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Incremental growth charts for condylar growth between 6 and 16 years of age

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SUMMARY This study provides sex specific reference data for the incremental growth of the mandibular condyle. The results pertain to a mixed-longitudinal sample of 113 males and 108 females followed annually between 6 and 16 years of age (total of 1647 observations). Growth of condylion was evaluated using naturally stable mandibular reference structures. The mean growth curves were estimated by multilevel models using iterative least squares procedures; between subject variation was estimated based on the sample's percentile distributions.

Mean yearly velocities of condylar growth for males ranged between 2.1 and 3.1 mm/year. Growth rates decreased during childhood, increased during adolescence, and attained a maximum of 3.1 mm/year at approximately 14.3 years of age. Females showed a more constant rate of condylar growth during childhood (2.0–2.7 mm/year), a smaller adolescent peak (2.3 mm/year) at approximately 12.2 years and rapid deceleration after the peak.

These reference data offer orthodontists an objective means of evaluating growth potential and treatment outcome in individual patients. Charts are provided for evaluating condylar growth of individual patients.

Introduction

Longitudinal reference data for condylar growth are necessary since the condyle is the mandible's most important growth site (Moss, 1960; Enlow and Harris, 1964; Koski, 1968; Moss and Rankow, 1968). Reference data for condylar growth would provide a means of estimating growth potential and anticipated treatment response (Hultgren *et al*., 1980; Petrovic *et al*., 1990). Most importantly, longitudinal reference data make it possible to identify patients in need of further investigation or treatment, and to monitor treatment results (Roche and Himes, 1980).

While reference data exist for the growth of mandibular length and ramus height, e.g. Co–Gn, Ar–Pg, Co–Go (Maj and Luzi, 1964; Tracy and Savara, 1966; Savara and Tracy, 1967; Bishara *et al*., 1981, 1984), guidelines related specifically to condylar growth are limited. It has been shown that boys have approximately 3 mm/year condylar growth during the juvenile period, a slight decrease in rate to a prepubertal minimum, followed by an adolescent spurt peaking at 5.5 mm/year (Björk, 1963). Rates of condylar growth are greater during the 3 years prior to than after the pubertal peak (Hägg and Attstrom, 1992). Baumrind and co-workers (1992) reported relatively constant rates of condylar growth for a sample of treated and untreated children between 8.5 and 15.5 years of age, although sex differences in growth patterns were identified. The remaining studies estimate various aspects of condylar growth during adolescence (Odegaard, 1970a,b) and compare condylar growth of children with treated and untreated malocclusion (Baumrind *et al*., 1983). Importantly, none of the existing studies provide appropriate reference data for the clinical evaluation of condylar growth.

The purpose of this study was to develop yearly incremental reference data, based on a

Table 1 Number of subjects with serial records at the ages indicated.

Age	Males	Females	Total
6–7	50	84	134
7–8	63	81	144
8–9	60	66	126
9–10	55	57	112
10–11	113	108	221
11–12	112	106	218
12–13	110	105	215
13–14	108	97	205
14–15	105	76	181
15–16	55	36	91

large group of healthy orthodontically untreated children, which can be easily applied to males and females between 6 and 16 years of age.

Materials and methods

The data were derived from serial lateral cephalograms collected by the Human Growth Research Center, University of Montreal. They pertain to French-Canadian children drawn from three school districts representing the different socio-economic strata of the larger population (Demirjian *et al*., 1971). A mixed-longitudinal sample of 113 males and 108 females were selected based on available and suitable serial records (Table 1). In order to obtain unbiased estimates of variation, children with normal occlusion and malocclusion were included in the sample.

All cephalograms were traced and digitized by the same technician. The analyses describe the growth of the cephalometric landmark condylion (Co), operationally defined as the point tangential to the most superior aspect of the condyle using a perpendicular to the ramal plane. The average of the right and left condyles was used for analysis. Technical reliability, defined as the proportion of error variance to error plus true variance (Buschang *et al*., 1987), has been estimated at 90 and 92 per cent for the horizontal and vertical aspects of condylion, respectively. Method errors ($\sqrt{\Sigma}$ deviations$^2/2n$) for condylion were 0.73 mm for the horizontal and 0.62 mm for the vertical aspects. The measurements were corrected for radiographic enlargement (11.08 per cent).

