent orthodontic treatment before the time that the T_2 casts were obtained. These subjects were on average 47.4 ± 4.7 years of age (range, 42.2 to 60.5 years) at the T_3 recall and were about 30 years beyond their orthodontic treatment age (average age, 17.9 ± 3.6 years; range, 15.0 to 29.5 years). This small study of treated subjects is marred with bias[36] and the analyses had low statistical power; however, because of the unique nature of the UMGS recall, the changes from T_2 to T_3 were examined to determine the long-term stability of dental arch dimensions in patients who had orthodontic treatment during adolescence.

Analysis of dental casts

The analysis of all casts was aided by digital-imaging system hardware and software (Bioscan OPTIMAS Imaging systems, Seattle, Wash.; version 2.02). This system, which had been modified previously for the specific analysis of study models,[37,38] allows calibrated 1:1 cast images to be digitized, stored, retrieved, and analyzed. Fifty landmarks were digitized on each maxillary cast and 48 on each mandibular dental cast.[37] These points were used by the OPTIMAS software to determine tooth centroids,[17] a calculated geographic center on the occlusal surface, and also to define the mesial, distal, buccal, and lingual surfaces for each tooth. Arch widths and depths of canines, premolars, and first molars as well as maxillary and mandibular arch perimeters were calculated from the digitized landmarks.

Overjet, overbite, curve of Spee, and incisor irregularity were measured directly from the dental casts. All cast digitizations and measurements were performed by one individual (G.A.C.).

Statistical evaluation

Means and standard deviations were calculated for all variables at T_1, T_2, and T_3. In addition, two-way repeated-measures analysis of variance (ANOVA) was used to test for differences among times by gender and combined (time effect). This ANOVA also was used to identify significant differences between gender groups and for group × times interactions. Furthermore, comparisons were conducted by using paired *t* tests to examine further the significant time effects identified by the repeated-measures ANOVA. Bonferroni's procedure for multiple comparisons was used to lower the α level of the paired *t* tests to 0.025 from the basic $p < 0.05$ level of significance.

Error of the method

Many orthodontic researchers use a double determination and Dahlberg's[39] formula to calculate error variance. In the present study, the casts were measured over a period of approximately 3 months. Houston[40] notes that if a study extends over an appreciable period of time, "drift" in the error variance may occur. Accordingly, to account for the random error and potential drift in error variance, Dahlberg's formula was modified to allow three replications for each variable: once at the beginning of the 3 month interval, once in the middle, and once at the end. A random numbers table was used to choose 10 sets of dental casts from the untreated sample of 53 subjects.[41] The previous ANOVA table was used to calculate the error variance. Overjet had the most variance (0.4 mm) and all the remaining measurements had variances of 0.3 mm or less.

RESULTS

Untreated sample

Tables II and III summarize the descriptive statistics for female and male data, respectively. Statistically significant changes (T_1 to T_2 and T_2 to T_3) identified with paired *t* tests are summarized in the right-hand columns of Tables II and III. Note that all the significant changes from T_2 to T_3 are decrements (< 3 mm) except for the increase in incisor irregularity.

Table IV lists the *F* ratios from the repeated-measures ANOVA of the sample data from 26 females and 27 males. The results in the *Combined* column note any significant time effect for each variable and ignore the gender effect. The results in the *Between Sexes* column note the significant male and female differences and ignore the time effect. The *Times × Group Interaction* column notes whether the time effect for each variable is the same for females and males, or if the difference between females and males is the same regardless of time.

It can be seen from the *Combined* column that the time effect was statistically significant for all of the variables with the exception of some maxillary transverse measurements. Note that there were no significant changes in the maxillary intermolar width and the interpremolar (first and second) widths.

Statistical significance in the *Between Sexes* column notes sexual dimorphism in some of the variables. There was a statistically significant difference between males and females for mandibular incisor irregularity. In this sample, males displayed more incisor irregularity at T_1, T_2, and T_3 than females (Tables II and III). The change in irregularity,

