European Journal of Orthodontics 33 (2011) 441–449
doi:10.1093/ejo/cjq099
Advance Access Publication 22 November 2010

A mixed longitudinal anthropometric study of craniofacial growth of Colombian mestizos 6–17 years of age

Cleidy Arboleda*, Peter H. Buschang**, Jesus A. Camacho*, Paola Botero* and Samuel Roldan*

Departments of Orthodontics, *CES University, Medellín, Colombia and **Baylor College of Dentistry, The Texas A&M University System Health Science Center, Dallas, TX, USA

Correspondence to: Dr Peter H. Buschang, Department of Orthodontics, Baylor College of Dentistry, 3302 Gaston Avenue, Dallas, TX 75246, USA. E-mail: phbuschang@bcd.tamhsc.edu

SUMMARY The purpose of this study was to evaluate the craniofacial growth of Colombian mestizos. Four age cohorts, including a total of 458 children and adolescents (262 males and 216 females), were included in this mixed-longitudinal study. The cohorts were first measured at ages 6, 9, 12, and 15 and every year thereafter for 3 years. Eight anthropometric measurements were taken, including three cranial (head perimeter, head width, and head length), two craniofacial (maxillary and mandibular length), and three facial (face height, bizygomatic width, and bigonial width).

Multilevel analyses showed that all dimensions increased between 6 and 17 years of age. The cranium grew less than the craniofacial, which in turn grew less than the facial dimensions. In addition, vertical dimensions showed more growth than antero-posterior dimensions, which in turn grew more than transverse dimensions. None of the measurement showed statistically significant growth differences between subjects with normal occlusion and Class I or Class II malocclusions. Males were generally larger than females and showed greater growth rates. Except for facial width, whose yearly velocities decreased regularly with age, an adolescent growth spurt was evident for most of the male measurements. Yearly velocities for females followed a simpler decelerating pattern.

The results provide reference data for Colombian mestizos, for whom normative data of other ethnic groups are not applicable. While occlusion had little or no effect, there were gender differences, as well as important growth differences between cranial and facial measurements.

Introduction

Since most body dimensions follow the same postnatal growth pattern as height and weight (Malina *et al.*, 2004), decreases in craniofacial growth rates might be expected during childhood, followed by increases during adolescence (Tanner, 1962; Veldhuis *et al.*, 2005). However, craniofacial dimensions might be expected to differ in their growth potential because some measurements tend to be more mature and have less growth potential than others (Baughan *et al.*, 1979). Cranial and facial dimensions at 6 years of age, for example, have attained approximately 94 and 84 per cent, respectively, of their 18 year size (Farkas, 1981). A postnatal craniofacial maturity gradient exists, with the cranium being more mature than the cranial base, which is in turn more mature than the midface, with the mandible being the least mature and having the greatest growth potential (Buschang *et al.*, 1983; Buschang and Hinton, 2005). Greater total relative growth increases might also be expected for the vertical than for the antero-posterior dimensions, which in turn show greater increases than the transverse dimensions (Meredith, 1971; Farkas, 1981; Snodell *et al.*, 1993; Gaži-Čoklica *et al.*, 1997).

Most studies have shown that males are slightly larger than females during childhood and that gender differences increase significantly during adolescence (Savara and Singh, 1968; Meredith, 1971; Farkas, 1981; Snodell *et al.*, 1993; Basyouni and Nanda, 2000; Lux *et al.*, 2004; Little *et al.*, 2006). However, reported gender differences vary depending on the population investigated. For example, some studies have reported relatively large gender differences in bizygomatic, bigonial, and head width during adolescence (Farkas, 1981; Basyouni and Nanda, 2000; Lux *et al.*, 2004); others have found smaller gender differences for the same dimensions (Little *et al.*, 2006). In contrast to most other measurements, gender differences in head perimeter are substantially greater during early childhood, then decrease until approximately 12 years of age, and increase thereafter (Farkas, 1981). Meredith (1971) showed that gender differences in head perimeter of Caucasians residing in the USA decreased to 16 years.

The aforementioned variability between measurements, age groups, and genders may be due to ethnic or population differences. While it is well known that reference data must be population specific (Le *et al.*, 2002; Malina *et al.*, 2004; Nichols and Cadogan, 2008), Caucasian norms are often

used for comparisons because they are the most readily available. This occurs despite the fact that anthropometric studies have demonstrated significant differences in facial measurements between populations (Meredith, 1971; Jacobson, 1978; Dawei *et al.*, 1997; Porter and Olson, 2001; Dangour, 2003; Porter, 2004; Farkas *et al.*, 2005). While normative data are available for North American whites and African-Americans (Farkas *et al.*, 2005), understanding of craniofacial growth of other ethnic groups remains limited.

An understanding of the timing, magnitude, and direction of facial growth enables orthodontists and surgeons to better plan the treatment of skeletal discrepancies and achieve more pleasing results (Arnett and Bergman, 1993). To understand facial variation, it is essential to have standard measurements that can be used for clinical evaluation (Hellman, 1939; Arnett and Bergman, 1993; Sarver and Jacobson, 2007). Diagnosis and treatment planning should be facially driven, and in order to measure faces, other types of biometric tools needs to be developed to supplement cephalometrics (Arnett and Bergman, 1993; Sarver and Ackerman, 2000; Sarver and Jacobson, 2007). The utility of anthropometrics as a supplement to radiolographic and visual assessments has been well established (Arnett and Bergman, 1993; Sarver and Ackerman, 2000; Sarver and Jacobson, 2007). The major advantage of anthropometry is its technical simplicity, making it a readily available tool for evaluating, monitoring, and describing patients. Perhaps, most importantly, anthropometry provides a simple three-dimensional quantification of craniofacial morphology.

To date, there have been no anthropometric studies evaluating the longitudinal growth of the cranial and facial dimensions of Colombian mestizo children and adolescents. Such studies are important because they provide direct information concerning the changes and, more importantly, the variability in the changes that take place. The aim of this study was to investigate growth of the cranial and facial regions of 6- to 17-year-old Colombians.

