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Age-related changes in sagittal relationship between the maxilla and mandible

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SUMMARY The aim of the study was to assess age-related changes in sagittal jaw relationship during pre-pubertal and pubertal development on the basis of angular [ANB, anteroposterior dysplasia indicator (APDI) and A–B plane angle] and linear (Wits, AF–BF, App–Bpp, and App–Pgpp) measurements. Lateral cephalograms of orthodontically untreated subjects were evaluated at 7, 9, 11, 13 and 15 years of age. Cephalometric standards and age-related changes were determined on the basis of Class I subjects with a good occlusion ($n = 18$, 10 males and 8 females).

With respect to changes related to growth, the main findings were, in both genders, a statistically significant age-related decrease in ANB angle, App–Bpp and App–Pgpp, a significant increase in APDI, but no age-related change in Wits. A reduction of sagittal jaw distance during pre-pubertal and pubertal development was observed arising from a relative dominance of sagittal mandibular growth.

For an evaluation of differences concerning jaw relationship in Class II subjects, a group with Class II division 1 malocclusions ($n = 17$) and a group with Class II division 2 malocclusions ($n = 12$ were compared with two control groups, i.e. the good occlusion group and a Class I group ($n = 37$). Conclusions about the sagittal discrepancy in Class II division 1 and Class II division 2 subjects depended on the geometric reference used in the various parameters, and further research is called for with respect to the diagnostic performance of the various measurements. Differences between Class II subjects and controls present at 15 years of age were already established at 7 years of age, but were less pronounced.

Introduction

In orthodontics, great importance has been attached to cephalometric assessment of the jaw relationship in the sagittal plane. A first step towards a description of the sagittal jaw relationship was the introduction of points A and B by Downs (1948), who additionally suggested the A–B plane angle, i.e. the relationship of the A–B plane to the facial plane, as a measure of the relationship of the dental bases to each other and to the profile. Riedel (1952) introduced the ANB angle, which has become the most commonly used parameter in orthodontics. In the following years, a number of publications revealed the geometric factors that can affect ANB angle (Taylor, 1969; Freeman, 1981; Pancherz and Sack, 1990; Oktay, 1991) and, as a consequence, adjustments to the ANB angle were proposed (Ferrazzini, 1976; Panagiotidis and Witt, 1977; Gebauer, 1979; Hussels and Nanda, 1984; Järvinen, 1986). Jacobson (1975) also recognized the potential problems that can arise when using cranial landmarks remote from the maxilla and mandible, and he introduced the Wits appraisal based on the functional occlusal plane, which is closer to the dental bases. Kim and Vietas (1978) correlated molar displacement to a combination of cephalometric measurements, the anteroposterior dysplasia indicator (APDI) consisting of the facial angle plus or minus the A–B plane angle and plus or minus the palatal plane angle. However, Yang and Suhr (1995) showed that the APDI, originally described as the sum of three angles, is equivalent to the angle between the A–B plane and the palatal plane, and thus comprises the information of a singular measurement rather than of a combination of three. Chang (1987) recommended the AF–BF distance, i.e. the distance between points A and B projected onto the Frankfort horizontal plane, a concept previously suggested by Luder (1978). In view of the shortcomings of the ANB angle, Chang (1987) considered this to be a more precise measurement of the sagittal relationship between the maxilla and mandible. Nanda and Merrill (1994) recommended the palatal plane as a reference plane for the assessment of sagittal jaw relationships. The major advantages of the palatal plane were seen as the independence from nasion and in its relative stability during growth. In addition, the use of a linear measurement was preferred to an angular measurement due to the fundamental fact that a linear measurement is affected by fewer variables than an angular one, which involves at least three points with six degrees of freedom (Moyers and Bookstein, 1979; Järvinen, 1986).

In summary, in the orthodontic literature a number of approaches have been described for assessment of sagittal jaw relationship. On the basis of these concepts, it was the aim of the present study to:

1. Evaluate age-related changes in sagittal jaw relationship over a sufficiently large time interval from pre-pubertal through pubertal development (7 to 15 years of age) using a large methodical base (angular and linear measurements).
2. Provide, separately for males and females, longitudinal cephalometric standards based on good occlusion samples.
3. Investigate possible growth differences between Class II malocclusions and Class I subjects.

Subjects and methods

The present longitudinal study was based on the lateral cephalograms of orthodontically untreated subjects from the Belfast Growth Study (Adams, 1972). Sagittal jaw relationship was measured on the lateral cephalograms at 7, 9, 11, 13 and 15 years of age.

In the present investigation, cephalometric standards were determined on the basis of subjects with good occlusion, i.e. bilateral Class I relationship, no congenitally missing teeth, correct overjet/overbite, no crossbites or transverse anomalies, and no or only minor crowding (n = 18, 10 boys, 8 girls). For an evaluation of deviations in Class II subjects, a group with Class II division 1 malocclusions (n = 17, 8 boys, 9 girls) and a group with Class II division 2 malocclusions (n = 12, 8 boys, 4 girls) were compared with two control groups, i.e. the good occlusion group described above and a Class I group (n = 37, 19 boys, 18 girls) which additionally comprised subjects with Class I anomalies, e.g. pronounced crowding. In conjunction with the distal occlusion, the Class II division 1 group was characterized by an increased overjet (≥ 5 mm), and the Class II division 2 group by retroclination of the upper incisors, at least of the two central incisors. The precise inclusion criteria and ages of the subjects in the four groups have been reported previously (Lux *et al.*, 2003; 2004a).

