## Transverse development of the craniofacial skeleton and dentition between 7 and 15 years of age—a longitudinal postero-anterior cephalometric study

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SUMMARY The aim of this study was to identify the transverse growth pattern of the craniofacial skeleton and dentition from 7 to 15 years of age. The database for this longitudinal study comprised the posteroanterior (PA) cephalograms and dental casts at 7, 9, 11, 13 and 15 years of age of 18 untreated Class I subjects with good occlusion from the Belfast Growth Study. Differential magnification of the PA cephalograms was corrected using the method of similar triangles.

Most of the craniofacial widths were larger in males than in females. At 15 years of age, the gender differences in craniofacial widths were more pronounced than at 7 years of age. The majority of the skeletal dimensions showed a progressive increase in width. In contrast, there was a deceleration in the increase in maxillary and mandibular intermolar widths after 11 years of age in males and even a slight decrease in the intermolar width beyond 11 years of age in females. Growth curves were calculated where the values of the respective variables were expressed in terms of percentage of attainment at 7, 9, 11 and 13 years of age when compared with 15 years of age. For mid-facial, bizygomatic and skeletal maxillo-mandibular widths, percentile attainments in the range of 84–91 per cent indicated a greater remaining growth potential at 7 years of age than for the cranial width where growth was almost complete. By the age of 7 years, over 95 per cent of the growth in the intermolar width had occurred.

## Introduction

Correction of transverse anomalies, such as crossbites, is a common orthodontic treatment objective. The importance of the transverse dimension becomes apparent when the potential and limits of certain treatment options, such as palatal expansion, have to be explored, or when deciding between extraction or non-extraction in borderline cases. When compared with the variety of data from lateral cephalograms, comparatively few studies have analysed the craniofacial width and its change over time. One reason for this is the problem of differential magnification, which makes determination of actual craniofacial sizes very difficult. As pointed out by Woods (1950), the correction of magnification in frontal films poses difficulties not found in lateral films. In the postero-anterior (PA) view, an object such as the upper canine is closer to the film than, for instance, the area of the gonial angle. Hence, the distance between the canines is enlarged less than the distance between both gonia. In addition, as anteroposterior growth proceeds, additional changes occur in the position of the landmarks to the film surface, which again affect the magnification of the width dimensions (Woods, 1950). To enhance the clinical significance of the information derived from the PA view, methods for magnification correction have been developed. These

range from the geometric approaches of the Wylie compensator and its modifications (Wylie and Elsasser, 1948; Woods, 1950; Vogel, 1967) to the mathematical approaches based on the principle of similar triangles, as described by Adams (1963), Mulick (1965), Wei (1970) and Hsiao *et al.* (1997).

In a detailed review of the orthodontic literature on PA cephalometry, Basyouni and Nanda (2000) found that the majority of investigations focused primarily on the assessment of facial symmetry. In the field of transverse craniofacial development, the research of Woods (1950) is of particular relevance to the present study, because the use of the Wylie compensator for magnification correction simplifies the comparison with the results in the present study. Ricketts (1981) developed PA variables focusing on the transverse maxillo-mandibular relationship and he also adjusted clinical norms for age. Athanasiou et al. (1992) described norm values for several transverse dimensions in a cross-sectional study of 588 Austrian schoolchildren. Instead of magnification correction, ratios between width dimensions were used to minimize the uncontrolled magnification due to antero-posterior growth of the skull and the varying distances between landmarks and film. Snodell et al. (1993) investigated vertical and transverse craniofacial growth in a Class I sample. When comparing, in terms of percentage, the increases in

transverse and vertical dimensions, stronger vertical growth was found, indicating earlier completion of transverse growth. Finally, Basyouni and Nanda (2000) analysed transverse growth between 5 and 18 years of age and identified asymmetry in the horizontal and vertical dimensions on both sides of the face. No magnification correction was performed.