Subjects and methods

A total of 2954 middle class Colombian mestizos were screened at three private schools in different areas of Medellin, in the province of Antioquia Colombia. Approximately 90 per cent of the mitochondrial DNA gene pool of Antioquia (north-west province of Colombia) is of Amerind origin, and by means of Y-chromosome microsatellites, male founders of this province were mostly of European ancestry (94 per cent; Carvajal-Carmona *et al.*, 2000, 2003; Rodas *et al.*, 2003). The sample was self-selected based on their willingness to participate and subdivided according to the following criteria:

Gender: males and females.

Age: at the start of the study, subjects between 5 and 17 years of age were screened and assigned to one of the following groups:

Age group 6: 5.5–6.5 years of age (primary dentition),
Age group 9: 8.5–9.5 years of age (early mixed dentition),
Age group 12: 11.5–12.5 years of age (late mixed dentition), and
Age group 15: 14.5–15.5 years of age (permanent dentition).

Occlusal status was determined based on a clinical examination and subjects were assigned to one of the following groups:

Normal occlusion: Class I molar relationship with less than 3 mm of crowding, an overjet of less than 3 mm, and an overbite less than one-third coverage of the lower incisors.

Class I malocclusion: Class I molar relationship with more than 3 mm of crowding, overjet greater than 3 mm, and an overbite more than one-third coverage of the lower incisors.

Class II malocclusion: at least one half cusp Class II molar relationship.

The subjects were excluded if they had congenitally missing teeth, signs or symptoms of temporomandibular dysfunction, a history of previous orthodontic treatment, and any teeth with more than two-thirds of their occlusal surfaces restored. Based on the selection and rejection criteria, a total of 458 children and adolescents (262 males and 216 females) were included in the study (Table 1). The study was approved by the Ethics Committee of CES University. Informed consent was obtained from all subjects and their parents.

Measurements were made over three consecutive years (i.e. each subject was measured a maximum of three times). Due to orthodontic treatment, restorative procedures, changing schools, sickness on the day of data collection, and unwillingness to participate further in the study, the sample lost 24 per cent of the subjects at the second visit and an additional 14 per cent at the third year visit.

Anthropometric measures

Eight anthropometric measurements (Figures 1 and 2) were taken of each of the subjects by one experienced anthropologist (JAC), who was calibrated prior to data collection and undertook all the measurements with an

Table 1 Initial sample and subsequent distribution according to age and gender.

Age group (years)	Gender	First year	Second year	Third year	Total
6	Male	67	56	48	171
	Female	54	42	36	132
9	Male	61	47	41	149
	Female	54	38	32	124
12	Male	53	43	32	128
	Female	54	40	27	121
15	Male	61	44	39	144
	Female	54	38	28	120
Total		458	348	283	1089

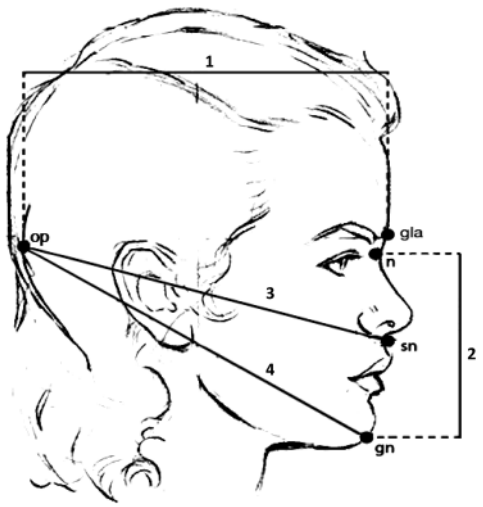

Figure 1 Craniofacial and face length measurements: 1, head length (Gla–Op); 2, face height (N–Gn); 3, antero-posterior maxillary length (Sn–Op); 4, antero-posterior mandibular length (Gn–Op).

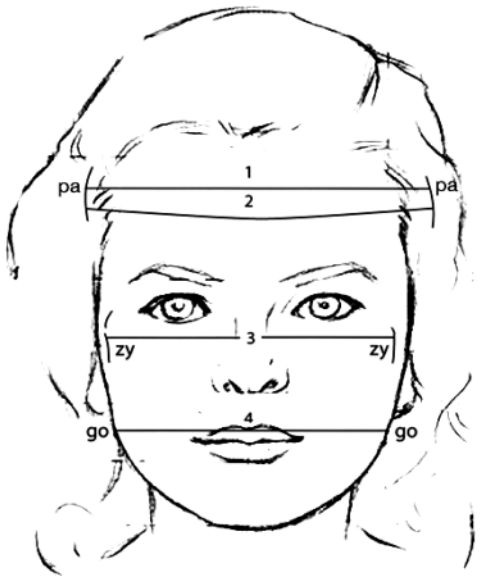

Figure 2 Transverse and perimeter measurements: 1, head width (Pa–Pa); 2, head perimeter; 3, bizygomatic width (Zy–Zy); 4, bigonial width (Go–Go).

anthropometer (Harpenden Anthropometer; Crosswell, Crymych, Pembrokeshire, UK). Three replicates were taken of each measurement and averaged; when one of the replicates deviated more than 3 per cent, a fourth was taken and the outlier was discarded. Intraclass correlations based on replicates of approximately 10 per cent of the subjects ranged from 0.96 to 0.99.

Statistical analysis

Age and gender specific means and standard deviations were estimated using the Statistical Package for Social Sciences version 15.0 (SPSS Inc., Chicago, Illinois, USA). In order to estimate the average growth curves for each of the measurements, the mixed longitudinal data were modelled longitudinally using MLWin® version 2.02 (Centre for Multilevel Modelling, University of Bristol, UK) statistical software (Goldstein, 1987). The multilevel approach used does not make the assumption of complete longitudinal data nor does it require exact intervals between age groups, making it well suited for this mixed longitudinal study. The fixed part of each polynomial model described the growth changes over time, with the constant term fixed at 11 years of age, and higher order terms describing growth changes (i.e. linear term described growth velocity, the quadratic term described acceleration or deceleration, etc.). The fixed part of the model also evaluated Class and gender differences in growth. The random part of each model partitioned variation at two levels, with subjects at the higher level, and age, nested within subjects, at the lower level. Estimates were derived using iterative generalized least squares.