Measurements

The lateral cephalograms were scanned at high resolution (600 dpi) and, after digitization, the seven parameters shown below were calculated using the relevant landmarks. On the lateral cephalograms, the landmarks were located according to the definitions of Riolo *et al.* (1974). Linear measurements made on the lateral cephalograms were corrected for magnification using a constant factor of 0.9214 (Adams, 1963). The landmark coordinates were used to calculate the following measurements (Figure 1):

Angular:

ANB angle (Riedel, 1952)
APDI (Kim and Vietas, 1978)
A–B plane angle (Downs, 1948)

Linear:

Wits (Jacobson, 1975)
AF–BF (Luder, 1978; Chang, 1987)
App–Bpp (Nanda and Merrill, 1994)
App–Pgpp (Nanda and Merrill, 1994)

For the linear measurements, a positive value indicates that point A is located anteriorly to point B. For the A–B plane angle, a negative value indicates that the A–B plane is sloped clockwise in relation to the N–Pg plane. For the Wits analysis, the occlusal plane was determined posteriorly by the midpoint of the distance between the mesial cusp tips of the first molars, and anteriorly by the midpoint between the incisal edges of the incisors, similar to the definitions of Downs (1948), Chang (1987), Järvinen (1988) and Ishikawa *et al.* (2000). Wits values measured at 7 years of age were excluded from the analysis as the lack of full incisor eruption prevented accurate identification of the occlusal plane.

Statistical analysis

Growth curves showing absolute size versus time were calculated for the seven sagittal parameters in the four groups, separately for males and females. Descriptive statistics for the seven parameters at 7, 9, 11, 13 and 15 years of age including mean, standard deviation and range are given in Tables 1 and 2. In the good occlusion group, a Wilcoxon signed rank test was applied to identify if significant age-related changes occurred during the total period of observation, i.e. 7–15 years and 9–15 years (Wits), separately for males and females. Here, a significance level of $\alpha = 0.05$ was chosen. In addition, a Wilcoxon signed rank sum test was used to evaluate group differences between the four groups (testing two groups at a time). No statistical testing was carried out between the Class I group and the good occlusion group. A significance level of $P \leq 0.01$ was chosen to satisfy a Bonferroni correction for the multiple testing of intergroup differences (five group comparisons).

Measurement error

Duplicate measurements on 20 lateral cephalograms were used for evaluating the measurement error according to Dahlberg's formula (Dahlberg, 1940). The error of the method for angular measurements was lowest for ANB (0.35 degrees), followed by the A–B plane angle (0.65 degrees) and APDI (0.82 degrees). The respective values for the linear measurements were lowest for Wits (0.43 mm), followed by App–Pgpp, App–Bpp and AF–BF with values ranging between 0.46 and 0.49 mm.

Results

Age-related changes in the good occlusion subjects

The age-related changes during the total period of observation were investigated on the basis of the three

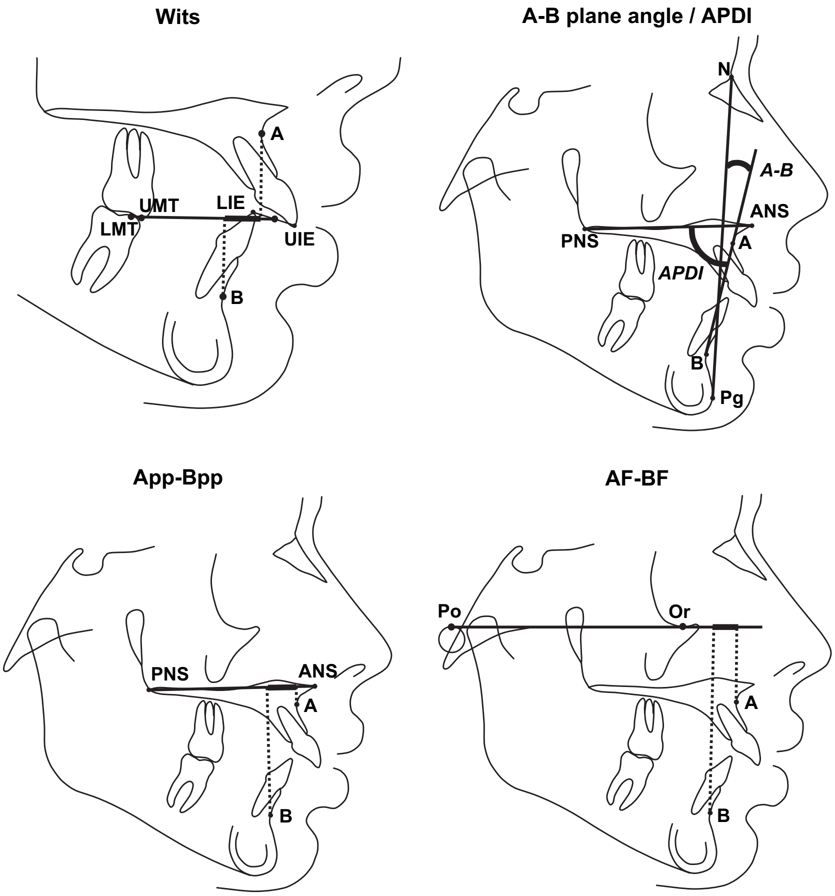

Figure 1 *Landmarks:* Pogonion (Pg), lower incisor incisal edge (LIE), upper incisor incisal edge (UIE), point A (A), point B (B), anterior nasal spine (ANS), posterior nasal spine (PNS), lower molar mesial cusp tip (LMT), upper molar mesial cusp tip (UMT), nasion (N), orbitale (Or), porion (Po) (definitions according to Riolo *et al.*, 1974). *Wits:* Projection of point A and point B on the occlusal plane (OcP). OcP is defined by the midpoint between the incisal edges (anterior) and the midpoint between the mesial cusp tips and the first molars (posterior). *A–B plane angle:* Formed by the A–B plane and N–Pg. *Anteroposterior dysplasia indicator (APDI):* Equivalent to the angle formed by the A–B plane and the palatal plane (PNS–ANS). *App–Bpp:* Distance between projections of point A and point B (and Pg in App–Pgpp, respectively) onto the palatal plane (PNS–ANS). *AF–BF:* Distance between projections of point A and point B on the Frankfort horizontal (Po–Or).

