European Journal of Orthodontics 31 (2009) 109–120
doi:10.1093/ejo/cjn124

Dentoalveolar development in subjects with normal occlusion. A longitudinal study between the ages of 5 and 31 years

Birgit Thilander
Department of Orthodontics, The Sahlgrenska Academy, University of Gothenburg, Sweden

SUMMARY The aim of the present study was to examine dentoalveolar development in subjects with an 'ideal' (normal) occlusion. The material comprised 436 study casts of 189 male and 247 female subjects of Swedish origin between the ages of 5 and 31 years with no history of orthodontic treatment. Tooth width, and arch length, width, and depth, as well as palatal height were measured. The data were analysed with a Student's *t*-test.

The results verified that continuous changes of the dental arches occur from the primary until the adult period, with individual variations. This change could be interpreted as a biological migration of the dentition, resulting in anterior crowding especially in the mandible, even in subjects with congenitally missing third molars.

The occlusion should be regarded as a dynamic rather than a stable interrelationship between facial structures. This natural development has to be considered in orthodontic treatment planning as well as in assessment of stability following orthodontic treatment. A continuous increase of palatal height up to adulthood seems to be an effect of a slow continuous eruption of the teeth. This finding is also of significance in explaining the infraposition of implant-supported crowns.

Introduction

The development of the human dentition is a continuous process (Friel, 1927; Baume, 1950; Moorrees, 1959). Their findings were further verified by Sillman (1964), Knott (1972), Leighton (1975), and Bishara *et al.* (1995). Today, it is clear that dentoalveolar development is a complex biological process (Duterloo, 1991).

The above studies have shown that not only morphological data (size and shape of the dental arches) but also time-related aspects of dental development are essential factors in orthodontic diagnosis and treatment planning, as well as for post-retention stability. A specific aim has been to find any association between arch dimensions and crowding (Little, 1975). A literature review concerning arch width and form (Lee, 1999) has shown that the results from those publications are far from conclusive. A Medline search of the last three decades indicates that such differences may be explained by differing ethnicity and age. The selection of the samples even varies, being generally classified as 'Angle Class I', 'normal occlusion', or 'acceptable occlusion'. Most studies refer to some specific chronological ages (Berg, 1983; Bondevik, 1998; Tibana *et al.*, 2004) and only a very few are longitudinal (DeKock, 1972; Sinclair and Little, 1983; Bishara *et al.*, 1998; Dager *et al.*, 2008). Small, clinically significant changes beyond the age of 20 years have even been reported (Ainamo and Talari, 1976; Richardson, 1992; Iseri and Solow, 1996; Harris, 1997; Bishara *et al.*, 1998; Carter and McNamara, 1998; Watanabe *et al.*, 1999). Finally, a secular trend has been found in adult skull material compared with modern adult samples (Lundström and Lysell, 1953; Mohlin *et al.*, 1978), a fact further demonstrated even in a short time span in modern populations (Lavelle, 1973; Corruccini and Lee, 1984; Lindsten, 2003).

The dentoalveolar processes unite, being a part of the craniofacial complex, and are influenced by changes in different parts of the skull (Thilander, 1995). A large number of cephalometric studies have shown that ethnic differences in facial traits exist and that the dentofacial pattern will change during periods of active growth. These findings have been confirmed in a longitudinal study of a Swedish population (5–31 years of age) with an 'ideal' occlusion and with no history of orthodontic treatment (Thilander *et al.*, 2005). The results clearly confirmed that the facial pattern changed during the observation period, with a growth acceleration of most recorded distances not only between the 13- and 16-year recordings but also between the 5- and 7-year recordings.

Dental arch form in untreated 'normals' (13–31 years of age), studied using a computer-assisted method (Henrikson *et al.*, 2001), indicated a more rounded mandibular arch form with age. Whether these changes represent a linear relationship with age or predominantly an early maturing dentition in the late teens, could not be answered. The aim of the present study was thus to further analyse the dimensions of the dental arches in subjects with an untreated ideal occlusion, followed chronologically from the primary to the adult developmental period.

Materials and methods

The material consisted of 436 study casts from 189 male and 247 female subjects of Swedish origin followed from 5 to 31 years of age. They were diagnosed as having a normal (ideal) occlusion, with no history of orthodontic treatment.

Table 1 Number of subjects (n) in the different age groups.

Age group	Males			Females		
	n	Age		n	Age	
		Mean	SD		Mean	SD
5	20	5.1	0.4	27	4.9	0.3
7	37	7.4	0.4	46	7.4	0.4
10	43	10.4	0.5	56	10.4	0.4
13	53	13.1	0.4	69	13.0	0.4
16	25	15.8	0.5	30	15.8	0.5
31	11	30.9	0.6	19	31.1	0.5
Total	189			247		

Table 2 Classification of age groups into developmental periods, based on their dental stages (DS), according to Björk *et al.* (1964).

Age groups		Developmental periods	DS
Year	Range		
5	4.2–5.8	Primary	DS02
7	6.6–8.2	Early mixed	DS1M0, DS1M1, DS2M0
10	9.5–11.2	Late mixed	DS2M1, DS3M1
13	12.3–13.8	Early permanent	DS3M2, DS4M1
16	14.9–17.1	Adolescence	DS4M2
31	29.7–32.2	Adulthood	DS4M2, DS4M3

The number of subjects in the age groups are shown in Table 1. Detailed data of the subjects have been published previously (Thilander *et al.*, 2005).

Dental casts and analysis

The casts were taken at 5, 7, 10, 13, 16, and 31 years of age. The subjects were also grouped into dental developmental periods (Table 2), based on dental stages according to the variation in tooth eruption described by Björk *et al.* (1964).

The following distances were measured on each study cast: tooth width, arch length, width, and depth, and palatal height (Figures 1–4).

The mesiodistal crown diameter of each tooth was obtained by measuring the greatest distance (mesiodistal crown diameter) between the contact points of each tooth.