To describe the growth of Co, each subject's serial radiographs were superimposed using natural reference structures in the mandible (Björk and Skieller, 1983). The superimposition orientated the radiographic tracing on: (1) anterior contour of the chin, (2) inner contour of the cortical plate at the lower border of the symphysis, (3) distinct trabecular structures in the symphysis, and (4) contour of the mandibular canal. Reliability of the mandibular superimpositions ranged between 94 and 99 per cent (Buschang *et al*., 1986a).

Percentiles were used to describe individual variation as increments can be skewed (Meredith, 1962; Garn and Rohmann, 1963). The 10th, 25th, 75th, and 90th percentiles were estimated; the sample size was considered to be too small to allow accurate estimation of the more extreme (3rd and 97th) percentiles. The shape of average growth curve was estimated using a two-level polynomial model (Goldstein, 1986a,b):

$$Y_{ij} = \beta_{0j} + \beta_{1j}t_{ij} + \beta_{2j}t_{ij}^2 + \ldots + e_{ij}$$

where subject j was measured on response variable Y on occasion i ($i = 1, \ldots n$). The estimate of condylar growth Y, was computed by adding the intercept (β_0) to the products of the other fixed coefficients (β_1, β_2, …) multiplied by age (t) at each occasion (i). The polynomial model takes full advantage of each individual's longitudinal growth data and statistically evaluates the shape of the curve. The basic model partitions variation between subjects at the higher level and between measurement occasions, nested within subjects, at the lower level. Iterative generalized least squares were used to estimate the model's parameters (Goldstein, 1987). The growth curves were drawn by plotting condylar growth rates at each of the ages indicated and smoothing the lines connecting them. The ages in the tables and percentile charts refer to the midpoint of each age interval. For example, an increment from 9 to 10 years should be plotted on the chart vertically above 9.5 years.

Results

The multilevel models (Table 2) indicated a more complex growth curve for females (5th order) than for males (4th order). Variation between subjects was significantly greater for males than females; variation within subjects was similar for the two sexes.

Table 3 provides estimates of average growth rates derived from the fixed portion of multilevel models and percentiles describing variability in growth rates. For males, growth rates decelerated from 3.1 mm/year at 6.5 years to 2.1 mm/year at 9.5 years, accelerated to 3.1 mm/year at 14.3 years, and then started to decelerate (Figure 1). Prior to the initiation of adolescence, there was negative condylar growth velocity for males at the lower end of the distribution, indicating a decrease in condylar length. It was not uncommon for individuals at the upper end of the distribution (>90 per cent) to show more than 5 mm of condylar growth per year.

Females showed a similar pattern of condylar growth (Figure 2). Growth rates decelerated from 2.7 to 2.0 mm/year between 6.5 and 9.4 years, and

Table 2 Multilevel models used to estimate the average growth curves for males and females.

Explanatory variables	Males		Females	
	Estimates	S.E.	Estimates	S.E.
Fixed coefficients:				
Intercept	3.758	0.05964	3.286	0.05111
Age	0.2602	0.003903	0.2294	0.005512
Age^2	0.01225	0.001489	0.003056	0.001963
Age^3	–0.0003411	0.0001427	–0.002162	0.0005652
Age^4	–0.0003193	0.00003861	–0.0003147	0.00007461
Age^5			0.00004079	0.00001467
Random coefficients:				
Subject level σ_0^2	0.0344	0.001543	0.02507	0.001176
Age level $\sigma^{2\mu}{}_{10}$	0.4475	0.05625	0.4021	0.04516
Iterations	4		4	
Age measured from	12 years		11 years	
Accuracy for convergence	10^{-3}		10^{-3}	

Table 3 Percentile distribution for condylar growth rates (mm/year) between 6–16 years of age.

Age	Males					Females				
	10%	25%	Average*	75%	90%	10%	25%	Average *	75%	90%
6.5	0.88	1.87	3.07	4.47	5.10	0.88	1.19	2.69	3.50	4.37
7.5	0.57	1.58	2.46	3.65	4.50	0.27	1.07	2.13	3.68	4.53
8.5	0.42	0.83	2.17	3.28	4.17	–0.15	1.15	2.01	2.85	3.88
9.5	–0.14	0.94	2.12	3.44	4.50	0.04	0.97	2.11	3.08	4.11
10.5	–0.12	1.46	2.25	3.74	5.23	0.26	1.27	2.25	3.21	4.36
11.5	0.65	1.41	2.48	3.27	4.31	0.27	0.92	2.31	2.93	3.90
12.5	0.20	1.04	2.72	3.95	5.19	0.47	1.18	2.21	3.25	4.25
13.5	0.74	1.78	2.90	4.32	5.21	0.29	1.01	1.92	2.64	4.11
14.5	0.98	1.91	2.95	4.58	5.80	–0.05	0.83	1.48	2.60	3.61
15.5	0.66	1.31	2.79	3.77	4.79	–0.95	–0.01	0.94	1.35	2.06

*Multilevel model.