angular and four linear variables (descriptive statistics in Tables 1 and 2). In the good occlusion group (growth curves in Figures 2 and 3), significant age-related changes were found for ANB and APDI and for the distances App–Bpp and App–Pgpp. Between 7 and 15 years of age, the ANB angle showed a statistically significant decrease from 4.44 to 2.79 degrees among males and from 3.41 to 2.11 degrees among females ($P = 0.002$ and $P = 0.039$, respectively). The distance App–Bpp was also characterized by a statistically significant decrease from 7.06 to 5.39 mm (males) and from 5.18 to 2.48 mm (females) ($P = 0.037$ and $P = 0.008$, respectively). The age-related decrease of the distance App–Pgpp was even more pronounced and statistically significant among males ($P = 0.010$) and females ($P = 0.008$). APDI increased significantly from 78.16 to 82.02 degrees (males) and from 80.50 to 85.97 degrees (females) ($P = 0.010$ and $P = 0.008$, respectively). No statistically significant age-related changes were found for Wits, AF–BF or the A–B plane angle during the total observation period. Among males, Wits remained nearly unaltered between 9 and 15 years, with values ranging around 0 mm in both genders. Between 7 and 15 years of age, AF–BF showed a slight decrease (not significant), and the A–B plane angle a slight increase, i.e. less negative values (not significant).

Group differences between Class II subjects and controls

Growth curves for the Class II subjects and controls are shown in Figures 2 and 3, and the descriptive statistics are given in Tables 1 and 2. Table 3 shows the results of the statistical testing concerning group differences. Among males, group differences between Class II division 1

Table 1 Males – Descriptive statistics ($\bar{x}$ = mean, s = standard deviation) at 7, 9, 11, 13 and 15 years of age in the four groups (angular measurements in degrees, distances in mm).

Males	Age	Good occlusion				Class I				Class II division 1				Class II division 2			
		$\bar{x}$	s	Min	Max	$\bar{x}$	s	Min	Max	$\bar{x}$	s	Min	Max	$\bar{x}$	s	Min	Max
ANB	7	4.44	2.02	1.89	8.00	3.86	1.77	0.65	8.00	5.27	1.56	3.36	8.25	5.77	1.74	3.21	9.08
	9	3.76	2.20	0.97	7.69	3.41	2.01	0.42	7.69	5.45	1.97	1.51	8.46	5.04	1.18	3.24	6.55
	11	3.64	2.13	1.40	7.47	3.20	1.97	0.44	7.47	5.25	1.64	2.90	8.05	5.43	1.41	3.71	7.54
	13	3.56	2.22	1.32	7.52	3.02	2.06	–0.11	7.52	5.60	1.59	3.37	7.88	5.57	1.36	3.78	7.51
	15	2.79	2.36	–0.46	6.52	2.45	2.33	–1.77	6.52	5.97	1.73	3.29	9.34	5.50	1.44	3.52	8.07
APDI	7	78.16	2.44	75.42	81.84	78.60	2.18	75.42	81.85	74.36	3.17	70.19	78.41	75.03	3.67	69.89	81.64
	9	78.98	3.23	75.36	83.21	79.14	2.94	75.36	84.41	74.20	3.76	69.74	81.43	76.67	3.10	72.63	80.47
	11	80.15	2.81	75.31	84.35	80.28	2.81	75.31	85.87	75.63	2.97	71.20	80.66	76.55	2.85	73.26	80.05
	13	80.89	3.34	75.88	84.46	81.07	3.56	75.82	87.66	75.66	2.52	72.03	80.58	76.69	2.87	73.08	80.78
	15	82.02	4.17	75.33	86.76	82.23	4.63	75.33	89.14	74.94	3.52	69.12	80.52	78.22	3.22	73.88	82.51
A-B plane angle	7	–6.02	2.49	–10.68	–2.80	–5.56	2.30	–10.68	–0.99	–7.83	2.49	–11.80	–5.06	–9.61	2.12	–14.26	–7.46
	9	–5.80	2.96	–11.28	–2.58	–5.67	2.87	–11.28	–0.66	–8.86	3.01	–12.22	–2.56	–9.35	1.69	–11.50	–6.75
	11	–5.86	2.80	–11.15	–2.90	–5.57	2.71	–11.15	–0.87	–8.80	2.55	–12.58	–5.14	–10.18	2.32	–14.27	–7.26
	13	–5.95	3.15	–11.20	–2.35	–5.55	3.07	–11.20	–0.11	–9.51	2.79	–13.78	–5.78	–10.88	2.28	–14.69	–7.43
	15	–5.09	3.24	–11.17	–0.04	–4.91	3.40	–11.17	1.09	–10.44	3.08	–15.48	–5.95	–11.10	2.57	–16.24	–7.75
Wits	7	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	9	–0.06	2.02	–2.61	3.06	–0.12	2.17	–3.59	4.37	3.17	1.73	0.22	5.33	1.57	1.71	–0.37	5.12
	11	–0.16	1.80	–2.72	2.18	–0.25	1.94	–2.97	2.51	3.57	2.22	0.21	7.88	2.65	1.85	0.42	5.63
	13	0.03	1.99	–3.74	3.32	0.05	2.86	–3.74	7.97	4.82	2.18	1.02	7.94	2.89	1.87	–0.15	5.56
	15	–0.10	3.02	–6.15	3.58	0.09	3.49	–6.15	7.62	5.85	3.31	0.92	10.85	3.73	1.63	0.85	5.81
AF-BF	7	6.17	1.13	4.31	8.20	5.69	1.91	1.78	8.20	8.56	2.19	5.51	11.78	7.49	2.22	4.24	10.01
	9	5.97	1.66	2.10	8.39	5.51	2.26	0.72	9.32	8.48	3.14	3.11	13.31	6.71	2.75	3.70	11.74
	11	5.11	1.72	2.89	8.72	4.60	2.59	–0.37	8.72	8.32	3.35	4.34	13.79	6.82	2.50	3.39	10.95
	13	5.18	2.19	1.48	8.18	5.29	2.61	0.81	10.06	9.23	3.66	4.70	14.08	7.23	3.14	4.12	13.12
	15	5.58	2.70	1.25	11.55	5.55	3.32	0.66	11.55	10.26	4.21	5.30	17.66	8.34	3.42	5.08	13.75
App-Bpp	7	7.06	1.23	5.05	8.38	6.75	1.23	4.35	8.38	9.27	2.52	6.59	13.43	8.05	2.04	4.10	10.57
	9	6.57	1.66	3.95	8.58	6.53	1.63	3.20	8.58	9.36	2.71	4.87	13.31	7.12	1.79	4.76	9.91
	11	6.08	1.73	3.74	9.01	6.10	1.79	2.40	9.01	8.68	2.36	5.33	13.21	7.37	1.72	5.05	9.68
	13	5.84	2.14	3.66	9.55	5.76	2.32	1.42	9.55	8.93	1.72	5.54	10.65	7.50	2.00	4.59	10.81
	15	5.39	2.82	2.46	10.10	5.33	3.22	0.54	10.14	9.79	2.52	6.03	13.45	7.04	2.39	4.57	11.45
App-Pgpp	7	8.18	1.83	5.47	10.12	7.54	1.67	5.47	10.12	10.17	3.15	7.68	15.99	7.76	2.63	1.77	9.98
	9	7.15	2.39	3.20	10.14	6.55	2.01	3.20	10.14	9.72	3.47	6.16	15.43	6.10	2.27	1.81	9.34
	11	6.22	2.57	2.88	10.35	5.64	2.31	1.92	10.35	8.77	3.14	5.64	14.96	6.15	2.07	2.34	8.79
	13	5.71	3.38	1.91	12.32	5.00	3.00	0.89	12.32	8.70	2.16	5.44	11.92	5.68	2.32	1.33	8.78
	15	4.70	4.18	0.11	12.76	3.96	3.91	–1.12	12.76	9.09	3.44	5.53	14.74	4.25	2.84	-0.01	9.18