Arch length was obtained by measuring the arch perimeter to the first permanent molars, divided into right/left posterior and anterior segments (Figure 1). The posterior length (m_2/P_2–c/C) represents the distance between the distal surface of m_2/P_2 and the mesial surface

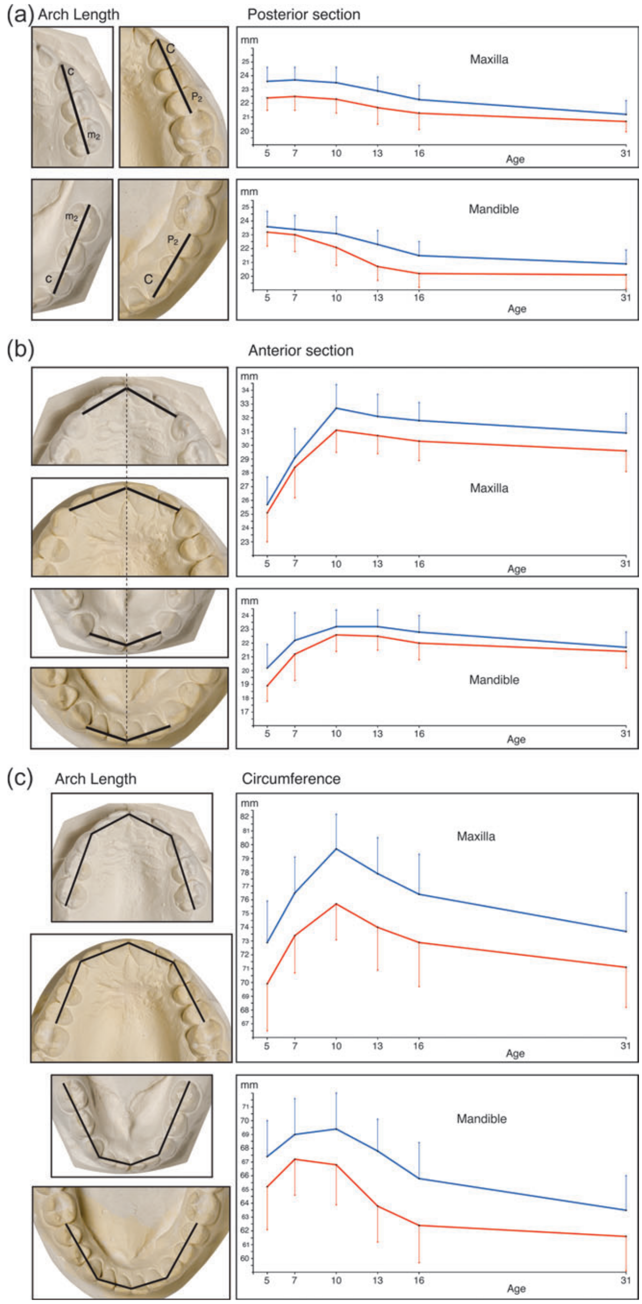

Figure 1 Dental arch length (mm) of the posterior (a) and anterior (b) segments and the circumference (mesial of the first permanent molars) (c) in the maxilla and mandible. Females (red) and males (blue), followed from 5 to 31 years of age. Mean and standard deviation for each recording.

of c/C on the right and left sides. The anterior length (i_1–i_2/I_1–I_2) represents the distance between the mesial surface of c/C and the midline of the dental arch and is given as the mean and standard deviation for the sum of the right and left sides. The circumference of each dental arch represents the distance (m_2–m_2/P_2–P_2).

The width of each dental arch was obtained by measuring the distance between the corresponding teeth

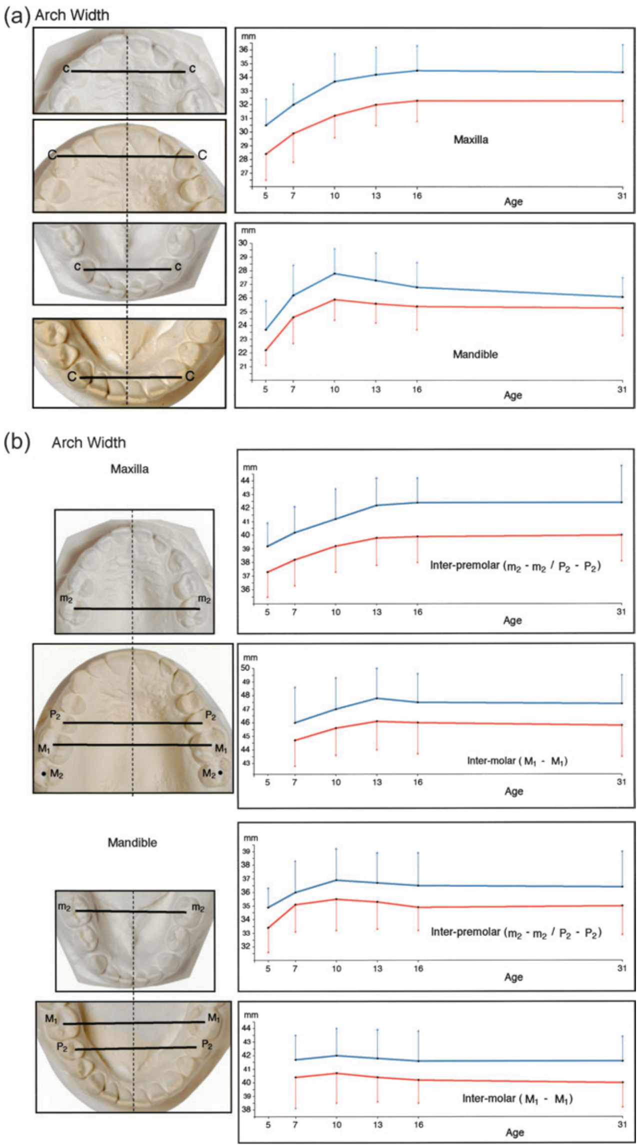

Figure 2 Dental arch width (mm) in females (red) and males (blue), followed from 5 to 31 years of age. Intercanine (a), interpremolar (b), and intermolar (b) distances in the maxilla and mandible. Mean and standard deviation for each recording.