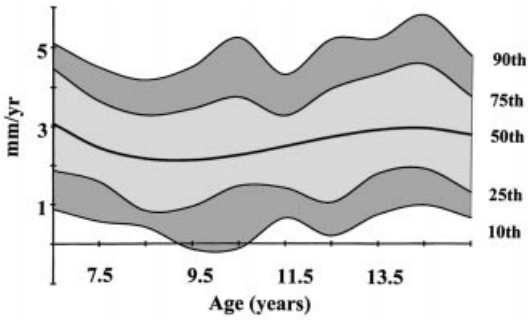

Figure 1 Total condylar growth (corrected for magnification). Incremental chart for males.

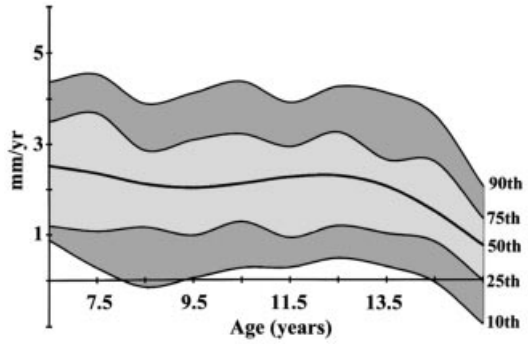

Figure 2 Total condylar growth (corrected for magnification). Incremental chart for females.

then accelerated to a maximum of 2.3 mm/year at 12.2 years. Growth rates decelerated rapidly thereafter, attaining rates of 0.9 mm/year at 15.5 years. There was negative condylar growth for approximately 25 per cent of the subjects at 15.5 years of age. Variability in condylar growth rates remained relatively constant until adolescent peak velocity, after which it decreased.

Discussion

The results provide, for the first time, longitudinal reference data for condylar growth during childhood and adolescence. They might be expected to differ from the description of mandibular growth (e.g. size increase between condylion and pogonion) which incorporates condylar growth and mandibular rotation. Condylar growth rates clearly change with age and the pattern of change closely parallels the growth of other craniofacial and somatic measurements (Björk, 1955; Nanda, 1955; Bambha and Van Nalta, 1963; Buschang *et al*., 1983). For both males and females, growth decelerates to a pre-adolescent minimum and then accelerates to maximum adolescent velocity. As expected, the shape of the condylar growth curve closely coincides with that of overall mandibular growth of French Canadians (Buschang *et al*., 1986b, 1988, 1989).

Sexual dimorphism in condylar growth was clearly indicated. Male condyles grew at slightly faster rates during childhood and at substantially faster rates during adolescence, as previously demonstrated for other craniofacial measures (Nanda, 1955; Hunter, 1966; Tracy and Savara, 1966; Savara and Tracy, 1967; Lewis *et al*., 1982). Dimorphism in the timing of the adolescent spurt (12.2 years and 14.3 years for females and males, respectively) coincides with estimated ages of peak adolescent velocity reported for other craniofacial and somatic measures (Bambha, 1961; Tanner, 1962; Bambha and Van Nalta, 1963; Maj and Luzi, 1964; Tracy and Savara, 1966; Savara and Tracy, 1967; Bergersen, 1972; Lewis *et al*., 1982; Goldstein 1986a).

The results suggest that some children exhibit negative growth velocities, especially around the prepubertal minimal growth period and towards the end of adolescence. This may be due to structural bony changes in the mandibular condyle associated with craniomandibular disorders, such as osteoarthosis, osteoarthritis, and polyarthritis. Dibbets and van der Weele (1992) reported such structural bony changes in approximately 5 per cent of a sample followed between childhood and adulthood. Most cases had been diagnosed between 12 and 16 years of age, and one 13-year-old patient showed a dramatic loss of vertical dimension in both joints within 1 year. Alternatively, the negative changes could be due to an unpredictable flattening and/or deformation of the condyles (Dibbets and van der Weele, 1991). Finally, the negative growth may reflect errors associated with identifying the cephalometric landmark condylion, which would be most pronounced during periods of minimal condylar growth.