Table 2 Females – Descriptive statistics ($\overline{x}$ = mean, s = standard deviation) at 7, 9, 11, 13 and 15 years of age in the four groups (angular measurements in degrees, distances in mm). (Female Class II division 2 group bracketed with respect to sample size).

Females	Age	Good occlusion				Class I				Class II division 1				Class II division 2			
		$\overline{x}$	s	Min	Max	$\overline{x}$	s	Min	Max	$\overline{x}$	s	Min	Max	$\overline{x}$	s	Min	Max
ANB	7	3.41	2.40	–1.05	5.65	3.89	2.26	–1.05	7.56	4.84	1.15	3.58	7.06	6.21	1.57	4.84	7.95
	9	2.63	2.33	–1.22	5.46	3.09	2.28	–1.22	7.23	4.56	1.38	3.30	7.12	6.30	1.93	3.56	7.95
	11	2.66	2.27	–1.07	5.29	2.91	2.67	–1.07	8.13	4.58	1.97	2.34	7.42	6.38	2.10	3.52	8.18
	13	2.21	2.65	–1.00	5.96	2.45	2.72	–1.00	7.37	4.83	2.46	2.44	8.79	6.52	2.49	3.56	9.59
	15	2.11	2.46	–1.24	5.31	2.40	2.96	–1.95	9.24	4.48	2.35	1.73	8.70	6.41	2.97	2.75	9.99
APDI	7	80.50	3.86	76.21	87.28	78.44	4.58	68.25	87.28	75.68	2.09	72.62	78.25	73.27	2.60	70.46	76.68
	9	81.50	3.71	75.79	87.76	79.77	4.55	69.61	87.76	75.38	2.34	71.55	78.70	73.07	1.95	70.37	75.00
	11	83.17	4.55	76.55	89.76	81.52	5.50	70.22	89.76	76.49	2.06	73.13	79.53	72.67	2.97	68.77	75.84
	13	84.68	4.90	78.54	91.83	82.93	5.66	71.26	91.83	76.55	2.55	72.63	80.96	73.30	3.74	69.69	77.22
	15	85.97	3.94	81.21	93.65	83.94	5.77	69.76	93.65	77.69	2.67	72.51	82.13	73.25	4.24	69.53	77.73
A-B plane angle	7	–5.36	3.06	–9.17	0.26	–5.83	2.70	–9.20	0.26	–7.71	1.68	–11.66	–6.05	–9.28	2.84	–12.71	–5.97
	9	–4.58	2.94	–8.08	0.65	–5.00	2.72	–8.38	0.65	–8.30	2.50	–13.57	–5.59	–10.59	2.14	–12.87	–7.69
	11	–4.83	2.74	–7.89	–0.25	–5.03	3.27	–10.89	0.33	–8.66	2.97	–14.13	–5.74	–11.25	2.83	–14.18	–7.62
	13	–4.69	3.38	–9.30	–0.92	–4.56	3.21	–9.30	–0.18	–9.44	3.36	–14.19	–5.66	–12.54	4.01	–17.66	–7.90
	15	–4.81	2.80	–8.21	–1.42	–4.64	3.46	–11.47	1.47	–9.19	3.13	–14.50	–5.64	–12.43	4.68	–18.28	–6.85
Wits	7	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	9	–0.20	1.12	–2.44	0.99	–0.46	1.52	–3.01	2.30	2.98	2.38	–1.34	6.11	3.24	1.28	1.51	4.60
	11	–0.18	1.36	–1.75	2.17	–0.39	1.73	–4.26	2.17	3.31	2.05	1.55	6.86	3.60	2.51	0.01	5.35
	13	–0.16	2.04	–4.02	1.91	–0.54	1.88	–4.02	1.91	4.81	2.14	2.04	8.10	4.01	2.80	0.35	6.99
	15	0.07	1.38	–2.39	2.04	–0.38	2.06	–5.53	2.12	4.55	2.20	1.09	7.41	5.06	2.46	2.35	8.09
AF-BF	7	4.96	2.76	–0.96	8.16	6.36	3.18	–0.96	11.68	6.73	2.09	3.17	10.08	8.54	2.56	4.91	10.85
	9	4.65	2.11	1.79	7.53	5.64	2.78	1.79	11.55	7.12	1.95	4.52	9.59	8.27	2.92	5.43	11.83
	11	3.78	2.67	–0.79	8.19	5.31	3.46	–0.79	11.61	6.90	1.97	3.71	10.15	8.63	3.58	4.59	13.17
	13	3.81	3.29	–0.38	9.38	4.99	3.90	–0.38	11.92	7.13	2.22	3.88	9.96	8.76	3.16	5.45	11.54
	15	3.22	3.11	–0.91	6.69	4.71	4.67	–3.34	14.64	7.46	2.62	3.52	12.71	8.91	3.99	5.18	13.01
App-Bpp	7	5.18	2.17	1.59	7.38	6.68	2.96	1.59	13.73	8.05	0.91	6.92	9.61	9.67	1.35	8.25	11.40
	9	4.67	2.10	1.26	8.03	5.96	3.07	1.26	13.97	8.14	1.22	5.90	9.66	9.43	1.53	7.91	11.50
	11	3.91	2.66	0.11	7.59	5.04	3.46	0.11	12.89	7.66	1.41	5.55	10.06	9.88	1.71	8.15	12.20
	13	3.14	2.87	–0.94	6.81	4.46	3.79	–0.94	13.49	7.96	1.97	5.53	12.12	9.45	2.12	6.88	11.43
	15	2.48	2.33	–1.90	5.27	3.98	4.05	–1.90	15.31	7.43	2.45	4.59	13.06	9.67	2.30	6.91	11.60
App-Pgpp	7	5.39	3.13	0.23	8.99	7.30	4.01	0.23	17.10	8.19	1.14	5.99	9.21	10.14	2.03	8.38	13.05
	9	4.67	3.11	0.03	9.36	6.42	4.17	0.03	17.57	7.72	1.45	6.31	10.56	9.45	2.46	7.71	13.01
	11	3.26	3.72	–1.58	8.19	4.92	4.79	–1.58	16.00	6.67	1.96	4.66	11.06	9.20	2.80	6.79	13.23
	13	1.49	4.16	–2.71	7.58	3.67	5.45	–3.35	16.76	6.19	3.36	1.00	13.37	7.89	3.06	4.62	11.73
	15	0.03	3.79	–5.21	5.07	2.67	5.69	–5.21	18.08	5.15	4.19	–0.27	14.61	7.85	3.17	4.44	11.75