A second group of publications refers to the transverse development of specific anatomical regions. A detailed depiction of maxillary growth was given by Singh and Savara (1966) and Savara and Singh (1968), separately for boys and girls. They ascertained that maxillary growth changes are most marked in the measurement of height, less in length and least in width. Through the combined use of lateral and PA cephalograms, magnification correction of the maxillary width measurements became feasible. Based on the Bolton-Brush growth study, Cortella et al. (1997) provided norms for the maxillary and antegonial widths in subjects with 'excellent static occlusion'. Magnification was corrected by subtracting the percentage of enlargement computed on the basis of the distance between the transporionic axis and the film. In addition, transverse development of the dental arches during adolescence has been investigated (Sillman, 1964; DeKock, 1972; Sinclair and Little, 1983; Bishara et al., 1997). Based on the Michigan Growth Study, an extensive analysis of model data in growing children was published by Moyers et al. (1976), comprising both dental and occlusal data.

In summary, as highlighted by Basyouni and Nanda (2000), in spite of numerous articles on PA cephalometry, there is only a limited number of publications dealing with transverse development of the craniofacial skeleton. Ricketts (1981) stated that in PA cephalometry, the lack of accepted reference points as well as of sufficient clinical data in both normal and treated patients has hampered the establishment of standards for actual clinical use. Thus, the aim of the present study was to identify the patterns and characteristics of transverse growth in various anatomical regions based on a purely longitudinal growth data set of a Class I sample with good occlusion. In addition, a mathematical correction of differential magnification was performed to enhance the clinical relevance of the norm values. Finally, the potential of a modified PA projection was explored to analyse growth of the craniofacial regions which have rarely been investigated, such as the cranial width, the bifrontotemporal width or the width between the maxillo-zygomatic sutures.

#### Subjects and methods

The data for this longitudinal study comprised the PA cephalograms and dental casts of subjects from the Belfast Growth Study (Adams, 1972). For magnification correction of the PA measurements, lateral cephalograms

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taken at the same time were also analysed. The Belfast Growth Study was carried out in the 1960s and 1970s and comprised 300 orthodontically untreated children where PA and lateral cephalograms were taken annually and plaster casts were made every 6 months. From these 300 cases, subjects were selected who fulfilled the following inclusion criteria:

- 1 bilateral Class I molar and canine relationship;
- 2 no congenitally missing teeth, i.e. all teeth except third molars in occlusion;
- 3 correct overjet and overbite (between 1 and 4 mm);
- 4 no crossbites or transverse anomalies;
- 5 crowding in upper and lower arches less than or equal to 3 mm.

Eighteen subjects (10 males, eight females) met the inclusion criteria. Growth was analysed in 2 yearly intervals at ages 7, 9, 11, 13 and 15 years, corresponding to the 5th, 9th, 13th, 17th and 21st growth study visit. If the respective radiograph was missing or could not be used (2 per cent of radiographs), the proximate radiographs before or after the respective date were used. The ages of the subjects when the radiographs were taken are shown in Table 1.

#### Measurements

In the Belfast Growth Study, the PA radiographs were taken in the depressed PA view (Adams, 1963). In this view, the line connecting the transportionic axis and the soft tissue point on the orbital rim is inclined downwards at an angle of 35 degrees to the horizontal plane, as shown in Figure 1.

The PA and lateral cephalograms were scanned using a high resolution (600 dpi). After digitizing the PA landmarks, the landmark co-ordinates were used to calculate the following eight craniofacial widths (Figure 2).

Cranial width: the distance between both eurya (Eu). The euryon is the most lateral point on the side of the skull, determined by the measurement of the greatest

 Table 1
 Age of the subjects during the radiographs.

Age	Males		Females			
	Mean	SD	Mean	SD		
t1	7.52	0.33	7.71	0.31		
t2	9.36	0.37	9.67	0.32		
t3	11.44	0.34	11.71	0.30		
t4	13.50	0.35	13.71	0.33		
t5	15.55	0.36	15.78	0.36		

SD, standard deviation.



**Figure 1** Depressed postero-anterior view: a line connecting the transporionic axis and the orbital point is inclined downwards at an angle of 35 degrees to the horizontal plane. For a precise adjustment in the cephalostat, the orbital point was marked by a small circular spot of lead foil (Adams, 1963).

cranial width (Martin and Saller, 1957; Raghavan et al., 1994).