Table II. Untreated female sample: Descriptive and inferential statistics

	T_1 (N = 22)		T_2 (N = 26)		T_3 (N = 26)		Change†			
Measure (mm)	*Mean*	*SD‡*	*Mean*	*SD*	*Mean*	*SD*	$T_1 - T_2$	*SD*	$T_2 - T_3$	*SD*
Maxillary arch width (Centroid)										
Intercanine	31.54	1.50	31.13	1.38	30.47	1.58	−0.27	0.78	−0.65*	0.72
Interpremolar (1st)	34.29	1.99	34.14	1.91	33.79	1.96	−0.10	0.66	−0.35*	0.61
Interpremolar (2nd)	38.79	2.65	38.67	2.55	38.69	2.33	−0.14	0.71	−0.23	0.82
Intermolar (1st)	44.11	2.76	43.95	2.67	43.74	2.87	−0.11	0.60	−0.22	0.66
Maxillary arch width (Lingual)										
Intercanine	24.03	1.88	23.48	1.56	22.50	1.72	−0.44	1.08	−0.98*	1.01
Interpremolar (1st)	25.94	2.55	25.94	2.31	25.62	2.58	0.02	0.66	−0.32	0.96
Interpremolar (2nd)	30.20	2.80	30.36	2.83	30.50	2.43	0.02	0.76	−0.16	0.85
Intermolar (1st)	33.70	2.79	33.59	2.70	33.29	2.79	−0.11	0.63	−0.30	0.91
Mandibular arch width (Centroid)										
Intercanine	24.52	1.17	24.01	1.43	23.43	1.71	−0.32*	0.60	−0.58*	0.63
Interpremolar (1st)	30.66	1.47	30.53	1.43	29.78	1.66	−0.06	0.45	−0.75*	0.77
Interpremolar (2nd)	35.65	2.15	35.23	2.10	34.65	2.00	−0.38*	0.39	−0.74*	0.77
Intermolar (1st)	40.32	2.34	40.05	1.84	39.11	2.24	−0.22	0.97	−0.93*	1.26
Mandibular arch width (Lingual)										
Intercanine	18.64	1.24	18.17	1.59	17.25	2.13	−0.26	0.80	−0.92*	0.95
Interpremolar (1st)	25.10	1.88	24.87	1.94	24.18	2.12	−0.17	0.61	−0.70*	0.77
Interpremolar (2nd)	28.54	2.62	28.33	2.63	27.72	2.61	−0.23	0.53	−0.81*	0.71
Intermolar (1st)	31.14	2.20	30.87	1.96	30.37	2.27	−0.15	0.61	−0.50*	0.81
Maxillary arch depth										
Canine	7.98	1.18	7.86	1.19	7.38	1.30	−0.24	0.59	−0.48*	0.63
1st premolar	15.60	1.01	15.41	1.20	14.77	1.29	−0.34*	0.50	−0.64*	0.50
2nd premolar	22.05	1.23	21.84	1.57	20.87	1.57	−0.41*	0.63	−0.93*	0.85
1st molar	28.40	1.30	28.03	1.56	26.93	1.58	−0.56*	0.62	−1.10*	0.71
Mandible arch depth										
Canine	4.13	0.97	4.24	1.10	3.87	1.31	−0.01	0.79	−0.37*	1.00
1st premolar	10.50	1.50	10.30	1.55	9.76	1.49	−0.27	0.53	−0.54*	0.77
2nd premolar	16.73	1.75	16.54	1.68	15.87	1.55	−0.30	0.63	−0.58*	0.77
1st molar	23.07	1.73	22.75	1.90	21.85	1.68	−0.54*	0.75	−0.89*	0.76
Maxillary arch perimeter	78.45	2.54	77.64	2.65	75.60	2.49	−0.85*	1.12	−2.03*	1.20
Man. arch perimeter	66.88	3.14	65.86	3.40	64.13	3.22	−0.98*	1.21	−1.73*	1.27
Incisor irregularity										
Maxillary	2.63	1.58	2.47	1.52	3.25	1.84	−0.23	0.92	0.78	1.70
Mandibular	2.29	1.92	2.50	2.08	3.91	2.40	0.18	0.98	1.41*	1.29
Overbite	3.21	1.23	3.09	1.22	2.83	1.36	−0.16	0.65	−0.26	0.79
Overjet	4.00	1.41	3.85	1.30	3.77	1.75	−0.07	0.96	−0.07	1.07
Curve of Spee	1.57	0.46	1.44	0.47	1.40	0.61	−0.15	0.30	−0.05	0.43

*$p < 0.025$ (Bonferroni correction).
†H_o: $\delta = 0$ tested by way of paired *t*-test.
‡SD, Standard deviation.

however, was the same in both sexes. Sexual dimorphism was evident mostly in the maxillary dimensions and not the mandibular dimensions. Furthermore, there was no difference in overbite, overjet, or curve of Spee between females and males.