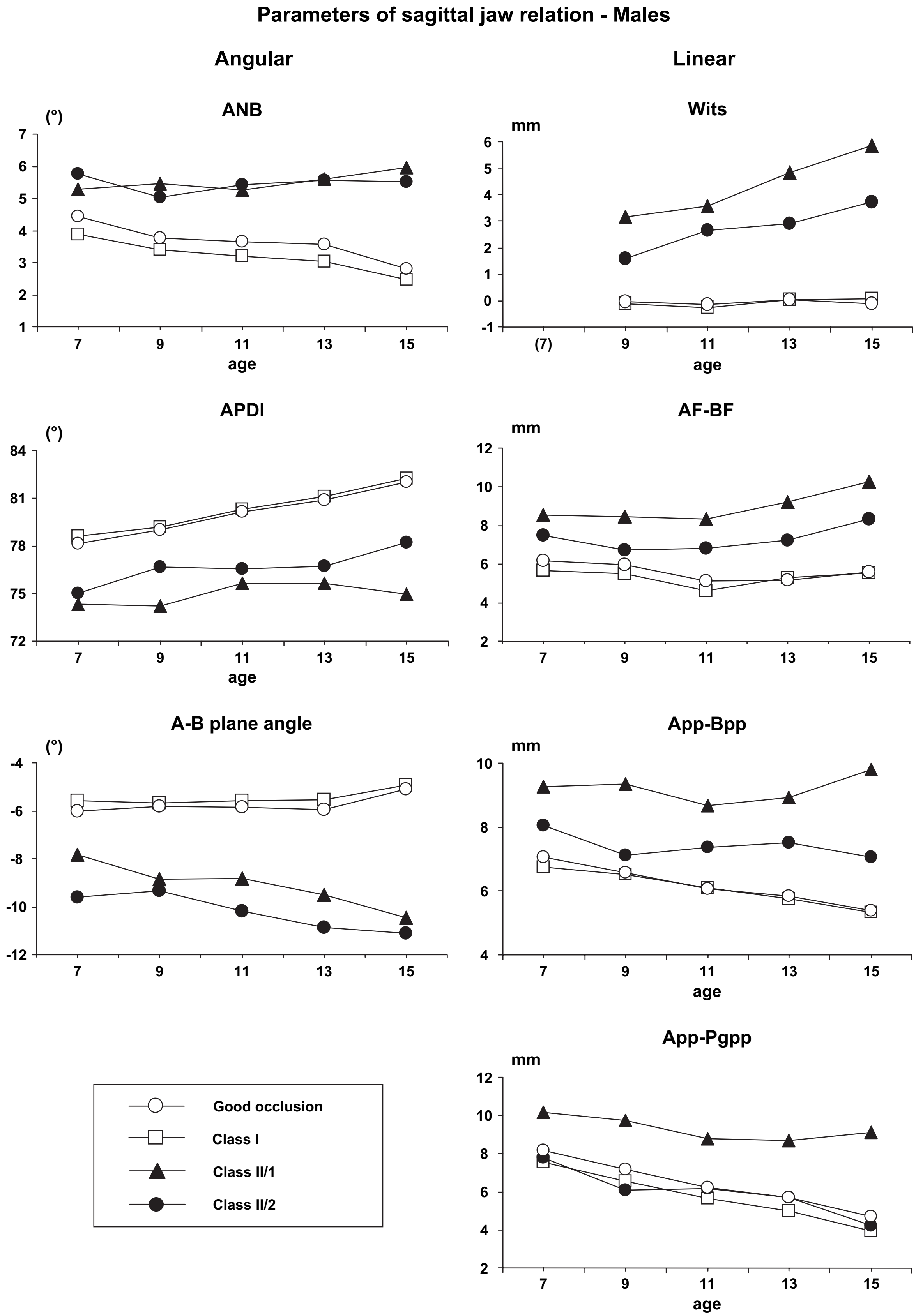

Figure 2 Growth curves for the seven cephalometric parameters in the four groups. Depiction in two-year intervals between 7 and 15 years of age in males.

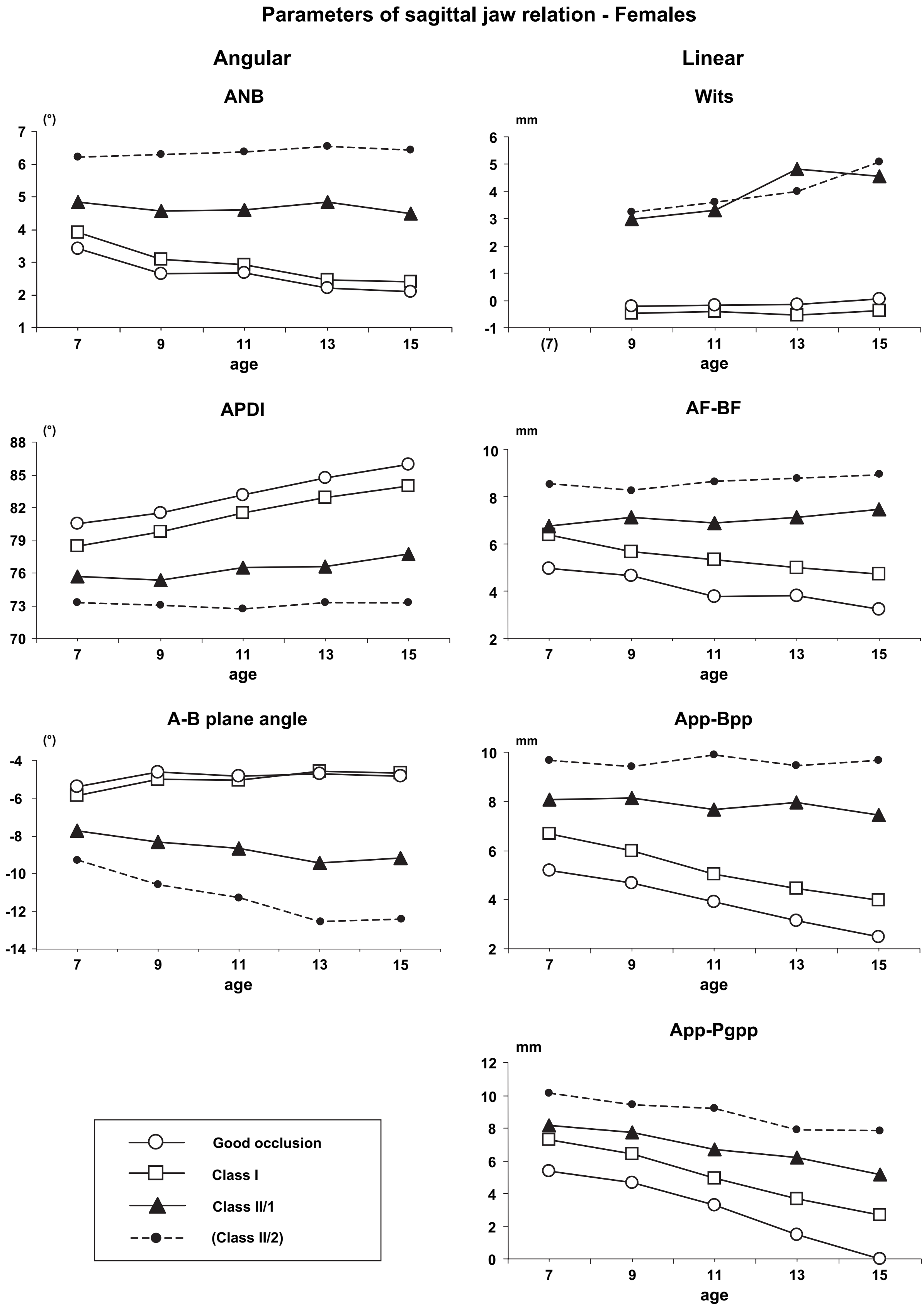

Figure 3 Growth curves for the seven cephalometric parameters in the four groups. Depiction in two-year intervals between 7 and 15 years of age in females.

subjects and controls were statistically significant at nearly all ages in the case of Wits and APDI, whilst on the basis of ANB, App–Bpp and App–Pgpp, group differences were significant only at 13 and 15 years of age. On the basis of AF–BF, group differences between Class II division 1 subjects and controls were significant only at 7 years of age (Class I control group). Statistically significant differences between male Class II division 2 subjects and both control groups were found for Wits and A–B plane angle, and in the latter at all ages (Class I control group). Among females, no significant group differences between Class II subjects and controls were found for ANB and AF–BF (Figure 3, Table 3). Group differences between female Class II division 1 subjects and controls were mainly significant on the basis of Wits and APDI (Figure 3, Table 3). Group differences between female Class I and Class II division 2 subjects were mainly significant for A–B plane angle and APDI. However, particularly in the female Class II division 2 group, sample size restrictions must be considered (female Class II division 2 growth curves are only shown as dotted lines in Figure 3).