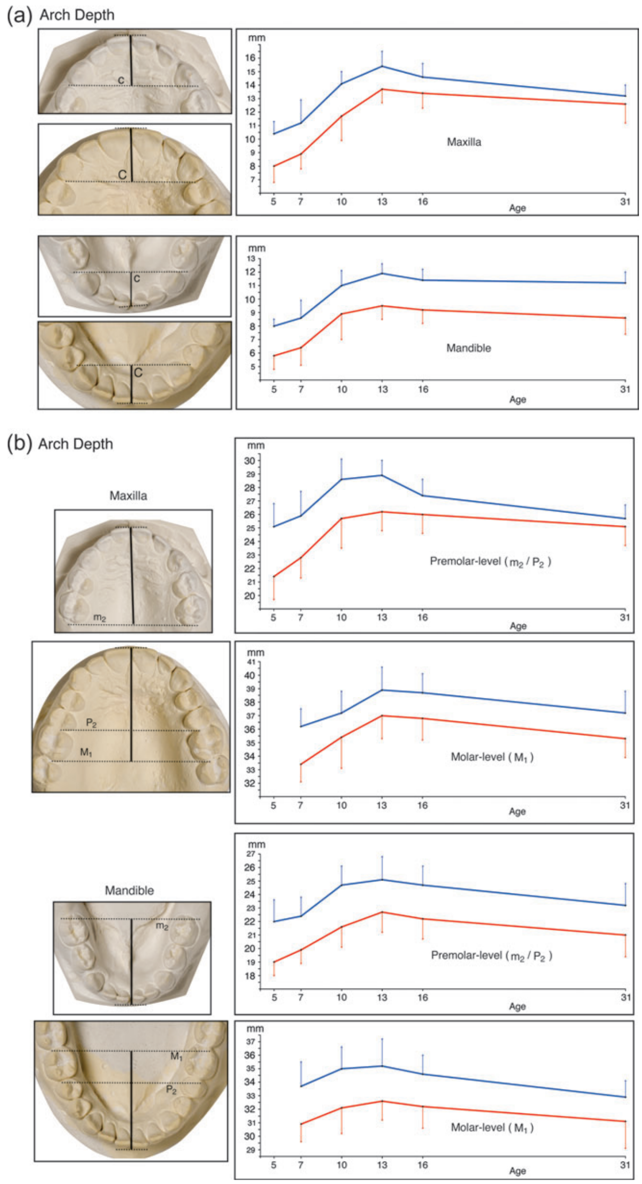

Figure 3 Dental arch depth (mm) at the different levels: distal surface of the canines (a) and second primary molar/premolar, and first permanent molar (b). Females (red) and males (blue), followed from 5 to 31 years of age. Mean and standard deviation for each recording.

on the right and left sides at different levels (Figure 2a–b). Intercanine width was measured as the distance between the crown tips of the canines (c−c/C−C), interpremolar width as the distance between the central fossa of the second primary molars/permanent premolars (m_2−m_2/P_2−P_2), and intermolar width as the distance between the central fossa of the first permanent molars (M_1−M_1) as well as for the second permanent molars (M_2−M_2).

The depth of the dental arch was obtained at the midline at different levels by measuring the perpendicular distance from the buccal surface of the central incisors to

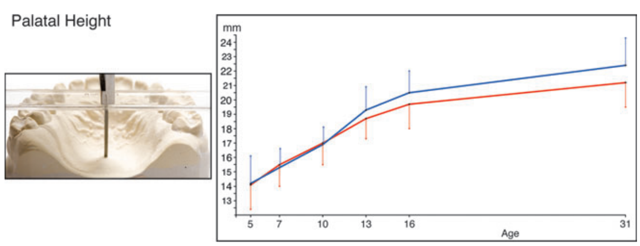

Figure 4 Palatal height (mm) in females (red) and males (blue), followed from 5 to 31 years of age. Mean and standard deviation for each recording.

Table 3 Dentoalveolar length (mm) in females (F) and males (M), from 5–31 years of age, given as the mean, standard deviation (SD), and range (lowest and highest values).

Gender	Age	Maxilla			Mandible		
		Mean	SD	Range	Mean	SD	Range
Posterior segment							
F	5	22.4	0.92	21.2–24.5	23.2	1.00	21.2–25.3
M		23.6	0.98	21.6–25.4	23.6	1.15	21.3–25.9
F	7	22.5	0.99	21.1–24.4	23.0	1.16	21.0–25.3
M		23.7	0.88	21.5–25.0	23.4	0.97	21.5–25.7
F	10	22.3	1.07	20.6–24.3	22.1	1.33	20.0–25.1
M		23.5	1.10	21.0–24.7	23.1	1.23	21.2–25.4
F	13	21.7	1.20	19.4–24.2	20.7	1.06	18.8–22.6
M		22.9	0.96	20.5–24.3	22.3	1.02	20.6–24.4
F	16	21.3	1.17	19.2–23.8	20.2	0.97	18.3–21.8
M		22.3	1.04	20.5–23.2	21.5	0.99	19.8–23.2
F	31	20.7	0.74	19.0–22.0	20.1	0.96	18.3–22.0
M		21.4	1.01	19.5–22.5	20.9	0.95	19.5–22.5
Anterior segment							
F	5	25.1	2.07	22.4–29.2	18.9	1.14	16.8–20.3
M		25.7	2.03	22.5–28.5	20.2	1.67	16.9–23.2
F	7	28.4	2.18	24.3–32.0	21.2	1.90	17.7–24.7
M		29.1	2.12	24.8–35.1	22.2	1.97	18.2–25.8
F	10	31.1	1.62	27.4–33.4	22.6	1.16	20.2–25.1
M		32.7	1.68	28.7–35.4	23.2	1.21	20.6–25.8
F	13	30.7	1.32	28.1–32.8	22.5	1.02	20.3–25.5
M		32.1	1.62	29.5–35.6	23.2	1.16	20.5–24.7
F	16	30.3	1.39	27.2–32.7	22.0	1.18	19.6–24.0
M		31.8	1.34	29.2–34.1	22.8	1.13	20.4–24.7
F	31	29.7	1.52	27.0–32.5	21.4	1.24	19.5–23.5
M		30.9	1.44	28.5–33.5	21.7	1.15	19.5–24.1
Total circumference							
F	5	69.9	3.42	64.8–76.6	65.2	3.11	59.1–69.7
M		72.9	3.04	65.3–78.6	67.4	2.55	64.7–74.7
F	7	73.4	2.71	66.7–79.7	67.2	2.61	61.4–72.6
M		76.5	2.61	71.1–80.0	69.0	2.58	64.8–74.5
F	10	75.7	2.63	69.9–80.2	66.8	2.93	61.5–72.8
M		79.7	2.49	73.1–81.0	69.4	2.63	62.9–73.6
F	13	74.0	3.14	68.4–79.4	63.8	2.62	57.9–67.8
M		77.9	2.59	72.6–82.1	67.8	2.26	60.7–69.4
F	16	72.9	3.20	68.1–78.4	62.4	2.69	57.6–65.6
M		76.4	2.85	67.5–80.5	65.8	2.61	60.6–69.9
F	31	71.1	2.69	68.0–77.3	61.6	2.51	57.7–65.0
M		73.7	2.82	67.5–78.6	63.5	2.45	59.1–67.0

the distal surfaces of the canines (c/C), second premolars (m_2/P_2), permanent first molars (M_1), and second molars (M_2; Figure 3) using a co-ordinated millimetric grid.

Palatal height in the midpalatal plane was determined by measuring the perpendicular distance from the occlusal plane constructed from the second primary premolars/permanent first molars (Figure 4). Through a hole in a plastic sheet, the end of the digital calliper was pressed to the palatal contour. This distance minus the thickness of the sheet (2 mm) represented palatal height.

All registrations were carried out with the use of digital callipers (Jocal, C E Johansson, Eskilstuna, Sweden).

Statistical analysis

Statistical analysis of the data was undertaken using a Student's *t*-test.