It is noted in the last column (*Interaction*) that the mandibular intercanine width, certain maxillary and mandibular arch depths, and mandibular arch perimeter may change differently in males and females. Statistical significance in this column also implies that if the mean values for males and females are plotted at T_1, T_2 and T_3, the two trend lines formed by connecting each of the three data points will be roughly parallel if the interaction is *not* statistically significant. See Table IV for other significant interactions.

Midadult sample

The analysis of the set of interim dental casts (T_{mid}) that were available on 10 of the untreated subjects in comparison to those taken at recall T_3 provided the opportunity of analyzing the changes in dental arch dimensions between the average ages of 31.9 and 45.3 years (Table V). The number of comparisons that were statistically significant was less that the total number of comparisons that were significant when the larger untreated sample was pooled, a finding that is not surprising given the small sample size.

Postorthodontic sample

The analysis of the dental casts of the last group of subjects, those with a history of previous ortho-

Table III. Untreated male sample: Descriptive and inferential statistics

Measure (mm)	T_1 (N = 24)		T_2 (N = 27)		T_3 (N = 27)		Change†			
	Mean	SD‡	Mean	SD	Mean	SD	$T_1 - T_2$	SD	$T_2 - T_3$	SD
Maxillary Arch Width (Centroid)										
Intercanine	32.21	1.66	32.25	1.64	31.49	1.72	−0.08	0.60	−0.76*	0.55
Interpremolar (1st)	35.68	2.11	36.08	1.88	35.86	2.19	0.33	0.86	−0.22	0.80
Interpremolar (2nd)	40.38	2.28	40.80	2.30	40.76	2.46	0.22	0.78	−0.04	0.77
Intermolar (1st)	45.66	2.59	46.31	2.62	46.20	2.62	0.45	1.09	−0.12	0.80
Maxillary arch width (lingual)										
Intercanine	24.46	1.30	24.12	1.94	22.76	2.01	−0.57*	0.87	−1.36*	1.07
Interpremolar (1st)	27.26	2.26	27.61	2.28	27.35	2.48	0.35	0.94	−0.26	0.97
Interpremolar (2nd)	31.86	2.73	32.34	2.57	32.20	2.52	0.32	0.79	−0.14	0.72
Intermolar (1st)	35.01	2.84	35.68	3.01	35.63	2.98	0.50	1.21	−0.05	1.16
Mandibular arch width (centroid)										
Intercanine	24.67	1.37	24.50	1.43	23.57	1.59	−0.39*	0.72	−0.92*	0.69
Interpremolar (1st)	31.43	1.83	31.56	1.96	30.77	1.95	−0.07	0.55	−0.78*	0.68
Interpremolar (2nd)	36.85	2.39	36.87	2.49	36.37	2.72	−0.19	0.61	−0.50*	0.73
Intermolar (1st)	41.21	2.24	41.02	2.57	40.45	2.61	−0.56	1.26	−0.57*	1.16
Mandibular arch width (lingual)										
Intercanine	18.92	1.25	18.55	1.37	17.31	1.61	−0.61*	0.94	−1.24*	0.90
Interpremolar (1st)	25.92	2.44	25.85	2.52	25.09	2.51	−0.16	0.72	−0.77*	0.79
Interpremolar (2nd)	29.89	2.92	30.15	3.12	29.62	3.46	−0.01	0.84	−0.52*	0.86
Intermolar (1st)	32.62	2.72	32.76	2.85	32.46	3.01	−0.08	0.63	−0.30	0.75
Maxillary arch depth										
Canine	8.70	1.29	8.09	1.25	7.44	1.30	−0.76*	0.71	−0.65*	0.58
1st premolar	17.19	1.20	16.30	1.44	15.39	1.58	−1.13*	0.97	−0.91*	0.60
2nd premolar	23.66	1.93	22.79	2.01	21.66	2.03	−1.15*	1.09	−1.13*	0.61
1st molar	30.04	1.96	29.04	2.10	27.93	2.14	−1.32*	1.28	−1.11*	0.69
Mandibular arch depth										
Canine	4.73	1.40	4.34	1.08	3.89	1.05	−0.46	0.95	−0.45*	0.64
1st premolar	11.31	1.26	10.66	1.27	10.03	1.16	−0.73*	0.81	−0.63*	0.59
2nd premolar	17.87	1.53	17.26	1.43	16.28	1.32	−0.89*	1.16	−0.99*	0.78
1st molar	23.77	1.67	22.97	1.47	21.65	1.53	−1.05*	1.12	−1.32*	0.85
Maxillary arch perimeter	81.80	3.49	80.45	3.56	78.65	3.82	−1.92*	1.78	−1.81*	1.24
Mandibular arch perimeter	68.94	2.64	67.88	2.75	65.51	2.93	−1.59*	1.59	−2.37*	1.21
Incisor irregularity										
Maxillary	2.59	1.90	2.90	2.00	3.51	2.21	0.14	0.59	0.61	1.60
Mandibular	3.11	2.14	3.67	2.62	5.43	2.90	0.75*	1.13	1.76*	1.59
Overbite	3.44	1.10	3.27	1.22	2.92	1.43	−0.21	0.74	−0.35	1.05
Overjet	4.89	1.98	4.24	1.27	3.94	1.25	−0.58*	0.89	−0.30	0.77
Curve of Spee	1.86	0.51	1.57	0.44	1.50	0.59	−0.35*	0.48	−0.06	0.39