Discussion

Age-related changes in the good occlusion subjects – cephalometric standards

In the present study, the age-related changes in sagittal jaw relationship were investigated on the basis of subjects with good occlusion. The age-related decrease in ANB angle observed in the good occlusion group is in agreement with the literature (Riolo *et al.*, 1974; Bhatia and Leighton, 1993) and is usually attributed to an age-related reduction of sagittal jaw distance (Williams *et al.*, 1985; Buschang *et al.*, 1986). However, Bishara *et al.* (1983) noted that while the ANB angle decreased significantly with age, the Wits indicated no sagittal change in jaw position between the age of five and adulthood. Also in the present study, in contrast to the ANB angle, the Wits values remained nearly unaltered between 9 and 15 years, with values ranging around 0 mm in both genders. Similarly, Bhatia and Leighton (1993) found no increase in Wits between 9 and 15 years of age. In contrast, Roth (1982) and Sherman *et al.* (1988) described a growth-related increase in Wits, which was attributed to the influence of geometric cofactors. Sherman *et al.* (1988) reported that any change in the angulation of the functional occlusal plane, usually an age-related counterclockwise (horizontal) rotation, may profoundly influence the Wits value. Roth (1982) showed that, beyond this counterclockwise rotation of the occlusal plane, the age-related vertical increase in the distance between points A and B has a positive summation effect, which may induce an increase in the Wits value without an actual shift in the sagittal position between points A and B. Also in the present study a horizontal rotation of the occlusal plane was observed, i.e. between 9 and 15 years of age the angle between the sella–nasion line and the occlusal plane decreased from 18.7 to 15.4 degrees among males and from 15.4 to 13.1 degrees among females. Hence, the constancy of the Wits in the good occlusion group does not necessarily argue against an age-related reduction of sagittal jaw distance. Williams *et al.* (1985) showed that if inclination of the occlusal plane is fixed, then the Wits analysis also supports the concept of a reduction of sagittal jaw relationship. In addition, the present study confirmed that a Wits value of 0 ± 2 mm provides an appropriate norm value both in males and females.

Of particular interest in the present study are the longitudinal changes of those parameters which have scarcely been investigated, such as APDI, AF–BF and App–Bpp. In the good occlusion group, between 7 and 15 years of age, App–Bpp showed a significant decrease in both genders (7.06 to 5.39 mm in males, 5.18 to 2.48 mm in females). Between 6 and 18 years of age, Nanda and Merrill (1994) found a similar decrease in App–Bpp from 5.40 to 4.44 mm (males) and from 6.68 to 3.13 mm (females). This trend towards a reduction of the sagittal jaw distance through growth is supported by the results of the present study. Chang (1987) suggested the use of the AF–BF distance. Luder (1978) who used AF–BF for the assessment of the sagittal jaw relationship rejected this measurement due to the high method error inherent in the identification of the Frankfort plane. In the present study, the method error of the AF–BF distance was comparable with other linear measurements. Concerning AF–BF, Judy *et al.* (1995) found an age-related decrease from 7.3 to 6.5 mm (males) and from 6.7 to 5.2 mm (females) in Class I subjects between 8 and 18 years of age. Although not statistically significant, similar age-related decreases in AF–BF were found in the good occlusion subjects in the present study. Finally, with respect to APDI, Kim and Vietas (1978) described, at 11.5 years of age, a mean value of 81.4 degrees (SD: 3.79) for subjects with normal occlusion. This corresponds quite well with the mean value of 80.15 degrees (SD: 2.81, males) and 83.17 degrees (SD: 4.55, females) found in the present study for 11-year-old subjects. In addition, the present study demonstrated that APDI increases through growth (statistically significant), which shows that the A–B plane undergoes a counterclockwise rotation in relation to the palatal plane. This again underlines the dominance of mandibular growth when compared with maxillary sagittal growth (Lux *et al.*, 2004b), resulting in a change of facial shape.

Growth pattern of Class II subjects

The growth curves (Figures 2 and 3) indicate that deviations in Class II subjects depend considerably on the geometric frame of reference used in the respective variables. For instance, among male Class II division 1 and Class II division 2 subjects, ANB angle showed a similar degree of sagittal jaw discrepancy in both groups (Figure 2). In contrast,

Table 3 Intergroup comparisons between the four groups, separately for males and females (I = Class I group, GO = good occlusion group, II/1, II/2 = Class II division 1, Class II division 2 groups). Only *P*-values ≤ 0.10 are depicted. Significant *P*-values ($P \leq 0.01$) are marked by an asterisk. Group comparisons with the female Class II division 2 group were bracketed with respect to the small sample size.