The precision of the registrations was tested by double measurements of 15 randomly selected cases. The error of the method was calculated according to the formula: $s_e = \sqrt{\Sigma d^2/2n}$, where d is the difference between the two measurements and n is the number of measurements. The accidental error varied from 0.11–0.16 mm (tooth width) to 0.22 mm (arch width) and 0.34 mm (arch depth), indicating a high degree of precision and accuracy.

Results

Tooth size. There were no differences between the right and left sides, neither in the primary nor in the permanent dentition. For that reason, the width of each tooth is given as mean and standard deviation from the total number of measured teeth. The lowest and highest values are given as the range (Table 4).

The tooth crowns of males were invariably broader than those of the females, especially in the permanent dentition. Some subjects had consistently small or broad teeth in both dentitions, indicating a genetic influence. The primary incisors and canines were smaller than their successors. The differences between the total widths of the incisors in both dentitions were approximately 7 mm in the maxilla and 5 mm in the mandible, with an additional 2 mm including the canines. The primary second premolars (m_2) were broader than their successors (P_2), especially in the mandible (2.7 mm), while the primary first molars (m_1) were generally the same size as their successors (P_1).

Table 4 Mesiodistal crown diameters (mm) of the primary and the permanent teeth in females (F) and males (M), given as the mean, standard deviation (SD), and range (lowest and highest values).

Tooth	Gender	Mean	SD	Range
(a) Primary				
Maxilla				
i_1	F	6.5	0.47	5.4–7.4
	M	6.7	0.39	5.9–7.2
i_2	F	5.3	0.32	4.6–6.0
	M	5.6	0.41	4.7–6.4
c	F	6.7	0.33	5.9–7.3
	M	6.8	0.57	5.6–7.9
m_1	F	7.1	0.54	6.1–8.4
	M	7.3	0.51	6.2–8.4
m_2	F	8.8	0.48	7.6–10.0
	M	8.9	0.57	7.7–10.1
Mandible				
i_1	F	4.0	0.31	3.4–4.6
	M	4.3	0.30	3.7–4.9
i_2	F	4.6	0.38	3.8–5.4
	M	4.9	0.32	4.0–5.4
c	F	5.7	0.34	5.1–6.3
	M	5.9	0.33	5.2–6.5
m_1	F	7.6	0.61	6.5–8.6
	M	7.7	0.57	6.4–8.5
m_2	F	9.7	0.41	8.5–10.4
	M	9.7	0.62	8.4–10.9
(b) Permanent				
Maxilla				
I_1	F	8.5	0.52	7.1–9.6
	M	9.0	0.46	8.2–10.0
I_2	F	6.6	0.62	5.0–8.2
	M	7.1	0.62	5.6–8.3
C	F	7.6	0.44	6.9–8.5
	M	8.3	0.52	7.1–9.4
P_1	F	7.0	0.45	6.3–7.8
	M	7.3	0.43	6.4–8.3
P_2	F	6.7	0.49	5.6–7.7
	M	6.9	0.38	6.1–7.7
M_1	F	10.3	0.54	9.4–11.4
	M	10.8	0.52	9.5–11.8
M_2	F	9.4	0.63	8.2–10.6
	M	10.0	0.64	8.9–11.2
Mandible				
I_1	F	5.4	0.33	4.8–6.0
	M	5.6	0.24	5.0–6.1
I_2	F	5.9	0.32	5.3–6.4
	M	6.1	0.27	5.5–6.6
C	F	6.6	0.43	5.7–7.6
	M	7.2	0.47	6.3–8.1
P_1	F	7.0	0.42	5.6–8.0
	M	7.4	0.56	6.3–8.4
P_2	F	7.1	0.43	5.9–8.0
	M	7.5	0.51	6.4–8.7
M_1	F	10.8	0.58	9.3–12.2
	M	11.3	0.62	10.0–12.5
M_2	F	9.9	0.59	9.1–11.8
	M	10.1	0.77	8.8–11.7

Of note is the observation that there was no significant difference between tooth widths in the present sample and those in a previous study of a Swedish population (Seipel, 1946).

Dental arches. The recorded distances of the dental arches were constantly larger in males compared with those of females. The results are given in Tables 3, 5 and 6, with the mean standard deviation and range for females and males in the different age groups. The distances are also presented graphically to illustrate changes during the observation periods (Figures 1–3).

Length. There were no statistical differences between the two sides, and hence the values in Table 3 are combined for the right and left sides. Arch length decreased between 7 and 13 years (approximately 1 mm in the maxilla and 3 mm in the mandible), due to differences between the mesiodistal crown diameters of the primary and permanent teeth, known as leeway space. After that period, a further decrease was observed (Figure 1a).

As shown in Table 3 and Figure 1b, there was an increase of the anterior segment between 5 and 10 years (maxilla: 6 mm, mandible: 4 mm) due to eruption of the incisors in a proclined position. A continuous decrease of approximately 2 mm in both jaws was then observed up to 31 years of age.

The circumference of each dental arch (m_2–m_2/P_2–P_2) verified the changes in the posterior and anterior segment (Table 3, Figure 1c), i.e. an increase up to 10 years of age (especially in the maxilla), followed by a continuous decrease (especially in the mandible). No change in the perimeter (mesial to the first permanent molars) was observed between 5 and 31 years in the maxilla, contrary to a decrease of 4 mm in the mandible.

Width. Intercanine width showed a different developmental pattern between the maxilla and mandible (Table 5, Figure 2a). In the maxilla, an increase was recorded up to 16 years of age (4 mm) especially between 5 and 10 years. In the mandible, an increase of the same degree was recorded to the age of 10 years followed by a continuous decrease, especially in males between 16 and 31 years of age. Interpremolar width followed the developmental pattern of intercanine width (Figure 2b) with an increase to 10–13 years of age and stability thereafter. Intermolar width decreased between 13 and 16 years of age, especially in the mandible (Figure 2b).

Table 5 Dentoalveolar width (mm) for females (F) and males (M), from 5–31 years of age, given as the mean, standard deviation (SD), and range (lowest and highest values).