Results

Gender and age-specific descriptive statistics for the eight measurements are provided in Table 2. Multilevel analyses showed increases in head perimeter for males and females between 6 and 17 years of age, but their growth patterns differed significantly (Table 3). Male head perimeter followed a sixth order polynomial, with yearly velocities decreasing until 9.3 years, increasing until 13.5 (peak), and then decreasing progressively thereafter (Figure 3). The female curve followed a simpler third order polynomial. Growth velocities for the head perimeter of females increased slightly until approximately 8 years of age and then decreased progressively.

Growth changes in head length were smaller than those in head perimeter but also showed significant gender differences. The male and female curves again followed sixth and third order polynomials, respectively. Growth velocities for males decreased to 10.1 years, peaked at approximately 14 years of age, and then decreased to 17 years. For females, growth velocities for head length increased slightly during the first few years, remained relatively stable until approximately 9.3 years, and then decreased slowly and consistently to 17 years of age.

Head widths of males and females also increased between 6 and 17 years of age, but the overall changes were even less than for head length. Both genders followed the sixth order polynomials. Male growth velocities decreased slowly until approximately 11 years and then increased to peak at approximately 14 years of age, with little or no change thereafter. Female growth rates decreased to approximately 10.2 years of age, peaked at 13.3 years, and then decreased progressively thereafter.

Table 2 Age and gender differences in cranial and facial dimensions (mean ± standard deviation) of Colombian children 6–17 years of age.

Age	Head perimeter		Head width		Head length		Bigonial width		Bizygomatic width		Face height		Maxillary length		Mandibular length	
	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
6	51.2 ± 1.3	50.2 ± 1.4	14.3 ± 0.5	14.0 ± 0.4	17.7 ± 0.6	17.3 ± 0.6	9.5 ± 0.3	9.3 ± 0.3	12.0 ± 0.4	11.8 ± 0.4	9.4 ± 0.4	9.2 ± 0.3	18.6 ± 0.6	18.4 ± 0.6	20.1 ± 0.7	19.9 ± 0.7
7	51.2 ± 1.3	50.3 ± 1.4	14.3 ± 0.4	14.0 ± 0.4	17.8 ± 0.6	17.3 ± 0.6	9.4 ± 0.3	9.3 ± 0.3	12.0 ± 0.4	11.9 ± 0.4	9.4 ± 0.4	9.2 ± 0.3	18.7 ± 0.6	18.5 ± 0.6	20.2 ± 0.5	20.0 ± 0.8
8	51.1 ± 1.2	50 ± 1.5	14.2 ± 0.4	14.0 ± 0.4	17.7 ± 0.6	17.3 ± 0.6	9.4 ± 0.3	9.2 ± 0.3	12.0 ± 0.4	11.8 ± 0.4	9.4 ± 0.4	9.2 ± 0.3	18.7 ± 0.6	18.5 ± 0.6	20.2 ± 0.5	20.0 ± 0.8
9	52.6 ± 1.4	51.4 ± 1.4	14.4 ± 0.4	14.3 ± 0.5	18.2 ± 0.6	17.7 ± 0.6	9.9 ± 0.4	9.8 ± 0.4	12.5 ± 0.4	12.3 ± 0.4	10.2 ± 0.4	9.9 ± 0.4	19.1 ± 0.5	18.8 ± 0.7	20.8 ± 0.7	20.4 ± 0.8
10	52.6 ± 1.4	51.6 ± 1.4	14.4 ± 0.5	14.3 ± 0.5	18.2 ± 0.6	17.8 ± 0.5	9.9 ± 0.5	9.8 ± 0.4	12.5 ± 0.5	12.3 ± 0.4	10.2 ± 0.4	9.9 ± 0.3	19.0 ± 0.5	18.9 ± 0.7	20.8 ± 0.7	20.6 ± 0.8
11	52.7 ± 1.5	51.7 ± 1.2	14.5 ± 0.5	14.3 ± 0.5	18.2 ± 0.5	17.8 ± 0.5	9.9 ± 0.5	9.8 ± 0.4	12.5 ± 0.5	12.3 ± 0.4	10.2 ± 0.4	9.9 ± 0.3	19.0 ± 0.5	18.9 ± 0.7	20.8 ± 0.7	20.7 ± 0.8
12	53.3 ± 1.4	52.8 ± 1.8	14.7 ± 0.5	14.5 ± 0.4	18.4 ± 0.5	18.0 ± 0.8	10.4 ± 0.5	10.2 ± 0.4	13.0 ± 0.5	12.8 ± 0.5	10.7 ± 0.5	10.5 ± 0.5	19.6 ± 0.6	19.3 ± 0.8	21.7 ± 0.8	21.0 ± 1.0
13	53.4 ± 1.4	52.6 ± 1.8	14.6 ± 0.4	14.5 ± 0.4	18.4 ± 0.6	18.0 ± 0.8	10.4 ± 0.4	10.1 ± 0.4	12.9 ± 0.5	12.8 ± 0.5	10.7 ± 0.5	10.4 ± 0.5	19.7 ± 0.6	19.2 ± 0.9	21.7 ± 0.8	20.7 ± 0.9
14	53.4 ± 1.4	52.8 ± 1.7	14.0 ± 0.4	14.5 ± 0.5	18.4 ± 0.6	18.1 ± 0.7	10.4 ± 0.4	10.2 ± 0.4	12.9 ± 0.5	12.8 ± 0.6	10.7 ± 0.4	10.4 ± 0.5	19.6 ± 0.6	19.4 ± 0.8	21.7 ± 0.8	21.0 ± 0.9
15	54.8 ± 1.4	53.4 ± 1.2	14.9 ± 0.5	14.5 ± 0.4	18.8 ± 0.6	18.3 ± 0.4	10.7 ± 0.4	10.4 ± 0.4	13.5 ± 0.5	13.1 ± 0.4	11.6 ± 0.6	10.9 ± 0.4	20.2 ± 0.6	19.5 ± 0.7	22.4 ± 0.8	21.4 ± 0.8
16	54.9 ± 1.3	53.2 ± 1.2	15.0 ± 0.5	14.5 ± 0.4	18.9 ± 0.5	18.2 ± 0.4	10.7 ± 0.3	10.4 ± 0.3	13.5 ± 0.5	13.1 ± 0.4	11.7 ± 0.6	10.9 ± 0.8	20.3 ± 0.5	19.4 ± 0.8	22.5 ± 0.7	21.3 ± 1.1
17	55.0 ± 1.3	53.2 ± 1.2	15.0 ± 0.5	14.4 ± 0.4	18.9 ± 0.6	18.2 ± 0.4	10.8 ± 0.3	10.4 ± 0.3	13.6 ± 0.5	13.1 ± 0.4	11.7 ± 0.6	10.9 ± 0.5	20.3 ± 0.5	19.4 ± 0.7	22.5 ± 0.7	21.3 ± 0.8