*$p < 0.025$ (Bonferroni correction)
†See Table III
‡SD, Standard deviation

dontic treatment as an adolescent, indicated that maxillary arch widths that showed statistically significant decreases (intermolar and inter-second premolar) were the same dimensions in the larger untreated sample that remained unchanged over the 30 year T_2 -T_3 time interval (Table VI). In addition, there was a statistically significant increase in mandibular incisor irregularity.

DISCUSSION

The purpose of this study was to recall UMGS subjects in their fifth or sixth decade of life (T_3) in order to investigate the natural dental arch changes that occur in adulthood. The recalled subjects had casts made previously at an age (T_2) when, on average, circumpubertal growth was complete.

Untreated sample

The most striking observation in this adult sample was that for every statistically significant change in arch width, depth, and perimeter, whether for females, males, or pooled, the change was a decrement. Causes for these decrements are elusive; however, the changes appear not to occur independently of each other and are not statistically associated with any one factor. It is intuitively reasonable that a light consistent force of muscular draping or function may cause this arch decrement. The decrement is interesting, especially as Proffit[42] noted that tongue pressure is greater than lip pressure during swallowing and at rest. If tooth position was determined solely by muscular forces from the tongue and lip, in the current study one might

Table IV. Repeated-measures ANOVA for 26 female and 27 male untreated MGS subjects

	F Ratios				
	Among Times				
Measure (mm)	*Females*	*Males*	*Combined*	*Between Sexes*	*Times × Group Interaction*
Maxillary arch width (centroid)					
Intercanine	8.48**	27.91**	28.18**	2.72	0.49
Interpremolar (1st)	2.64	1.83	2.62	7.95**	1.70
Interpremolar (2nd)	0.89	0.89	0.22	5.16*	1.57
Intermolar (1st)	1.02	2.14	0.83	5.70*	2.63
Maxillary arch width (lingual)					
Intercanine	11.98**	50.84**	42.26**	0.30	0.89
Interpremolar (1st)	1.07	1.72	2.12	4.46*	0.64
Interpremolar (2nd)	0.02	1.76	0.88	3.85	0.66
Intermolar (1st)	0.88	1.67	0.69	4.07*	2.08
Mandibular arch width (centroid)					
Intercanine	13.87**	41.67**	51.00**	0.02	3.20*
Interpremolar (1st)	13.28**	19.73**	32.56**	2.17	0.27
Interpremolar (2nd)	21.98**	7.80**	25.73**	2.97	0.91
Intermolar (1st)	9.92**	8.66**	17.60**	1.28	0.49
Mandibular arch width (lingual)					
Intercanine	19.62**	43.77**	60.19**	0.01	2.18
Interpremolar (1st)	11.36**	14.07**	25.18**	1.45	0.17
Interpremolar (2nd)	19.31**	3.58	14.81**	2.26	0.90
Intermolar (1st)	4.82*	1.80	6.20**	4.34*	0.36
Maxillary arch depth					
Canine	10.75**	33.90**	40.64**	0.96	3.94*
1st premolar	25.54**	48.37**	68.48**	7.51**	8.97**
2nd premolar	29.26**	52.08**	77.63**	5.10*	5.17*
1st molar	50.57**	45.71**	86.11**	5.11*	4.39*
Mandibular arch depth					
Canine	6.16**	10.40**	15.01**	1.21	1.74
1st premolar	15.58**	31.82**	45.23**	1.69	2.75
2nd premolar	13.20**	29.84**	40.53**	3.35	5.11*
1st molar	29.05**	45.32**	72.18**	0.25	4.48*
Maxillary arch perimeter	50.70**	52.60**	97.66**	9.36**	3.35
Mandibular arch perimeter	35.18**	46.65**	79.05**	2.97	3.63*
Incisor irregularity					
Maxillary	4.51*	3.86	8.06*	0.06	0.38
Mandibular	20.47**	29.94**	48.95**	4.34*	2.24
Overbite	2.71	2.97	5.46**	0.24	0.14
Overjet	0.10	8.47**	4.24*	1.30	2.41
Curve of Spee	1.49	8.87**	8.92**	0.99	1.89

*$p < 0.05$.
**$p < 0.01$.

hypothesize that an increase in at least one arch dimension would occur; however, an increase was not found in any dimension.