Gender	Age	Maxilla			Mandible		
		Mean	SD	Range	Mean	SD	Range
Intercanine width							
F	5	28.4	1.96	25.6–32.3	22.2	1.11	20.0–23.5
M		30.5	1.87	26.8–32.8	23.7	2.14	20.0–26.4
F	7	29.9	2.09	26.6–33.9	24.6	1.93	20.3–27.8
M		32.0	1.48	28.4–35.2	26.2	2.18	21.5–28.9
F	10	31.2	1.65	28.0–34.8	25.9	1.51	21.3–28.0
M		33.7	2.02	29.6–36.8	27.8	1.82	22.0–29.5
F	13	32.0	1.50	28.5–35.3	25.6	1.42	22.2–28.2
M		34.2	2.05	30.1–37.6	27.3	1.99	22.3–29.2
F	16	32.3	1.53	29.0–35.3	25.4	1.70	22.1–28.4
M		34.5	1.77	30.4–37.8	26.8	1.79	23.5–29.1
F	31	32.3	1.49	29.1–34.5	25.3	2.01	21.0–28.0
M		34.4	2.02	30.1–37.5	26.1	1.38	22.5–28.5
Interpremolar$_2$ width							
F	5	37.3	1.87	35.0–39.2	33.4	1.82	31.7–36.0
M		39.2	1.72	37.5–41.5	34.9	1.40	32.0–37.0
F	7	38.2	1.99	36.1–40.4	35.1	1.97	32.3–38.5
M		40.2	1.90	38.1–43.0	36.0	2.28	32.5–39.0
F	10	39.2	1.93	37.3–41.5	35.5	2.33	32.8–40.3
M		41.2	2.18	39.0–44.5	36.9	2.30	33.0–39.5
F	13	39.8	2.05	37.8–42.2	35.3	2.02	32.5–40.0
M		42.2	1.97	39.5–45.0	36.7	2.22	33.0–42.5
F	16	39.9	1.88	38.0–44.5	34.9	1.73	31.8–39.1
M		42.4	1.83	39.8–42.1	36.5	2.37	32.5–41.5
F	31	40.0	1.95	38.4–42.4	35.0	2.11	31.6–37.0
M		42.4	2.75	38.0–45.5	36.4	2.64	32.0–41.0
Intermolar$_1$ width							
F	7	44.7	1.93	39.7–49.2	40.4	2.29	36.0–45.8
M		46.0	2.60	41.0–50.1	41.7	1.84	39.2–44.5
F	10	45.6	2.00	42.0–49.8	40.6	2.07	35.9–45.6
M		47.0	2.29	42.0–51.5	42.0	1.96	38.5–46.0
F	13	46.1	2.15	42.5–51.4	40.4	1.77	35.5–44.5
M		47.8	2.16	42.5–51.7	41.8	2.10	38.3–46.5
F	16	46.0	2.28	42.0–51.2	40.2	1.69	36.0–44.2
M		47.5	2.12	43.0–51.4	41.6	2.22	38.0–47.0
F	31	45.8	2.26	41.5–49.5	40.0	1.77	36.5–44.0
M		47.4	2.11	44.5–51.0	41.5	1.92	39.9–46.5
Intermolar$_2$ width							
F	13	49.5	2.29	45.0–54.5	44.9	2.43	41.0–49.5
M		52.2	2.73	47.5–57.0	47.1	2.48	42.5–52.0
F	16	50.2	2.37	45.0–54.5	44.5	2.04	41.0–49.5
M		53.3	1.93	48.5–57.0	47.3	2.16	43.0–52.0
F	31	50.5	2.39	45.5–54.0	45.1	2.13	41.0–49.5
M		54.0	1.83	50.5–57.0	49.1	2.07	45.5–53.5

Depth. As shown in Table 6 and Figure 3a,b, an increase was observed up to 13 years of age in both jaws, especially between 7 and 13 years (maxilla: 5 mm, mandible: 3 mm), due to eruption of the permanent incisors in a proclined position. A continuous slow decrease of 1–2 mm was then noted in both jaws until adulthood, indicating a slow anterior migration of the occlusion. Such physiological migration may explain the decrease of overjet (0.7 mm) between 13 and 31 years (Table 7).

Palatal height. A continuous increase was noted during the total observation period, in total 7.1 mm for females and 8.2 mm for males (Table 8, Figure 4). The increase between 5 and 16 years of age was 6.6 mm in females and 6.3 mm in males, i.e. around 0.5 mm/year. Between the ages of 16 and 31 years, the increase was 1.5 mm in females and 1.9 mm in males, i.e. 0.1 mm/year.

Discussion

The findings of the present study demonstrated significant changes in the dentition from the primary until the adult period. The development of the dental arches is a continuous process with some changes during the mixed developmental

Table 6 Dentoalveolar depth (mm) in females (F) and males (M), from 5–31 years of age, given as the mean, standard deviation (SD) and range (minimum and maximum values).

Gender	Age	Maxilla			Mandible		
		Mean	SD	Range	Mean	SD	Range
Canine level							
F	5	8.0	1.22	6.5–10.0	5.8	0.95	4.5–7.5
M		10.4	0.90	8.5–12.0	8.0	0.50	7.0–9.5
F	7	8.9	1.10	7.0–10.5	6.4	1.33	4.5–9.0
M		11.2	1.66	10.0–13.5	8.6	1.32	6.5–10.0
F	10	11.7	1.78	9.0–13.5	8.9	1.85	5.0–12.0
M		14.1	0.91	12.0–15.5	11.0	1.09	9.0–12.5
F	13	13.7	1.05	11.5–15.5	9.5	0.99	7.5–11.5
M		15.4	1.06	13.0–16.0	11.9	0.70	10.5–13.0
F	16	13.4	1.13	11.0–15.0	9.2	0.98	7.0–11.0
M		14.6	0.95	12.5–15.0	11.4	0.77	9.5–12.5
F	31	12.6	1.41	10.5–14.5	8.6	1.18	6.0–11.0
M		13.2	0.78	12.0–14.0	11.2	0.84	9.0–11.0
Premolar$_2$ level							
F	5	21.4	1.75	18.0–25.0	19.0	0.95	17.5–20.5
M		25.1	1.67	22.0–28.5	22.0	1.60	19.0–25.0
F	7	22.8	1.48	20.0–25.0	19.9	0.96	18.0–21.0
M		25.9	1.79	22.5–30.0	22.4	1.44	19.5–25.0
F	10	25.7	2.25	21.5–30.0	21.6	1.48	18.5–24.5
M		28.6	1.45	26.0–31.0	24.7	1.41	22.0–27.5
F	13	26.2	1.42	23.5–29.0	22.7	1.45	20.0–25.0
M		28.9	1.11	26.0–30.0	25.1	1.72	21.5–28.0
F	16	26.0	1.44	23.5–29.0	22.2	1.50	19.5–25.0
M		27.4	1.22	25.0–29.5	24.7	1.41	22.0–27.0
F	31	25.1	1.39	22.5–27.5	21.0	1.59	18.0–24.0
M		25.7	0.95	24.0–27.0	23.2	1.55	20.0–26.0
Molar$_1$ level							
F	7	33.4	1.29	30.5–35.0	30.9	1.26	27.5–32.0
M		36.2	1.33	33.5–38.5	33.7	1.80	30.0–37.5
F	10	35.4	2.31	30.5–40.0	32.1	1.95	28.5–35.5
M		37.2	1.62	34.5–40.5	35.0	1.63	32.0–38.0
F	13	37.0	1.67	32.5–40.0	32.6	1.42	29.5–35.0
M		38.9	1.71	35.0–41.5	35.2	1.99	31.0–37.0
F	16	36.8	1.60	33.5–40.0	32.2	1.55	29.0–35.0
M		38.7	1.35	35.5–40.5	34.6	1.44	31.5–36.5
F	31	35.3	1.35	32.0–38.0	31.1	2.05	27.0–35.0
M		37.2	1.64	34.0–39.5	32.9	1.20	29.5–35.0
Molar$_2$ level: M_2–M_2							
F	13	45.9	2.04	42–50	41.9	1.87	38–45
M		46.3	2.17	43–48	43.2	1.54	41–45
F	16	45.6	2.01	41–49	41.7	1.53	38–45
M		47.3	1.15	45–49	43.0	1.26	40–45
F	31	43.9	2.02	40–48	40.5	2.07	36–44
M		45.4	1.78	42–47	41.7	1.42	40–44