Table 3 Polynomial model estimates (Est) and standard errors (SEs) describing cranial growth changes of Colombian children 6–17 years of age, with random variation partitioned between subjects and between ages.

	Head perimeter				Head length				Head width			
	Male		Female		Male		Female		Male		Female	
	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE
Constant	5.28×10^{1}	1.08×10^{-1}	5.24×10^{1}	1.08×10^{-1}	1.84×10^{1}	4.56×10^{-2}	1.80×10^{1}	4.45×10^{-2}	1.46×10^{1}	3.76×10^{-2}	1.44×10^{1}	3.99×10^{-2}
Age	2.29×10^{-1}	3.09×10^{-2}	3.17×10^{-1}	3.32×10^{-2}	1.42×10^{-1}	1.02×10^{-2}	1.23×10^{-1}	1.12×10^{-2}	6.66×10^{-2}	1.11×10^{-2}	2.64×10^{-2}	1.38×10^{-2}
Age^2	5.86×10^{-2}	1.06×10^{-2}	-2.75×10^{-2}	4.18×10^{-3}	9.78×10^{-3}	3.44×10^{-3}	-6.25×10^{-3}	1.31×10^{-3}	1.01×10^{-2}	3.84×10^{-3}	8.26×10^{-3}	5.00×10^{-3}
Age^3	4.25×10^{-3}	2.78×10^{-3}	-2.58×10^{-3}	9.31×10^{-4}	2.72×10^{-3}	8.88×10^{-4}	-1.22×10^{-3}	2.84×10^{-4}	1.79×10^{-3}	1.00×10^{-3}	2.12×10^{-3}	1.15×10^{-3}
Age^4	-2.56×10^{-3}	5.37×10^{-4}	—	—	-4.91×10^{-4}	1.72×10^{-4}	—	—	-4.95×10^{-4}	1.94×10^{-4}	-6.86×10^{-4}	2.41×10^{-4}
Age^5	-8.23×10^{-5}	7.01×10^{-5}	—	—	-6.42×10^{-5}	2.24×10^{-5}	—	—	-3.49×10^{-5}	2.53×10^{-5}	-4.04×10^{-5}	2.55×10^{-5}
Age^6	3.15×10^{-5}	1.02×10^{-5}	—	—	7.57×10^{-6}	3.26×10^{-6}	—	—	8.19×10^{-6}	3.69×10^{-6}	9.67×10^{-6}	3.99×10^{-6}
Random variation												
Subjects	2.06×10^{0}	1.92×10^{-1}	1.86×10^{0}	1.92×10^{-1}	4.23×10^{-1}	3.90×10^{-2}	3.69×10^{-1}	3.64×10^{-2}	2.44×10^{-1}	2.29×10^{-2}	2.05×10^{-1}	2.08×10^{-2}
Ages	1.39×10^{-1}	1.05×10^{-2}	2.95×10^{-1}	2.47×10^{-2}	1.40×10^{-2}	1.06×10^{-3}	2.53×10^{-2}	2.12×10^{-3}	1.81×10^{-2}	1.37×10^{-3}	2.47×10^{-2}	2.06×10^{-3}

Example of estimating: head perimeter male: $5.28 \times 10^{1} + (2.295.28 \times 10^{-1} \times age) + (5.865.28 \times 10^{-2} \times age^2) + (4.255.28 \times 10^{-3} \times Age^3) + (-2.565.28 \times 10^{-3} \times sge^4) + (-8.235.28 \times 10^{-5} \times age^5) + (3.155.28 \times 10—^{5} \times age^6)$.