Variable	Age	Males					Females				
		I vs II/1	I vs II/2	II/1 vs II/2	GO vs II/1	GO vs II/2	I vs II/1	(I vs II/2)	(II/1 vs II/2)	GO vs II/1	(GO vs II/2)
ANB	7	0.044	0.017	----	----	----	----	0.089	0.064	----	0.089
	9	0.017	0.038	----	0.076	----	----	0.027	0.090	----	0.042
	11	0.015	0.007*	----	0.091	0.051	----	0.041	0.090	----	0.042
	13	0.005*	0.006*	----	0.051	0.076	0.045	0.022	----	0.068	0.027
	15	0.003*	0.002*	----	0.033	0.021	0.100	0.033	----	----	0.027
APDI	7	0.003*	0.015	----	0.021	0.041	----	0.041	----	0.012	0.017
	9	0.003*	0.080	----	0.021	----	0.010*	0.011	----	0.004*	0.007*
	11	0.002*	0.006*	----	0.008*	0.013	0.009*	0.008*	0.045	0.002*	0.007*
	13	<0.001*	0.008*	----	0.003*	0.021	0.003*	0.005*		0.001*	0.007*
	15	0.001*	0.038	----	0.006*	0.051	0.003*	0.006*	0.064	<0.001*	0.007*
A-B plane angle	7	0.026	<0.001*	----	0.076	0.013	----	0.050	----	----	0.062
	9	0.026	0.003*	----	0.062	0.010*	0.021	0.005*	0.064	0.034	0.011
	11	0.009*	0.001*	----	0.033	0.010*	0.018	0.008*	0.090	0.054	0.011
	13	0.007*	<0.001*	----	0.041	0.008*	0.003*	0.006*	----	0.027	0.017
	15	0.001*	<0.001*	----	0.004*	0.003*	0.005*	0.006*	----	0.027	0.017
Wits	7	—	—	—	—	—	—	—	—	—	—
	9	0.002*	0.063	0.059	0.006*	----	0.002*	0.004*	----	0.012	0.007*
	11	<0.001*	0.003*	----	0.003*	0.008*	<0.001*	0.017	----	0.003*	0.027
	13	<0.001*	0.007*	0.074	<0.001*	0.010*	<0.001*	0.011	----	<0.001*	0.042
	15	0.002*	0.007*	----	0.003*	0.006*	<0.001*	0.002*	----	0.001*	0.007*
AF-BF	7	0.008*	0.071	----	0.026	----	----	----	----	----	0.062
	9	0.017	----	----	0.062	----	----	----	----	0.021	0.089
	11	0.011	0.080	----	0.021	----	----	----	----	0.012	0.062
	13	0.015	----	----	0.041	----	----	0.089	----	0.034	0.042
	15	0.015	0.089	----	0.016	0.062	0.080	0.089	----	0.009*	0.042
App-Bpp	7	0.011	0.038	----	0.076	----	----	0.027	0.045	0.004*	0.007*
	9	0.015	----	0.093	0.033	----	0.018	0.027	----	0.004*	0.011
	11	0.011	0.080	----	0.021	----	0.018	0.014	0.045	0.004*	0.007*
	13	0.003*	0.089	----	0.008*	----	0.014	0.017	----	0.002*	0.007*
	15	0.007*	----	0.036	0.010*	----	0.006*	0.014	----	0.001*	0.007*
App-Pgpp	7	0.038	----	----	----	----	----	0.089	0.045	0.054	0.011
	9	0.019	----	0.046	----	----	----	----	----	0.054	0.062
	11	0.011	----	----	0.062	----	----	0.050	0.064	----	0.017
	13	0.005*	----	0.016	0.051	----	----	----	----	0.034	0.027
	15	0.008*	----	0.009*	0.041	----	----	0.041	----	0.021	0.011

the linear measurement, App–Bpp, suggests that in male Class II division 2 subjects the sagittal discrepancy is less developed than in Class II division 1 males (Figure 2). In addition, the results of the statistical testing suggest that the geometric frame of reference is essential for the diagnostic value of the variables. Hence, studies on the validity and diagnostic performance of the various measurements are required (e.g. Han and Kim, 1998), and conclusions concerning sagittal jaw relationship should be based on a combination rather than on a single measurement. This is in keeping with Jacobson (1988) and Bishara *et al.* (1983) who recommended the combined use of Wits analysis and ANB measurement. Similarly, Ishikawa *et al*. (2000) suggested a combination of ANB, Wits and APDI as a clinically appropriate method for the assessment of jaw relationships in individuals. Finally, with respect to Class II malocclusion subjects, the growth curves (Figures 2 and 3) show that the differences between the Class II malocclusion and control groups present at 15 years of age were already established at 7 years of age, but were less pronounced.

Limitations

The limitations of this study, particularly the small sample sizes, must be taken into account. In addition, Sherman *et al*. (1988) emphasized in the context of the Wits appraisal that the use of mean figures disguises a wide range of individual variation, which must also be considered when growth curves are interpreted. Finally, Ongkosuwito *et al*. (2002) pointed out that cephalometric methods are generally poor in measuring skeletal jaw relationships longitudinally, irrespective of whether digital or conventional cephalometric techniques are used.

Conclusions

The present study provides longitudinal data and cephalometric standards in two-year intervals between the ages of 7 and 15 years for various angular (ANB, APDI, A–B plane angle) and linear measurements (Wits, AF–BF, App–Bpp, App–Pgpp) of sagittal jaw relationship. On this basis the following conclusions can be drawn:

1. With respect to age-related changes, the main findings in the good occlusion subjects were, in both genders, a statistically significant age-related decrease in ANB angle, App–Bpp and App–Pgpp, a significant increase in APDI, but no age-related change in Wits. Finally, AF–BF tended towards a slight age-related decrease, and the A–B plane angle towards a slight increase (less negative), but these changes were not statistically significant.
2. For subjects with a good occlusion and Class I subjects, a reduction of sagittal jaw distance during pre-pubertal and pubertal development was observed as a result of a relative dominance of sagittal mandibular growth.
3. Conclusions about the sagittal discrepancy in Class II division 1 and Class II division 2 subjects depend considerably on the geometric reference (e.g. palatal or occlusal plane) used, and further research is necessary with respect to the validity and diagnostic performance of the various measurements. In general, growth differences between Class II subjects and controls present at 15 years of age were already established at 7 years of age, but were less pronounced.

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