Perhaps, "function" of the oral musculature is the culprit. Indeed, a possible consequence of function, the anterior component of force, has been measured and was correlated with anterior dental malalignment[43-44]; however, to argue that muscle function is a probable cause of the arch decrement merely begs the question. At best, it is extremely difficult or impossible to measure reliably, quantify, or simply even to describe muscle function. It also can be hypothesized that dental attrition could affect cast measures as well.

Sexual dimorphism existed in most variables that were analyzed, a finding that has been reported previously by Moyers et al.[17] for the juvenile and adolescent growth periods. Expectedly, this dimorphism continues in adulthood and is manifested mainly by the larger size (1 to 3 mm) in males compared with females. The maxillary arch exhibits dimorphism in width, depth, and perimeter, whereas mandibular arch dimensions were remarkably similar between genders, possibly reinforcing the concept that maxillary arch dimensions, not mandibular, are more amenable to change.

Arch width changes

Intercanine width. In the untreated UMGS and a similar Iowa growth study,[32] the maxillary and man-

Table V. Mid-adult sample: Descriptive and inferential statistics of untreated subjects (N = 10; five females, five males)

Measure (mm)	*Mean at age 31.9*	*Mean at age 45.3*	*Change*		*t*
			Mean	*SD*	
Maxillary arch width (centroid)					
Intercanine	30.66	30.45	−0.21	0.49	1.37
Interpremolar (1st)	34.82	34.67	−0.15	0.41	1.08
Interpremolar (2st)	39.79	39.75	−0.03	0.43	0.26
Intermolar (1st)	45.15	45.27	0.12	0.52	−0.74
Maxillary arch width (lingual)					
Intercanine	22.35	22.09	−0.26	0.28	2.96*
Interpremolar (1st)	26.79	26.51	−0.27	0.77	0.32
Interpremolar (2st)	31.57	31.45	−0.13	0.58	0.70
Intermolar (1st)	34.82	35.11	0.29	1.02	−0.88
Mandibular arch width (centroid)					
Intercanine	24.10	24.03	−0.07	0.32	0.67
Interpremolar (1st)	31.30	31.11	−0.19	0.27	2.26
Interpremolar (2st)	36.81	36.77	−0.05	0.27	0.54
Intermolar (1st)	42.20	42.22	0.02	0.48	−0.13
Mandibular arch width (lingual)					
Intercanine	17.86	17.59	−0.27	0.41	2.12
Interpremolar (1st)	25.54	25.40	−0.15	0.44	0.32
Interpremolar (2st)	29.73	29.52	−0.21	0.41	1.60
Intermolar (1st)	32.84	32.73	−0.11	0.66	0.51
Maxillary arch depth					
Canine	7.62	7.48	−0.13	0.40	1.06
1st premolar	15.54	15.42	−0.12	0.26	1.35
2nd premolar	21.38	21.07	−0.31	0.35	2.76*
1st molar	27.52	27.11	−0.41	0.41	3.20*
Mandibular arch depth					
Canine	4.05	3.92	−0.13	0.50	0.84
1st premolar	10.07	9.98	−0.09	0.53	0.59
2nd premolar	16.21	16.03	−0.18	0.41	1.40
1st molar	22.87	22.57	−0.29	0.32	2.88*
Maxillary arch perimeter	76.64	75.93	−0.71	0.75	2.99*
Mandibular arch perimeter	65.66	65.14	−0.51	0.80	2.03
Incisor irregularity					
Maxillary	3.38	4.04	0.66	0.94	−2.23
Mandibular	3.08	3.56	0.48	0.59	−2.57*
Overbite	2.73	2.50	−0.23	0.52	1.37
Overjet	3.50	3.55	0.06	0.39	−0.46
Curve of Spee	1.46	1.46	−0.01	0.16	0.13

*$p < 0.05$.
**$p < 0.01$.
SD, Standard deviation.

dibular intercanine widths decreased significantly in both sexes; the mandibular width more than the maxillary. These findings contradict the suggestion by Knott[11,12] and Moorrees and Chadha[45] that the intercanine width remains unchanged after the eruption of the permanent teeth.