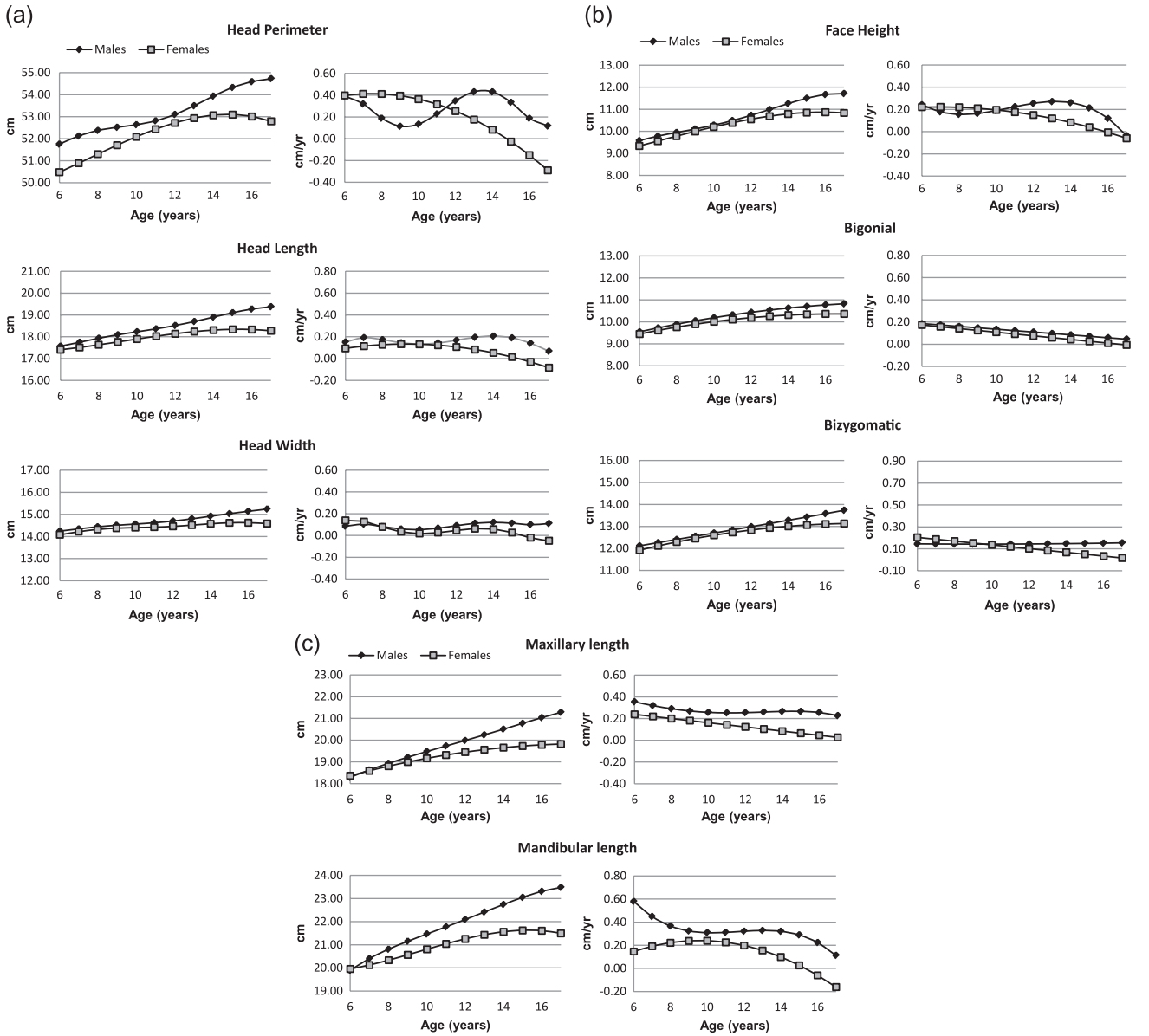

Figure 3 Growth status (left) and growth velocity (right) curves curves for (a) cranial, (b) facial, and (c) craniofacial dimensions of Colombian mestizo children 6–17 years of age.

Growth changes in face height followed a pattern similar to head perimeter. The male and females curves followed the fourth and third order polynomials, respectively (Table 4, Figure 3b). Yearly growth velocities of males decreased until approximately 9 years of age, peaked at approximately 13.2 years, and then decreased thereafter. Female growth velocities showed regular decreases to 17 years of age. While both bigonial and bizygomatic widths increased between 6 and 17 years of age, the changes were simpler than the patterns displayed by the cranial and face height measurements. Male and female bigonial widths followed a second order polynomial; yearly growth velocities were greatest at the youngest ages and decreased regularly with increasing age. Bizygomatic width followed a third polynomial in males and a second order polynomial in females. Female growth velocities decreased regularly between 6 and 17 years of age. Male velocities decreased slightly to approximately 11 years of age and then increased only slightly thereafter.

Between 6 and 17 years of age, maxillary length increased approximately 3 and 1.5 cm in males and females, respectively. Males followed a fifth order polynomials and females a second order polynomial (Table 5, Figure 3c). Male velocities decreased until approximately 11.3 years, increased until 15.2 years of age, and then decreased thereafter. Female growth velocities decreased progressively between 6 and 17 years of age.

Table 4 Polynomial model estimates (Est) and standard errors (SEs) describing facial growth changes of Colombian children 6–17 years of age, with random variation partitioned between subjects and between ages.

	Bigonial width				Bizygomatic width				Face height			
	Male		Female		Male		Female		Male		Female	
	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE
Constant	1.03×10^{1}	3.18×10^{-2}	1.01×10^{1}	3.22×10^{-2}	1.28×10^{1}	3.44×10^{-2}	1.27×10^{1}	3.55×10^{-2}	1.05×10^{1}	4.16×10^{-2}	1.04×10^{1}	3.44×10^{-2}
Age	1.22×10^{-1}	6.23×10^{-3}	9.16×10^{-2}	6.40×10^{-3}	1.45×10^{-1}	9.41×10^{-3}	1.19×10^{-2}	6.41×10^{-3}	2.24×10^{-1}	1.27×10^{-2}	1.76×10^{-1}	1.19×10^{-2}
Age^2	-6.34×10^{-3}	1.31×10^{-3}	-8.19×10^{-3}	1.33×10^{-3}	3.26×10^{-4}	1.16×10^{-3}	-8.51×10^{-3}	1.20×10^{-3}	1.71×10^{-2}	4.20×10^{-3}	-1.13×10^{-2}	1.60×10^{-3}
Age^3	—	—	—	—	6.80×10^{-5}	2.55×10^{-4}	—	—	-5.85×10^{-4}	-4.65×10^{-4}	-9.17×10^{-4}	3.71×10^{-4}
Age^4	—	—	—	—	—	—	—	—	-4.65×10^{-4}	$1.05E \times 10^{-4}$	—	—
Random variation												
Subjects	1.55×10^{-1}	1.62×10^{-2}	1.54×10^{-1}	1.62×10^{-2}	2.22×10^{-1}	2.14×10^{-2}	2.19×10^{-1}	2.20×10^{-2}	1.99×10^{-1}	2.07×10^{-2}	1.51×10^{-1}	1.70×10^{-2}
Ages	4.74×10^{-2}	3.58×10^{-3}	3.27×10^{-2}	2.74×10^{-3}	2.96×10^{-2}	2.23×10^{-3}	2.32×10^{-2}	1.94×10^{-3}	6.29×10^{-2}	4.76×10^{-3}	5.24×10^{-2}	4.38×10^{-3}

Mandibular length increased 3.6 cm in males and 1.5 cm in females between 6 and 17 years of age. Males followed a fourth order polynomial, while females followed a third order polynomial. Male growth velocities decreased between 6 and 11 years of age, increased slightly until 13.1 years, and then decreased progressively to 17 years. Female growth velocities increased slowly between 6 and 9.9 (peak) years of age and then decreased progressively to 17 years of age.