period. Between adolescence and adulthood, a slow continuous change in all dimensions occurred. These findings are of importance for orthodontic diagnosis and treatment planning, as well as for post-treatment stability.

Crowding depends on the relationship between the size of the teeth and the dimensions of the dental arches. The length, width, and depth of the jaws, as well as the size of the teeth, are integrated parts of this equation. Thus, any change in dental arch circumference has an influence on this relationship.

Significant changes occurred in the dental arches during the early mixed developmental period. Eruption of the permanent incisors resulted in an increase of the anterior segment, especially in the maxilla. With eruption of the permanent canines, a further minor increase was recorded in the maxilla. Concurrently, the depth of the arch increased. In the posterior segment, on the other hand, a decrease (maxilla: 1 mm, mandible: 3 mm), equivalent to the difference between the sum of the tooth size of the primary molars and their permanent successors (leeway space), was observed. This means that the permanent first mandibular molars will drift mesially, resulting in a decrease, not merely in length but also in depth and width of the dental arch. Approximal caries or extraction of primary molars will accelerate this migration. Hence, early oral hygiene

Table 7 Overjet and overbite (mm) in females (F) and males (M) at 13, 16, and 31 years of age, given as the mean, standard deviation (SD), and range (minimum and maximum values).

Gender	Age	Overjet			Overbite		
		Mean	SD	Range	Mean	SD	Range
F	13	2.7	0.75	1.5–3.5	2.8	0.92	1.0–4.5
M		2.6	0.70	1.5–4.0	2.6	0.96	1.0–4.5
F	16	2.4	0.58	1.5–3.0	2.7	0.88	1.0–4.5
M		2.3	0.64	1.5–3.5	2.3	0.60	1.0–4.0
F	31	2.0	0.50	1.0–3.0	2.6	1.05	1.0–4.5
M		2.1	0.55	1.5–3.0	2.2	0.49	1.0–3.0

Table 8 Palatal height (mm) in females (F) and males (M), from 5 to 31 years of age, given as the mean, standard deviation (SD), and range.

Gender	Age	Mean	SD	Range
F	5	14.1	1.67	12.0–16.0
M		14.2	1.90	12.5–17.0
F	7	15.5	1.46	13.0–18.0
M		15.3	1.28	13.5–18.0
F	10	17.0	1.50	14.0–19.0
M		16.9	1.18	15.0–19.0
F	13	18.7	1.41	15.0–21.0
M		19.3	1.59	16.5–22.0
F	16	19.7	1.65	16.0–23.0
M		20.5	1.53	18.0–23.5
F	31	21.2	1.74	18.5–24.5
M		22.4	1.89	20.0–25.0

instruction is of importance for normal occlusal development. Of note is that a slow decrease in the length of the dental arches will continue after 16 years of age, especially in males. This continuous decrease (1–2 mm) indicates a slow physiological migration of the occlusion, which may explain the decrease of overjet (0.7 mm) between 13 and 31 years and may be responsible for late anterior crowding.

Development of the dental arches, expressed as the circumference, is dependent not only on a decrease in the posterior segment (due to mesial migration) and an increase in the anterior segment (due to erupting incisors in a proclined position), but also to an increase of arch width. In spite of these developmental changes, no change in the arch perimeter, mesial of the first molars, was observed between 5 and 31 years in the maxilla, contrary to a decrease of 4 mm in the mandible. This natural dentoalveolar development has to be considered in orthodontic treatment planning in subjects with crowding as well in assessment of stability after orthodontic treatment.

All 55 subjects included in the present study fulfilled the criteria of normality at 16 years of age; some were also considered normal at the age of 31 years (Figure 5). Of the 30 adult subjects, examined at 31 years of age, maxillary anterior crowding was recorded in three (Figure 6), contrary to 12 mandibular arches with incisor crowding of different degrees, even in those with congenitally missing third molars (Figure 7). Late changes during the post-retention period cannot generally be distinguished from normal ageing processes that occur regardless of whether or not a subject has been orthodontically treated (Thilander, 2000). The continuous change of the dental arches might be interpreted as a biological migration of the dentition, resulting in anterior crowding, especially in the mandible. The occlusion is a result of a developmental process in which the main events are facial growth, dental development, and function. These genetically and environmentally conditioned processes continue to change throughout life, showing significant individual variations, clearly verified in the present study. Therefore, the occlusion is to be regarded as a dynamic rather than a stable interrelationship between the facial structures. The dynamics of facial development with variations in maxillary and mandibular growth, together with concomitant dentoalveolar development, need to be better understood before orthodontists can expect to achieve more stable treatment results.

One of the most interesting findings in the present study was the development of palatal height. In earlier studies, the length and width of the dental arches have been the focus of attention, while information of the development of palatal height in normal subjects is lacking. From the studies of dentofacial development, it is known that sagittal growth of the nasomaxillary complex is the result of anterior displacement of the maxilla due to bone deposition at the tuberosity and adjacent structures, thus creating space for eruption of the posterior teeth (Figure 8a). Vertical growth is the combined result of a sutural lowering of the maxilla as a whole and remodelling at the bone surfaces (Björk and Skieller, 1977). This lowering creates space for the nasal cavity, which continues to be

Figure 5 Study casts of a female at 5, 13, and 31 years of age.

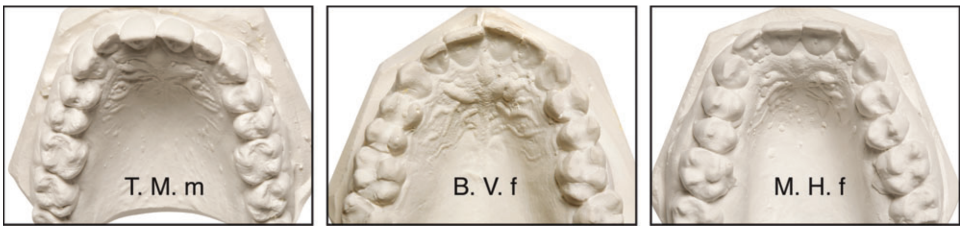

Figure 6 Study casts from three subjects with minimal crowding in the anterior segment of the maxilla: tooth 12 in case TM, 21 in BV, and 22 in MH.