In the 13 UMGS subjects who had undergone orthodontic treatment as adolescents, the average significant decrease in mandibular intercanine width (centroid, 1.1 mm) was greater than the significant decrease in the untreated female (0.6 mm) or male (0.9 mm) subjects. Postorthodontic decreases in intercanine width also has been noted by other investigators.[46-48] Even though the UMGS untreated sample demonstrated that intercanine width decreased naturally in adulthood, it appears that a change in intercanine width of less than 0.5 mm between treated and untreated subjects over a 30 year time period may be clinically insignificant. Variations in the type of orthodontic treatment and the nature and length of retention also may be factors affecting the stability of intercanine width, but the specifics of treatment and retention of these 13 subjects was not known.

Intermolar width. The current study also noted an insignificant change in maxillary intermolar width for both females and males. This finding suggests strongly that maxillary intermolar width is stable in untreated subjects from 17 to 48 years of age. An exception was noted in the Michigan study; if the

Table VI. Post-orthodontic sample: Descriptive and inferential statistics of treated subjects (N = 13; nine females, four males)

Measure (mm)	Mean at age 17.9	Mean at age 47.4	Change		t
			Mean	SD	
Maxillary arch width (centroid)					
Intercanine	31.16	30.19	−0.97	0.61	5.71**
Interpremolar (1st)	35.40	34.06	−1.34	0.53	6.18**
Interpremolar (2st)	37.85	37.02	−0.82	0.99	3.02*
Intermolar (1st)	44.25	43.56	−0.70	0.89	2.84*
Maxillary arch width (lingual)					
Intercanine	23.04	21.69	−1.35	1.20	4.05**
Interpremolar (1st)	29.14	28.63	−0.51	0.82	2.25*
Interpremolar (2st)	33.78	33.49	−0.29	2.18	0.35
Intermolar (1st)	34.03	33.65	−0.38	0.99	1.38
Mandibular arch width (centroid)					
Intercanine	25.10	24.02	−1.08	0.50	7.73**
Interpremolar (1st)	31.83	30.93	−0.90	0.96	2.49*
Interpremolar (2st)	34.61	34.18	−0.43	0.76	2.02
Intermolar (1st)	40.91	40.53	−0.38	0.72	1.90
Mandibular arch width (lingual)					
Intercanine	19.31	17.96	−1.34	0.62	7.85**
Interpremolar (1st)	25.72	24.78	−0.93	0.74	3.32*
Interpremolar (2st)	27.39	27.15	−0.24	0.95	0.91
Intermolar (1st)	31.50	31.21	−0.29	1.04	1.00
Maxillary arch depth					
Canine	8.71	7.99	−0.72	0.81	3.17**
1st premolar	15.82	15.30	−0.52	0.89	1.43
2nd premolar	19.57	18.73	−0.84	0.92	3.31**
1st molar	25.73	24.86	−0.86	0.83	3.76**
Mandibular arch depth					
Canine	5.15	4.64	−0.52	0.62	3.01*
1st premolar	10.78	10.01	−0.78	0.87	2.37
2nd premolar	14.82	13.98	−0.84	0.59	5.12**
1st molar	21.43	20.48	−0.96	0.62	5.56**
Maxillary arch perimeter	73.00	71.37	−1.63	1.56	3.76**
Mandibular arch perimeter	63.11	61.51	−1.60	1.70	3.40**
Incisor irregularity					
Maxillary	3.64	4.71	1.07	1.85	−2.09
Mandibular	2.78	4.71	1.93	1.66	−4.18**
Overbite	3.19	3.33	0.15	1.17	−0.45
Overjet	3.93	3.75	−0.18	0.80	0.83
Curve of Spee	1.97	2.11	0.14	0.47	−1.08

*$p < 0.05$.
**$p < 0.01$.
SD, Standard deviation.

subjects had had orthodontic treatment (see Table VI), the maxillary intermolar width decreased significantly over the 30 year posttreatment period, but the decrease was less than 1 mm and may be clinically irrelevant.

Mandibular intermolar width in females and males decreased significantly in the present study, but not in the study by the Iowa group. This difference may be attributed to a difference in sample sizes. Given that the ability to identify significant differences was increased with the larger sample size of the UMGS, the decrement in intermolar width, in turn, probably became statistically detectable.

It is interesting that the subjects who had an additional set of records in midadulthood had significant changes in some mandibular measurements (see Table V); however, the mandibular intermolar width, similar to the Iowa study, did not change. One could infer from these results that in adulthood, the decrement occurs so slowly that it is measurable only with a large serial sample over an extended period of time.