Discussion

All dimensions increased between 6 and 17 years of age, but the amounts and patterns of increase depended on the region. This supports previous studies reporting increases in craniofacial parameters between 6 and 18 years of age (Farkas, 1981; Gaži-Čoklica *et al.*, 1997; Basyouni and Nanda, 2000; Little *et al.* 2006; Thordarson *et al.* 2006). On average, the cranial and facial dimensions increased approximately 9 and 14 mm, respectively, and the two dimensions that spanned the facial and cranial vault increased approximately 23 mm. Similar differences between cranial and facial measurements have previously been reported over the same age range (Farkas, 1981; Snodell *et al.*, 1993; Gaži-Čoklica *et al.*, 1997; Lux *et al.*, 2004; Little *et al.*, 2006; Thordarson *et al.*, 2006). The results suggest greater relative maturity throughout the age range studied for the cranial than the facial dimensions. Differences in relative maturity between the cranial dimensions were originally explained based on Scammon's (1930) general and neural growth curves, with Baughan *et al.* (1979) later adding an intermediary facial growth curve. The craniofacial complex is actually graded between neural and general curves, with the relative growth of the components defined by the relative contribution of the tissues involved (Buschang *et al.*, 1983). The gradient is important because it provides information about the response potential of structures to environmental and epigenetic factors (Buschang and Hinton, 2005).

Although exhibiting differences in absolute growth, the cranial dimensions followed similar patterns of change. All three measurements showed size increases between 6 and 17 years of age. However, the amount of overall growth was greater for head perimeter than for head length, which was in turn greater than the overall increase in head width. Farkas (1981) reported similar differences between head perimeter, head width, and head length for females; males showed slightly greater increases in head width than length between 6 and 16 years of age. Gaži-Čoklica *et al.* (1997) and Little *et al.* (2006) also found that head length grew more over the time than head width. With respect to the rates of growth, males showed more complex curves, with velocities changing several times; minimal velocities were attained at approximately 9–11 years of age and peak adolescent velocities at approximately 14 years. Female

Table 5 Polynomial model estimates (Est) and standard errors (SEs) describing craniofacial growth changes of Colombian children 6–17 years of age, with random variation partitioned between subjects and between ages.

	Maxillary length				Mandibular length			
	Male		Female		Male		Female	
	Est	SE	Est	SE	Est	SE	Est	SE
Constant	1.97×10^{1}	6.42×10^{-2}	1.93×10^{1}	5.62×10^{-2}	2.18×10^{1}	7.52×10^{-2}	2.10×10^{1}	6.81×10^{-2}
Age	2.53×10^{-1}	2.36×10^{-2}	1.42×10^{-1}	1.15×10^{-2}	3.12×10^{-1}	2.45×10^{-2}	2.26×10^{-1}	2.59×10^{-2}
Age^2	-4.81×10^{-4}	7.76×10^{-3}	-9.66×10^{-3}	2.56×10^{-3}	3.96×10^{-3}	8.38×10^{-3}	-1.03×10^{-2}	3.58×10^{-3}
Age^3	1.09×10^{-3}	1.86×10^{-3}	—	—	1.19×10^{-3}	9.10×10^{-4}	-2.44×10^{-3}	8.81×10^{-4}
Age^4	-8.86×10^{-5}	2.28×10^{-4}	—	—	-4.35×10^{-4}	2.15×10^{-4}	—	—
Age^5	-9.30×10^{-6}	4.24×10^{-5}	—	—	—	—	—	—
Random variation								
Subjects	4.72×10^{-1}	4.83×10^{-2}	4.16×10^{-1}	4.62×10^{-2}	5.14×10^{-1}	5.91×10^{-2}	4.34×10^{-1}	5.89×10^{-2}
Ages	1.27×10^{-1}	9.66×10^{-3}	1.35×10^{-1}	1.13×10^{-2}	2.85×10^{-1}	2.15×10^{-2}	3.48×10^{-1}	2.89×10^{-2}

head width followed a pattern similar to that of males, but their velocities for perimeter and head length decreased regularly after 8–10 years of age. Based on cross-sectional data, Farkas (1981) reported the maximum increments of head dimensions at 14 years for boys and at 14 years or younger for females. Gaži-Čoklica *et al.* (1997), who followed 32 boys and 29 girls longitudinally between 4.7 and 11.8 years of age, reported the largest increases at the oldest ages.

Face height increased approximately 32 per cent more between 6 and 17 years of age than bizygomatic and bigonial widths. Farkas (1981) also showed that face height increased more than bizygomatic and bigonial width. The greater increments in bizygomatic than biogonial width identified in the present study are in agreement with previous findings (Farkas, 1981; Snodell *et al.*, 1993; Gaži-Čoklica *et al.*, 1997; Basyouni and Nanda, 2000; Lux *et al.*, 2004; Little *et al.*, 2006). This difference might be explained by the greater transverse growth potential of the maxilla than the mandible (Korn and Baumrind, 1990; Gandini and Buschang, 2000). Rates of growth for bigonial and bizygomatic widths for males and females decreased regularly from 6 to 17 years of age. Regular decreases in annual increments have been reported previously for bigonial (Newman and Meredith, 1956) and bizygomatic (Meredith, 1954; Savara and Singh, 1966) widths. In contrast, Basyouni and Nanda (2000) reported decreases in yearly velocities for bizygomatic and bigonial widths during childhood and increases during adolescence, with a peak around 13–14 years and 15–16 years for females and males, respectively. Lux *et al.* (2004) found peak velocities for these two width measurements around 13–15 years and 9–13 years for boys and girls, respectively.