Bifrontotemporal width: the distance between both frontotemporalia (Ft). The frontotemporale is the most medial and anterior point on the temporal line of the frontal bone (Martin and Saller, 1957).

Bizygomatic width: the distance between both zygia (Zy). The zygion is the most lateral aspect of the zygomatic arch (Martin and Saller, 1957; Major *et al.*, 1994).

Mid-facial width: the distance between both zygomaxillaria (Zm). The zygomaxillare is topographically closely related to the most lateral and inferior aspect of the maxillo-zygomatic suture (Martin and Saller, 1957).

Maxillary skeletal base width: the distance between the right and left maxillare (Ma). The maxillare is the intersection of the lateral contour of the maxillary alveolar process and the lower contour of the maxillozygomatic process of the maxilla (Athanasiou *et al.*, 1992; Raghavan *et al.*, 1994; Hsiao *et al.*, 1997).

Bigonial width: the distance between both gonia (Go). The gonion is the most inferior, posterior and lateral point on the external angle of the mandible (Martin and Saller, 1957).

Biantegonial width: the distance between both antegonia (Ag). The antegonion is the deepest point on the curvature at the antegonial notch (Svanholt and Solow, 1977; Athanasiou *et al.*, 1992; Major *et al.*, 1994).

Nasal width: the greatest distance between the right and left lateral bony walls of the nasal cavity (NC) (Raghavan *et al.*, 1994; Da Silva Filho *et al.*, 1995).



**Figure 2** (a) A postero-anterior radiograph in depressed view. (b) A tracing of a radiograph showing the landmarks used: Eu, euryon: cranial width; Ft, frontotemporale: bifrontotemporal width; Zy, zygion: bizygomatic width; Zm, zygomaxillare: mid-facial width; Ma, maxillare: maxillary skeletal base width; Go, gonion: bigonial width; Ag, antegonion: biantegonial width; NC, nasal cavity: nasal width.

## Model analysis

Measurements of the transverse development of the dental arches were made directly on the plaster models with a dial calliper (Mitutoyo Absolute Digimatic Caliper, Japan) to the nearest 0.02 mm. The following variables were determined (Kahl-Nieke *et al.*, 1996; Tollaro *et al.*, 1996):

Maxillary intermolar width: the distance between the central fossae of the right and left first maxillary molars.

Mandibular intermolar width: the distance between the tips of the distobuccal cusps of the right and left first mandibular molars.

#### Correction of differential radiographic magnification

Generally, magnification is a function of the distance between the anode and the landmark as well as the distance between the anode and the headfilm (Hsiao et al., 1997). Due to the divergence of X-ray beams, the mathematical method based on the principle of similar triangles (Figure 3; Adams, 1963; Hsiao et al., 1997) is appropriate for correcting the differential magnification in PA cephalograms. With this technique, the landmarks have to be identified on both the frontal and lateral radiographs. For some craniofacial variables, such as the bigonial, biantegonial or mid-facial width, the respective landmarks gonion, antegonion or key ridge representing the position of the zygomaxillare, can be located on the lateral cephalogram, thus making possible an individual, i.e. age- and subject-related correction of magnification. Nevertheless, one should consider that a slight difference



**Figure 3** The geometric principle of similar triangles for correction of differential magnification on postero-anterior cephalograms: by means of the formula shown above, the actual anatomical size of any craniofacial width, here distance DE, can be determined if X, which represents the distance between the vertical plane of the transporionic axis (TA) and the plane of the respective landmarks (here DE), is known. FG is the craniofacial width as measured on the PA radiograph. The distances AB (anode–TA) and AC (anode–film) are determined by the geometry of the cephalostat, here 1524 and 1654 mm. X can be determined on the lateral cephalogram (Adams, 1963; Hsiao *et al.*, 1997).