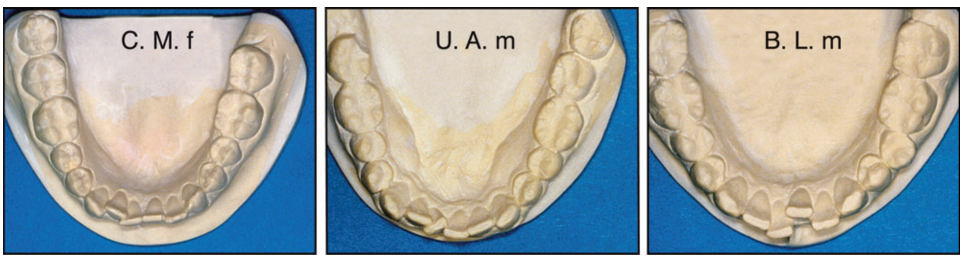

Figure 7 Study casts from three subjects with different degrees of crowding in the mandibular anterior segment. Case CM: 42 in a crowded position. Fully erupted 48, congenitally missing 38. Case UA: 41 rotated in a crowded position. Congenital missing 48, fully erupted 38. Case BL: 31 crowded and lingually positioned. All third molars congenitally missing; broad intermolar distance.

lowered due to resorption nasally with simultaneous deposition of bone orally on the palate (Figure 8b). Vertical growth is hence a result of two separate processes: drift (because of remodelling growth) and displacement of the maxilla as a whole, a procedure that occurs without any kind of rotation (Thilander *et al.*, 2005). Vertical growth of the alveolar process is rapid during tooth eruption (Figure 8c). With premolars and molars in occlusion, there should not be any further increase of the alveolar process and hence no further increase of palatal height (Figure 8d). On the other hand, continuous remodelling of the palate with bone deposition orally should decrease this distance (Figure 8c). Furthermore, tooth wear is a common occurrence with increasing age (Silness *et al.*, 1994), which also should decrease palatal height. However, the continuous increase of palatal height (0.1 mm/year), observed in the present study, seems to be an effect of a slow continuous eruption of the teeth. Even if the mechanisms of tooth eruption have still not been fully elucidated, the slow continuous increase of this distance seems to indicate an important role in the eruption mechanisms. This knowledge is of importance in

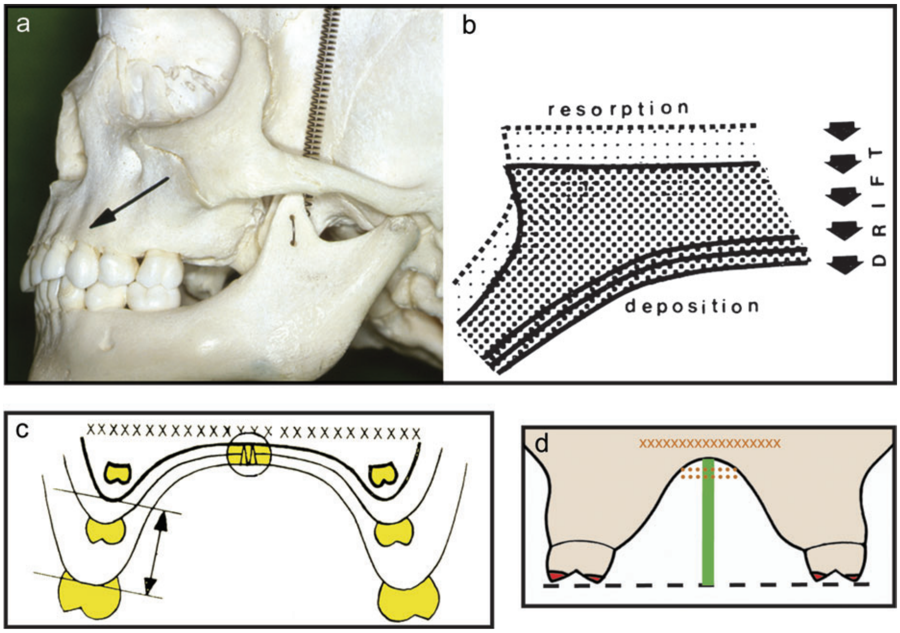

Figure 8 Growth and development of the maxilla. Displacement (a) and drift (because of remodelling) (b). The young maxilla (c); erupting teeth causing alveolar bone deposition (arrow). The adult period (d); palatal height (green), remodelling (orange), and dental wear (red).

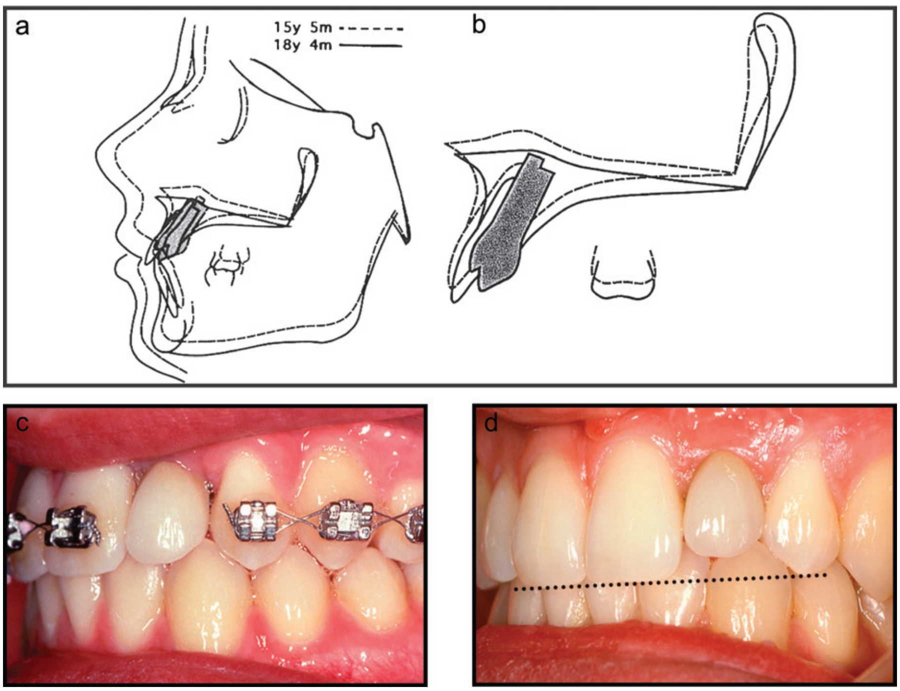

Figure 9 Superimposed tracings of lateral cephalograms of a boy with implants replacing lateral incisors at the age of 15 years and 3 years later (a). Superimposition of the maxilla on the fixtures shows remodelling on the alveolar bone and a change in the position of the teeth (b). A 15-year-old boy with an implant-supported crown replacing a missing lateral (c) and 10 years later with infraposition (1.2 mm) (d).