Overbite

In the present study, overbite was measured directly on study models. Other studies have used plaster casts or cephalograms to measure overbite. Regardless of the method, changes in overbite are comparable. Bishara et al.[32] noted a statistically significant increase in overbite (1.0 mm) in females but not in males. In contrast, the present investigation noted no change in overbite in females or males. It is interesting to note that many subjects in the UMGS demonstrated moderate amounts of incisal attrition. Obviously, attrition could affect an assessment of overbite; nonetheless, as measured in the UMGS, overbite appears to be stable in untreated adults.

Overjet

In untreated UMGS males, there was a slight but statistically significant decrease in overjet (0.6 mm) from 13.8 to 17.2 years of age; there was no significant change in females. In addition, there was no change in overjet for both sexes in the UMGS sample from the average age of 17 to 48 years. Results from the previous Iowa study are in concordance.

Small anteroposterior changes in the maxillomandibular relationship continue in adulthood.[27-29,32] It has been noted, however, that there is a poor correlation between the anteroposterior relationships of the jaws and overjet due to compensations in incisor inclination.[49] Similarly, in adult jaws it appears that incisor compensations may result in a stable overjet and also masks the anteroposterior growth changes.

Curve of Spee

The curve of Spee in the present study decreased significantly only in the untreated male sample. In addition, this decrease occurred in the same age range that the overjet changed significantly, i.e., 13.8 years (T_1) to 17.2 years of age (T_2). The curve of Spee, similar to overbite and overjet, is stable in adulthood.

Arch perimeter

Before the present study, longitudinal changes in arch perimeter in persons over the age of 18 years had not been reported. The findings from this adult study are consistent with those from studies of younger subjects (3 to 18 years of age) by Moorrees et al.[15,16] and the Michigan group.[17] The results from the UMGS suggest that in general, arch perimeter decreases from 17 to 48 years of age. In fact, of all the variables that decreased, mandibular arch perimeter decreased the most (e.g., 2.4 mm in the male sample; see Tables II and III). Furthermore, the statistically significant decrease in maxillary perimeter is similar over time for males (1.8 ± 1.2 mm) and females (2.0 ± 1.2 mm); however, mandibular arch perimeter in males decreased significantly more from 17 to 48 years of age (2.4 ± 1.2 mm) than the same perimeter in females (1.7 ± 1.3 mm). This continual decrease in arch perimeter consequently may affect tooth alignment over the long term.

Arch depth

There was a significant decrease in arch depth at all levels of measurement (canine, first and second premolars, and first permanent molar), in both dental arches, and for both females and males. These observations are not new; there is a consensus in the literature that arch depth decreases over time,[11,17,19,33,50] at least up to 26 years of age.[30]

Notably, 17 of the 53 pooled subjects in the present study had some interdental spacing in the mandibular arch at T_1 or T_2. In every subject, these spaces had closed by the recall age. This finding substantiates the mesial drift that was described by Trauner[51] and Downs.[52] The anterior component of force (ACF) measured by Southard et al.[43,44] may help to explain mesial drifting and the decrement in arch perimeter and arch depth noted in the current study. If the ACF is a cause of this decrement, the statistically significant interaction (Table IV) noted in the perimeter and depth parameters suggests also that the ACF may be different in females and males. To date, gender differences in the ACF have not been demonstrated.

Incisor irregularity

Maxilla. Even though there were statistically significant increases in lower incisor irregularity for both males (1.8 mm) and females (1.4 mm), the increase in upper irregularity (0.7 mm) was significant only in the pooled UMGS sample and is less of a clinical concern than lower irregularity.

Mandible. To date, the change in incisor irregularity[53] has not been evaluated longitudinally in untreated male and female subjects over 20 years of age. The present investigation uniquely describes how the incisor alignment may change in dental arches beyond this age. Maturational changes could affect orthodontic retention,[54] and the findings of the present study corroborates this conclusion.

The change in incisor irregularity (T_2 to T_3) was not significantly different between males and females (Table IV, column 6). Behrents[27,28] and Bishara et al.[32] noted that the pattern of mandibular growth in adulthood is different in females and males, i.e., on average, males have a forward rotation and females have a backwards rotation. Furthermore, West[29] noted these same pattern differences in cephalograms from the UMGS sample evaluated in the current study. Statistically similar changes in female and male incisor irregularity in light of different mandibular growth patterns casts doubt on the theory of latent mandibular growth as a cause of incisor irregularity. When Sinclair and Little[20] studied untreated occlusions at 9, 13, and 20 years of age, they noted more mandibular incisor irregularity in females than males. In addition, Carmen[55] noted in a sample of 50 subjects at age 12 and 18 years that females had a propensity for more severe crowding than males. In contrast, in the UMGS sample, males demonstrated more mandibular irregularity than females at all times. The explanation for these contradictory findings is unclear.