Due to the errors inherent in cephalometrics, it is imperative to use appropriate and consistent techniques to identify and measure the position of condylion. First, operational definitions of condylion based on mandibular reference planes should be used and every effort should be made to have the same technician at the beginning and end of each interval. Intensifying screens or open mouth radiographs could also be used to enhance the resolutions of the condyles (Adenwalla *et al*., 1988; Stickel and Pancherz, 1988; Forsberg and Odenrick, 1989). Finally, if the position of condylion is replicated and the measurements are averaged, the confidence limits can be reduced according to the square root of the number of replicates (Houston, 1983). For example, errors could be cut by approximately 30 per cent by averaging two replicates, and by 50 per cent by averaging four replicates.

Since most orthodontists do not see their patients at exactly 1-year intervals, adjustments may be necessary to convert the observed increments. Adjustments can be made by dividing the observed increment by the subject's chronological decimal age interval. Tables for estimating exact decimal age are available (Tanner *et al*., 1966; Eveleth and Tanner, 1990). The table and charts also assume that the observed increment of condylar growth has been corrected for magnification (see Thurow, 1970, for correction factors).

The primary purpose of these reference data is to help orthodontists identify children who require further investigation or therapy. Since the majority of patients with Class II and Class III skeletal malocclusions have abnormal mandibular growth (Renfroe, 1948; McNamara, 1981; Mitani, 1981), and the condyles are the foci of treating mandibular growth problems (Hultgren *et al*., 1980; McNamara, 1981), our charts provide standards against which individual patients' past growth can be assessed. Based on sample size, our estimates of condylar growth between 10.5–14.5 are the most accurate; the extreme percentiles for the other ages must be interpreted with caution.

The reference data also provide a means for monitoring treatment outcomes, making it possible to more accurately evaluate the response of condylar growth to treatment. For example (Figure 3), subject 1 is an 11-year-old male who presented with a severe skeletal Class II malocclusion, and was treated for 1 year and 2 months with a functional appliance. His favourable condylar growth increment (4.8 mm/year), which was well above the 90th percentile, was a response that would not normally have been expected. It played an important role in the non-surgical correction of his malocclusion. Subject 2, a boy aged 8 years and 9 months who presented with a comparable malocclusion and underwent the same functional appliance therapy as subject 1, showed a much more limited condylar growth response (2.9 mm). His condyle grew 2.6 mm/year, placing him at the 50th percentile, which was insufficient to resolve his skeletal discrepancy.

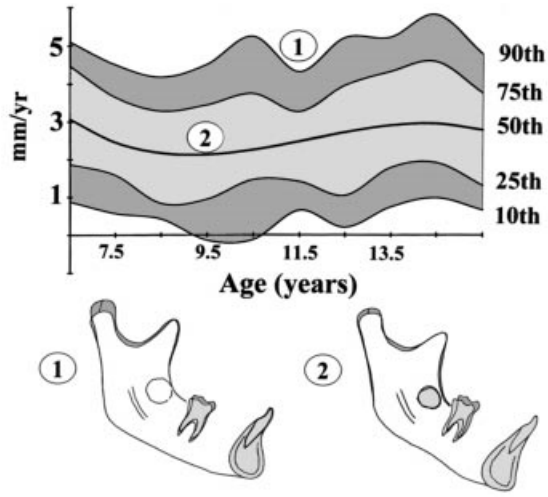

Figure 3 Subject 1: 6.2 mm of condylar growth from 11 years to 12 years 2 months = 5.3 mm/year (6.2 mm/1.17 years) × 0.91 (correction for magnification) = 4.8 mm/year (incremental condylar growth). Subject 2: 2.9 mm of condylar growth from 8 years 11 months to 9 years 11 months = 2.9 mm/year (2.9 mm/1.0 year) × 0.91(correction for magnification) = 2.6 mm/year (incremental condylar growth).

Conclusions

1. The condyles follow the general or somatic pattern of growth with childhood deceleration, acceleration during adolescence to peak velocity, and rapid deceleration after the peak.

2. There is sexual dimorphism in condylar growth. Females have less intense rates of condylar growth, especially during adolescence, than males and they attain peak adolescent velocity approximately 2 years earlier than boys.
3. There is substantial individual variation in condylar growth. Some individuals had little or negative growth, while others showed more than 5 mm of growth per year.
4. The reference data and charts provide an objective means of evaluating patients' growth potential and treatment outcome.

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