With the exception of head perimeter, all measurements showed small gender differences favouring males during childhood that increased substantially during adolescence. The gender differences observed during childhood compare well with those reported by Farkas (1981), Lux *et al.* (2004), and Basyouni and Nanda (2000) but are slightly larger than those reported by Little *et al.* (2006) and Savara and Singh (1968). Small increasing gender differences favouring boys are well established during childhood for various measurements of body size (Veldhuis *et al.*, 2005); reference data for the Caucasian population living in the USA show that gender differences in stature, again favouring males, increase from approximately 0.5 cm at 6 years of age to 1 cm at 11 years. (http://www.cdc.gov/nchs/growthcharts). During adolescence, gender differences increased from approximately 0.1– 0.4 cm at 12 years to 0.5–1.9 cm at 17 years of age, depending on the dimensions measured. They are similar to the gender differences reported by Basyouni and Nanda (2000) but somewhat larger than previously reported for most other samples (Savara and Singh, 1968; Farkas, 1981; Basyouni and Nanda, 2000; Little *et al.*, 2006). Gender differences during adolescence are primarily due to the two extra years of growth that males have before starting their pubertal phase, as well as hormonal differences—especially sex steroids—producing slightly more intense adolescent growth (Tanner, 1962; Klein *et al.*, 1994; Veldhuis *et al.*, 2005).

Unlike the other dimensions, head perimeter showed larger gender differences during early childhood; the differences decreased until 12 years of age and then increased thereafter. A similar pattern has been previously reported for longitudinal evaluations of head perimeter of Caucasians living in the USA and Canada (Meredith, 1971; Farkas, 1981). The magnitude of the gender difference for perimeter has been reported to increase during infancy, decrease during childhood, and increase again between adolescence and adulthood (Meredith, 1971). The rather large gender difference in head perimeter observed at 6 years appears to be already evident at birth; the average

head perimeter of newborn males is approximately 1 cm larger than that of newborn females (http://www.cdc.gov/nchs/growthcharts).

In comparison with other ethnic groups, the cranial and facial dimensions of Colombians differ both in terms of size and shape. The most comprehensive study with comparative data was performed by Farkas (1981), who evaluated 1312 Canadian children (654 boys and 658 girls) between 6 and 18 years of age cross-sectionally. Based on the 95 per cent confidence intervals estimated for Canadians, Colombians have significantly ($P < 0.05$) larger transverse cranial and facial dimensions. For example, bigonial width is 7.5–13.3 mm larger in Colombian than in Canadian males (Figure 4). While the transverse differences decrease with increasing age, significant differences are still evident at 15 years of age. Compared with North American white children from the Iowa sample (Meredith, 1954; Newman and Meredith, 1956), Colombian children also show substantially larger bizygomatic and bigonial widths, but head widths tend to be similar (Meredith, 1953; Snodell *et al.*, 1993). The faces of Colombians are also wider than those of Zapotec Indians (Little *et al.*, 2006), children of northern and western European ancestry living in the USA (Basyouni and Nanda, 2000), and Irish children from the Belfast growth study (Lux *et al.*, 2004). In contrast to breadth measurements, head length, head perimeter, and face height of Colombians were significantly smaller than those of Canadian children and adolescents (Farkas, 1981). The differences in head perimeter increased with age, while those for head length decreased, and differences in face height remained unchanged over age. Meredith (1971) reported values for head perimeter for Caucasians in the USA that were similar to Colombians during childhood but larger during adolescence. These population differences provide clear evidence that separate craniometric norms are needed for Colombian mestizos. Because mestizos are commonly found throughout Latin America, these reference data may be more broadly applicable.

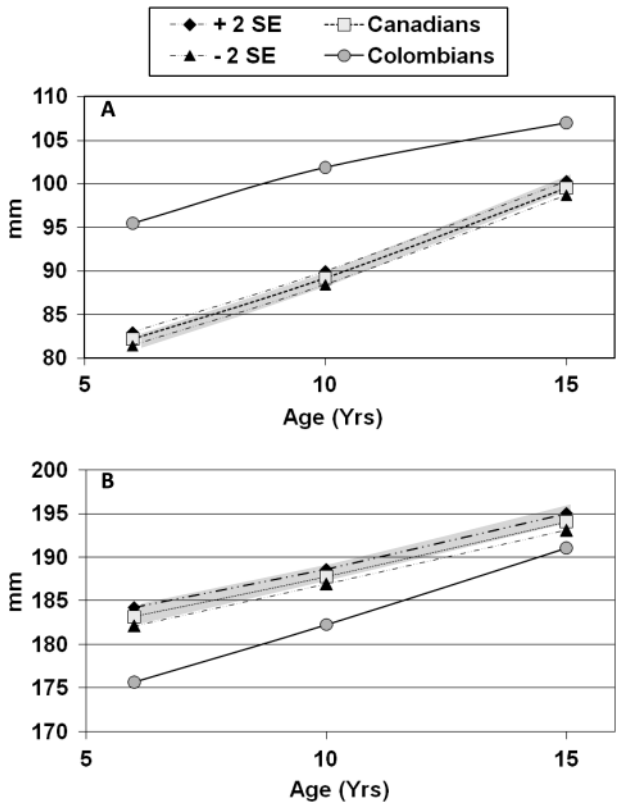

Figure 4 Population comparison of anthropometric measurements. (A) Bigonial width of Canadian males (means ± 2 SEs) compared with Colombians males. (B) Head length of Colombian males and Canadian males (means ± 2 SEs).

Conclusions

1. Craniofacial dimensions increased between 6 and 17 years of age, but the amounts and patterns of increase depended on the region. The vertical components showed the greatest growth, followed by the antero-posterior, and transverse.
2. Males have larger dimensions than females during childhood and gender differences generally increased during adolescence.
3. Yearly velocities of males indicated an adolescent spurt around 14 years of age; female velocities followed a simpler deceleration pattern with little or no indication of an adolescent spurt.

Funding

Instituto Colombiano para el Desarrollo de la Ciencia y la Tecnologia, Colciencias (1228-04-16446); the Escuela de Nutrición y Dietética; University of Antioquia; EAFIT University.