exists when the same landmark is located on the depressed PA and lateral view. For landmarks where identification in the lateral view was not possible, e.g. the euryon or zygion, mean values for their relative position to neighbouring anatomical structures were used to define the position on the lateral cephalogram (Adams, 1963; Hsiao et al., 1997). For example, in the present study it was found (from examination of 10 crania) that the zygion is located approximately on the Frankfort horizontal and on average 31.7 mm in front of the porion. Subsequently, the co-ordinates of the zygion in the lateral view could be determined and the magnification of the bizygomatic width could be corrected. Hsiao et al. (1997) investigated the accuracy of the similar-triangle approach on 20 skulls. They found that the differences between direct measurements on a skull and those obtained by means of the correction method were very small (less than 0.5 mm), resulting in a nearly comparable accuracy of the corrected indirect measurements and the direct craniometric measurements. Adams (1963) also confirmed the accuracy of the method for the bizygomatic width when he found that the corrected indirect measurements were very close to those made directly on skulls.

#### Measurement error

Replicate measurements on 20 PA cephalograms, 20 lateral cephalograms and 20 models were used to evaluate the measurement error according to Dahlberg's formula (Dahlberg, 1940). The combined error of the method is given in Table 2.

#### Data analysis and statistical methods

Growth curves showing craniofacial size versus time were calculated to depict the longitudinal growth behaviour of the various craniofacial widths in the male and female groups. In addition, descriptive statistics for craniofacial sizes and growth increments, including means, standard deviations and ranges, were calculated.

**Table 2** Dahlberg errors of the measurements made on themodels and the radiographs (in mm).

Variable	Measurement error				
Maxillary intermolar width (model)	0.17				
Mandibular intermolar width (model)	0.25				
Cranial width	0.27				
Nasal width	0.29				
Biantegonial width	0.50				
Bifrontotemporal width	0.50				
Bizygomatic width	0.55				
Maxillary skeletal base width	0.56				
Bigonial width	0.61				
Mid-facial width	1.04				

An unpaired Wilcoxon rank sum test was used to test for differences between the male and female groups. In addition, a paired Wilcoxon test was applied to identify significant changes occurring in each 2 year time interval and during the total period of observation, i.e. 7–15 years of age, separately for males and females. Non-parametric tests were used, because in small samples even a single outlier can affect parametric testing. A significance level of  $\alpha = 0.05$  was chosen. In a second step, growth curves were calculated where the values of the respective variables were expressed in terms of the percentage of attainment at 7, 9, 11 and 13 years of age. The size at 15 years of age was set as 100 per cent attainment.

#### Results

#### Growth pattern of the transverse dimensions

Figure 4 shows the growth curves for size versus age for the 10 transverse craniofacial variables. In addition, for comparison with total body development, the growth curve for standing height is depicted. Descriptive statistics of the craniofacial distances are given in Table 3 and the growth increments in the respective 2 year intervals and during the total period of observation are shown in Table 4. At 7 years of age (Figure 4), the gender differences were slight, mainly statistically nonsignificant (Figure 4, Table 3). In contrast, at 15 years of age, for all transverse measurements, males were larger



**Figure 4** Growth curves showing absolute size versus time for the eight skeletal and two dental variables, separately for males and females. Standing height is given to allow a comparison of facial growth with body development.