Much variation was evident when the UMGS casts were analyzed for incisor irregularity. The raw data from the present investigation was revisited to categorize the individual variation in lower incisor irregularity from 17 to 48 years of age; the irregularity increase was less than 1 mm in 46% of the females and 37% of the males. Irregularity increased between 1 to 3 mm in 39% of the females and 26% of the males; it increased more than 3 mm in 12% of the females and 30% of the males, and it decreased in 3% of the females and 7% of the males.

The decrease in mandibular irregularity in some subjects is worth comment. Sinclair and Little[20] noted also that 34% of the subjects in their study had a decrease in irregularity as compared with only 10% of the relatively older subjects in the UMGS investigation. Similarly, Carmen[55] noted a decrease in irregularity in a number of his subjects. Sinclair and Little could find no significant correlations between irregularity and arch dimensions. In addition, Carmen concluded that a direct relationship does not exist between arch width and incisor irregularity. Indeed, when the raw data in the current study were analyzed further with independent *t* tests, no significant correlation was noted between the change in intercanine width and change in mandibular irregularity. Furthermore, a correlation between existing space in the mandibular dental arch and the change in irregularity in adulthood was not found. A change in any one dimension is not the proximate cause for increased mandibular malalignment.

Mandibular incisor irregularity in orthodontically treated MGS subjects

Little et al.[56] noted that 10 years postretention, two thirds of 65 subjects had unsatisfactory lower incisor alignment. Changes in mandibular irregularity in the untreated UMGS sample to the changes in the 13 orthodontically treated UMGS subjects who were, on average, 30 years beyond orthodontic treatment. When the null hypothesis ($H_o \delta_{Treated} = \delta_{Untreated}$) was tested, it could not be rejected. The similar increase in irregularity in treated and untreated adults attests to the need for judicious retention procedures for the average orthodontic patient.

Clinical significance of arch change in the adult

When Hellman[57] conducted a cross-sectional study of American Indian skulls, he noted that "the skeletal structure of the human face does not remain the same, but continues to change as long as life lasts." Similarly, Bishara et al.,[32] Behrents,[27,28] and West[29] demonstrated that subtle skeletal craniofacial growth continues in adulthood. The results of the present study permit further inference regarding adult craniofacial growth, i.e., when examined longitudinally, there is a small but statistically significant decrement in most adult dental arch dimensions. Why these changes occur is unknown; perhaps the reasons are related similarly to the elusive causes of senescence. Change, indeed, appears to be incessant and lifelong.

Fortunately for orthodontists, the present study noted that the average decrement in any one arch dimension was less than 3 mm. These small changes, however, hardly could be described as "clinically insignificant," especially in view of the fact that the correction of a full cusp Angle Class II molar relationship is only about 5 mm.[58]

Orthodontists are fortunate that the majority of improvements achieved by tooth movements are stable. It is unfortunate, however, that success or failure of orthodontic treatment often is judged by patients and orthodontists to be associated with the recurrence of mandibular irregularity. Mandibular irregularity, on average, appears to increase throughout life regardless of orthodontic treatment provided. It is prudent, therefore, to consider retention procedures, interproximal reduction procedures,[59,60] or limited orthodontic retreatment, if optimum incisor alignment is desired throughout life.

SUMMARY AND CONCLUSIONS

Longitudinal dental casts from 82 subjects were obtained as part of a recall study of subjects from the University of Michigan Elementary and Secondary School Growth Study. From the parent sample, three groups were identified (untreated, midadult, and treated). Measures of dental arch width, arch depth, and arch perimeter were evaluated with the aid of digital-imaging hardware and software. Incisor irregularity, curve of Spee, overjet, and overbite were measured directly from the dental casts.

Statistically significant decrements occurred in arch width, depth, and perimeter. The mean decrement in any one dimension was less than 3 mm. At all times, males displayed significantly more mandibular incisor irregularity than females. In addition, the increase in mandibular incisor irregularity that occurred in males and females was the same; however, irregularity did not increase in all subjects, and it decreased in 3% of the males and 7% of the females. In general, overbite, overjet and curve of Spee were stable during adulthood. Statistically significant correlations between the changes in dental arch measures could not be established.

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