References

Arnett G, Bergman R T 1993 Facial keys to orthodontic diagnosis and treatment planning. Part I. American Journal of Orthodontics and Dentofacial Orthopedics 103: 299–312

Basyouni A A, Nanda S K 2000 An atlas of the transverse dimensions of the face. In: McNamara J A (ed). Monograph No. 37, Craniofacial growth series, center of human growth and development University of Michigan, Ann Arbor, pp. 1–235

Baughan B, Demirjian A, Levesque G Y, Lapalme-Chaput L 1979 The pattern of facial growth before and during puberty, as shown by French-Canadian girls. Annals of Human Biology 6: 59–76

Buschang P H, Hinton R J 2005 A gradient of potential for modifying craniofacial growth. Seminars in Orthodontics 11: 219–226

Buschang P H, Baume R M, Nass G G 1983 A craniofacial growth maturity gradient for males and females between 4 and 16 years of age. American Journal of Physical Anthropology 61: 373–381

Carvajal-Carmona L G *et al.* 2000 Strong Amerind/white sex bias and possible sephardic contribution among the founders of a population in Northwest Colombia. American Journal of Human Genetics 67: 1287–1295

Carvajal-Carmona L G *et al.* 2003 Genetic demography of Antioquia (Colombia) and the Central Valley of Costa Rica. Human Genetics 112: 534–541

Dangour A D 2003 Cross-sectional changes in anthropometric variables among Wapishana and Patamona Amerindian adults. Human Biology 75: 227–240

Dawei W, Guozheng Q, Mingli Z, Farkas L G 1997 Differences in horizontal, neoclassical facial canons in Chinese (Han) and North American Caucasian populations. Aesthetic Plastic Surgery 21: 265–269

Farkas L G 1981 Anthropometry of the head and face in medicine. Elsevier, New York

Farkas L, Katic M J, Forrest C R 2005 International anthropometric study of facial morphology in various ethnic groups/races. Journal of Craniofacial Surgery 16: 615–646

Gandini L G, Buschang P H 2000 Maxillary and mandibular width changes studied using metallic implants. American Journal of Orthodontics and Dentofacial Orthopedics 117: 75–80

Gaži-Čoklica V, Muretič Ž, Brčič R, Kern J, Miličič A 1997 Craniofacial parameters during growth from the deciduous to permanent dentition—a longitudinal study. European Journal of Orthodontics 19: 681–689

Goldstein H 1987 Multilevel models in educational and social research. Oxford University Press, Oxford

Hellman M 1939 Some facial features and their orthodontic implication. American Journal of Orthodontics and Oral Surgery 25: 927–951

Jacobson A 1978 The craniofacial skeletal pattern of the South African Negro. American Journal of Orthodontics 73: 681–691

Klein K O, Baron J, Colli M J, McDonnell D P, Cutler G B Jr 1994 Estrogen levels in childhood determined by an ultrasensitive recombinant cell bioassay. The Journal of Clinical Investigation 94: 2475–2480

Korn E L, Baumrind S 1990 Transverse development of the human jaws between the ages of 8.5 and 15.5 years, studied longitudinally with use of implants. Journal of Dental Research 69: 1298–1306

Le T T, Farkas L G, Ngim R C, Levin L S, Forrest C R 2002 Proportionality in Asian and North American Caucasian faces using neoclassical facial canons as criteria. Aesthetic Plastic Surgery 26: 64–69

Little B B, Buschang P H, Peña Reyes M E, Tan S K, Malina R M 2006 Craniofacial dimensions in children in rural Oaxaca, Southern Mexico: secular change, 1968-2000. American Journal of Physical Anthropology 131: 127–136

Lux C J, Conradt C, Burden D, Komposch G 2004 Transverse development of the craniofacial skeleton and dentition between 7 and 15 years of age—a longitudinal postero-anterior cephalometric study. European Journal of Orthodontics 26: 31–42

Malina R M, Bouchard C, Bar-or O 2004 Growth, maturation, and physical activity. Human kinetics, Champaign

Meredith H V 1953 Growth in head width during the first twelve years of life. Pediatrics 12: 411–429

Meredith H V 1954 Growth in bizygomatic face breadth during childhood. Growth 18: 111–134

Meredith H V 1971 Human head circumference from birth to early adulthood: racial, regional, and sex comparisons. Growth 35: 233–251

Newman K J, Meredith H V 1956 Individual growth in skeletal bigonial diameter during the childhood period from 5 to 11 years of age. American Journal of Anatomy 99: 157–177

Nichols S, Cadogan F I 2008 Anthropometric reference values in an Afro-Caribbean adolescent population. American Journal of Human Biology 20: 51–58

Porter J P, Olson K L 2001 Anthropometric facial analysis of the African American woman. Archives of Facial Plastic Surgery 3: 191–197

Porter J P 2004 The average African American male face. Archives of Facial Plastic Surgery 6: 78–81

Rodas C, Gelvez N, Keyeux G 2003 Mitochondrial DNA studies show asymmetrical Amerindian admixture in Afro-Colombian and Mestizo populations. Human Biology 75: 13–30

Sarver D M, Ackerman J L 2000 Orthodontics about face: the re-emergence of the esthetic paradigm. American Journal of Orthodontics and Dentofacial Orthopedics 117: 575–576

Sarver D M, Jacobson R S 2007 The aesthetic dentofacial analysis. Clinics in Plastic Surgery 34: 369–394

Savara B S, Singh I J 1966 Norms of size and annual increments of seven anatomical measures of maxillae in girls from three to sixteen years of age. Angle Orthodontist 36: 312–324

Savara B S, Singh I J 1968 Norms of size and annual increments of seven anatomical measures of maxillae in boys from three to sixteen years of age. Angle Orthodontist 38: 104–120

Scammon R E 1930 The measurement of the body in childhood. In: Harris J A, Jackson C M, Paterson D G, Scammon R E (eds). The measurement of man University of Minnesota Press, Minniapolis, pp. 173–215

Snodell S F, Nanda R S, Currier G F 1993 A longitudinal cephalometric study of transverse and vertical craniofacial growth. American Journal of Orthodontics and Dentofacial Orthopedics 104: 471–483

Tanner J M 1962 Growth adolescence, 2nd edn. Blackwell Scientific Publications, Oxford

Thordarson A, Johannsdottir B, Magnusson T E 2006 Craniofacial changes in Icelandic children between 6 and 16 years of age—a longitudinal study. European Journal of Orthodontics 28: 152–165

Veldhuis J D *et al.* 2005 Endocrine control of body composition in infancy, childhood, and puberty. Endocrine Reviews 26: 114–146