	Age	Males				Females					P-value	
		Mean	SD	Minimum	Maximum	PA	Mean	SD	Minimum	Maximum	PA	
Cranial width	7	139.17	4.59	131.29	146.53	97.1	135.71	5.45	127.86	144.62	97.5	0.23
	9	140.28	4.39	132.79	147.27	97.9	136.58	5.65	128.83	145.21	98.1	0.31
	11	140.82	4.39	133.99	148.49	98.3	137.81	5.62	130.00	146.96	99.0	0.35
	13	142.08	4.52	135.70	150.14	99.2	138.41	5.51	130.55	146.46	99.4	0.23
	15	143.25	4.66	136.70	151.16	100.0	139.17	5.52	131.41	147.91	100.0	0.17
Bifrontotemporal width	7	93.54	3.13	86.38	97.55	93.3	92.32	4.98	84.52	100.84	95.6	0.27
	9	95.47	3.09	88.51	100.03	95.2	93.97	5.55	85.35	103.43	97.3	0.27
	11	96.98	3.05	89.96	100.43	96.7	95.14	4.94	87.01	103.68	98.5	0.27
	13	98.79	3.82	90.81	105.57	98.5	96.00	4.72	87.57	103.66	99.4	0.17
	15	100.33	3.69	94.24	108.08	100.0	96.55	4.59	88.91	104.50	100.0	0.056
Bizygomatic width	7	110.97	4.00	106.26	119.05	86.6	109.43	3.22	104.19	114.43	89.1	0.69
	9	114.23	4.20	108.51	122.29	89.2	112.90	3.40	106.78	117.05	91.9	1.0
	11	118.16	3.95	114.07	125.57	92.2	116.76	3.20	110.52	120.20	95.0	1.0
	13	122.66	4.20	118.92	130.62	95.7	120.48	3.23	113.51	123.20	98.1	0.97
	15	128.11	4.47	124.49	136.80	100.0	122.88	3.59	116.04	126.56	100.0	0.011
Mid-facial width	7	79.99	2.18	76.59	83.01	84.4	77.59	3.33	72.79	82.00	89.1	0.14
	9	82.89	3.30	76.25	86.40	87.4	81.16	3.98	75.62	85.94	93.1	0.40
	11	86.29	2.43	82.16	89.08	91.0	82.42	3.87	77.93	89.16	94.6	0.056
	13	89.90	3.70	84.59	94.20	94.8	85.06	4.07	79.27	91.56	97.6	0.056
	15	94.88	3.81	88.47	100.14	100.0	87.16	4.43	81.64	94.55	100.0	0.003
Maxillary skeletal base width	7 9 11 13 15	55.14 57.55 59.89 62.17 63.75	1.63 1.93 2.05 2.33 2.46	52.12 53.47 56.17 59.05 59.46	57.99 60.65 63.00 65.93 68.17	86.6 90.3 94.0 97.5 100.0	52.93 54.67 55.91 57.30 58.46	2.10 1.88 2.40 2.40 2.84	49.25 51.57 51.40 53.47 52.25	55.84 57.01 59.04 60.95 62.07	90.6 93.6 95.7 98.1 100.0	0.023 0.005 0.003 0.003 0.001
Nasal width	7	27.48	2.78	21.07	30.67	79.9	26.29	1.60	23.53	28.41	86.2	0.12
	9	29.56	2.01	26.23	31.93	86.1	27.51	1.67	24.64	29.21	90.2	0.056
	11	30.89	2.13	27.36	33.24	89.9	28.66	1.66	25.61	30.70	93.9	0.046
	13	32.68	2.61	28.52	35.45	95.1	29.62	1.44	27.41	32.34	97.1	0.019
	15	34.37	2.60	29.85	37.54	100.0	30.50	1.55	28.37	33.01	100.0	0.004
Bigonial width	7 9 11 13 15	80.50 83.05 86.54 90.44 94.64	3.01 3.51 3.93 3.93 4.63	75.47 77.96 80.70 83.10 87.46	84.81 88.80 92.79 96.45 101.23	85.1 87.8 91.5 95.6 100.0	80.48 83.52 86.68 89.86 91.54	3.81 3.12 3.17 3.22 3.17	76.27 79.11 83.06 85.88 88.28	85.88 87.35 90.94 94.39 96.58	87.9 91.2 94.7 98.2 100.0	0.89 0.89 0.63 0.20
Biantegonial width	7	72.94	2.41	69.25	76.92	86.7	73.02	3.70	68.55	77.74	88.0	0.97
	9	75.59	3.23	71.62	81.64	89.8	76.01	3.46	70.98	80.13	91.7	0.82
	11	78.29	2.76	75.29	83.23	93.1	79.07	3.42	74.10	83.54	95.4	0.76
	13	80.71	3.39	77.79	88.21	95.9	81.13	4.16	75.20	87.12	97.8	0.89
	15	84.16	3.51	78.97	90.87	100.0	82.92	3.57	77.14	88.06	100.0	0.56
Maxillary intermolar width	7 9 11 13 15	46.84 47.71 48.51 49.08 49.28	2.08 1.96 2.52 2.69 2.61	42.81 44.09 44.78 44.30 44.72	50.13 50.97 52.44 53.41 52.96	95.1 96.9 98.5 99.6 100.0	44.73 45.56 46.53 46.41 46.11	1.52 1.80 1.96 1.97 1.62	42.12 42.63 42.70 43.17 43.30	46.66 47.57 48.68 48.62 47.90	97.0 98.8 100.9 100.6 100.0	0.037 0.019 0.083 0.037 0.015
Mandibular intermolar width	7 9 11 13 15	47.07 48.02 48.68 49.05 49.16	2.09 2.03 2.36 2.56 2.51	44.41 45.02 44.97 44.68 44.93	50.59 51.37 52.58 53.70 52.61	95.8 97.8 99.1 99.8 100.0	45.15 45.97 46.61 46.51 45.99	2.35 2.11 2.19 2.11 1.74	41.14 42.46 42.70 43.23 43.29	47.69 48.20 48.83 48.80 48.50	98.2 99.9 101.3 101.1 100.0	0.14 0.083 0.083 0.023 0.009