Figure 10 A 34-year-old female with an implant-supported crown because of trauma (a and b) and 12 years later with infraocclusion (c).

explaining the infraposition of an implant-supported crown as a continuous eruption of its adjacent teeth (Figures 9 and 10; Thilander *et al.*, 2001).

Address for correspondence

Professor Birgit Thilander
Department of Orthodontics
The Sahlgrenska Academy
University of Gothenburg
Box 450
SE-405 30 Göteborg
Sweden
E-mail: birgit.thilander@odontologi.gu.se

References

Ainamo J, Talari A 1976 Eruptive movements of teeth in human adults. In: Poole D F G, Stack M V (eds). The eruption and occlusion of teeth Butterworths, London, pp. 97–107.

Baume L J 1950 Physiological tooth migration and its significance for the development of the occlusion. Journal of Dental Research 29: 331–348

Berg R 1983 Dentofacial development between 6 and 12 years of age. A longitudinal study on plaster models and lateral skull radiographs of 113 Norwegian children. Thesis. University of Oslo, pp. 1–175

Bishara S E, Khadivi P, Jacobsen J R 1995 Changes in tooth size-arch length relationships from the deciduous to the permanent dentition: a longitudinal study. American Journal of Orthodontics and Dentofacial Orthopedics 108: 607–613

Bishara S E, Jacobsen J R, Treder J, Nowak A 1998 Arch length changes from 6 weeks to 45 years. Angle Orthodontist 68: 69–74

Björk A, Skieller V 1977 Growth of the maxilla in three dimensions as revealed radiographically by the implant method. British Journal of Orthodontics 4: 53–64

Björk A, Krebs A, Solow B 1964 A method for epidemiological registration of malocclusion. Acta Odontologica Scandinavica 22: 27–41

Bondevik O 1998 Changes in occlusion between 23 and 34 years. Angle Orthodontist 68: 75–80

Carter G A, McNamara J 1998 Longitudinal dental arch changes in adults. American Journal of Orthodontics and Dentofacial Orthopedics 114: 88–99

Corruccini R S, Lee G T 1984 Occlusal variation in Chinese immigrants to the United Kingdom and their offspring. Archives of Oral Biology 29: 779–782

Dager M, McNamara J, Baccetti T, Franchi L 2008 Aging in the craniofacial complex. Angle Orthodontist 78: 440–444

DeKock W H 1972 Dental arch depth and width studied longitudinally from 12 years of age to adulthood. American Journal of Orthodontics 62: 56–66

Duterloo H S 1991 An atlas of dentition in childhood. Orthodontic diagnosis and panoramic radiology. Wolfe Publishing Ltd., London

Friel S 1927 Occlusion. Observations on its development from infancy to old age. Transactions of the First International Orthodontic Congress. C V Mosby, St Louis, pp. 138–159

Harris E F 1997 A longitudinal study of arch size and form in untreated adults. American Journal of Orthodontics and Dentofacial Orthopedics 111: 419–427

Henrikson J, Persson M, Thilander B 2001 Long-term stability of dental arch form in normal occlusion from 13 to 31 years of age. European Journal of Orthodontics 23: 51–61

Iseri H, Solow B 1996 Continued eruption of maxillary incisors and first molars in girls from 9 to 25 years, studied by the implant method. European Journal of Orthodontics 18: 245–256

Knott V 1972 Longitudinal study of dental arch width at four stages of dentition. Angle Orthodontist 42: 387–394

Lavelle C L 1973 Variation in the secular changes in the teeth and dental arches. Angle Orthodontist 43: 412–421

Lee R 1999 Arch width and form: a review. American Journal of Orthodontics and Dentofacial Orthopedics 115: 305–313

Leighton B C 1975 The early development of normal occlusion. Transactions of the European Orthodontic Society pp. 67–77

Lindsten R 2003 Secular changes in tooth size and dental arch dimensions in the mixed dentition. Swedish Dental Journal Supplement 157: 1–87

Little R M 1975 The irregularity index: a quantitative score of mandibular anterior alignment. American Journal of Orthodontics 68: 554–563

Lundström A, Lysell L 1953 An anthropological examination of a group of medieval Danish skulls, with particular regard to the jaws and occlusal conditions. Acta Odontologica Scandinavica 11: 111–128

Mohlin B, Sagne S, Thilander B 1978 The frequency of malocclusion and the craniofacial morphology in a medieval population in Southern Sweden. OSSA 5: 57–84

Moorrees C F A 1959 The dentition of the growing child. A longitudinal study of dental development between 3 and 18 years of age. Harvard University Press, Cambridge

Richardson M 1992 Lower arch crowding in the young adult. American Journal of Orthodontics and Dentofacial Orthopedics 101: 132–137

Seipel C M 1946 Variation of tooth position. A metric study of variation and adaptation in the deciduous and permanent dentitions. Swedish Dental Journal Supplement 39: 1–176

Sillman J H 1964 Dimensional changes of the dental arches. Longitudinal study from birth to 25 years. American Journal of Orthodontics 50: 824–842

Silness J, Berge M, Johannessen G 1994 Prevalence, pattern and severity of incisal wear in dental students. Acta Odontologica Scandinavica 52: 178–181

Sinclair P M, Little R M 1983 Maturation of untreated normal occlusions. American Journal of Orthodontics 83: 114–123

Thilander B 1995 Basic mechanisms in craniofacial growth. Acta Odontologica Scandinavica 53: 144–151

Thilander B 2000 Biological basis for orthodontic relapse. Seminars in Orthodontics 6: 195–205

Thilander B, Ödman J, Lekholm U 2001 Orthodontic aspects of the use of oral implants in adolescents: a 10-year follow-up study. European Journal of Orthodontics 23: 715–731

Thilander B, Persson M, Adolfsson U 2005 Roentgen-cephalometric standards for a Swedish population. A longitudinal study between the ages of 5 and 31 years. European Journal of Orthodontics 27: 370–389

Tibana R H, Palagi L M, Miguel J A 2004 Changes in dental arch measurements of young adults with normal occlusion—a longitudinal study. Angle Orthodontist 74: 618–622

Watanabe E, Demirjian A, Buschang P 1999 Longitudinal post-eruptive mandibular tooth movements of males and females. European Journal of Orthodontics 21: 459–468