**Table 3** Descriptive statistics for the absolute values at 7, 9, 11, 13 and 15 years of age (in mm). The *P*-values indicate genderdifferences. In addition, the percentile attainments (PA) are given (%).

SD, standard deviation.

than females and gender differences were statistically significant for bizygomatic, mid-facial, nasal, maxillary skeletal base and intermolar widths (Table 3). Correspondingly, growth increments (Table 4) were higher in males, particularly in the time interval between 13 and 15 years of age. During that time interval, gender differences were statistically significant for most skeletal widths (Table 4).

	Age	Males			Females				P-value	
		Mean	SD	Minimum	Maximum	Mean	SD	Minimum	Maximum	
Cranial width	7–9	1.11	0.65	0.26	2.07	0.87	0.73	-0.76	1.49	0.56
	9–11	0.54	0.53	-0.34	1.22	1.23	0.63	0.61	2.25	0.046
	11–13	1.26	0.74	0.05	2.32	0.59	0.68	-0.50	1.73	0.14
	13–15	1.17	0.62	-0.25	1.96	0.77	0.91	-0.84	2.03	0.23
	7–15	4.09	1.00	2.71	5.44	3.46	1.10	1.82	4.80	0.40
Bifrontotemporal width	7–9 9–11 11–13 13–15 7–15	1.93 1.51 1.81 1.54 6.79	0.87 1.17 1.51 0.95 2.18	$\begin{array}{c} 0.74 \\ -0.02 \\ 0.08 \\ 0.01 \\ 3.41 \end{array}$	3.61 3.72 5.24 3.43 10.53	1.65 1.17 0.87 0.55 4.23	0.65 0.97 0.71 0.60 0.78	0.83 -0.21 -0.02 -0.41 2.98	2.59 2.45 1.84 1.35 5.50	0.63 0.63 0.20 0.015 0.007
Bizygomatic width	7–9	3.26	0.85	2.01	4.55	3.47	1.09	2.58	5.11	0.76
	9–11	3.93	0.93	3.18	6.41	3.86	0.62	2.87	4.55	0.51
	11–13	4.50	1.74	2.11	7.16	3.72	1.05	1.91	4.80	0.31
	13–15	5.45	0.88	3.89	6.97	2.40	0.98	1.34	4.10	<0.001
	7–15	17.14	2.23	13.17	20.17	13.45	2.99	9.50	18.08	0.019
Mid-facial width	7–9	2.90	2.04	-0.35	5.92	3.57	1.63	1.94	6.93	0.76
	9–11	3.39	1.64	0.55	6.80	1.25	1.71	-2.43	3.22	0.015
	11–13	3.61	2.98	-0.04	10.60	2.65	1.26	1.34	5.16	0.45
	13–15	4.98	1.07	2.82	6.44	2.10	0.93	0.91	3.75	<0.001
	7–15	14.89	3.22	9.87	19.87	9.57	1.59	8.45	13.35	0.001
Maxillary skeletal base width	7–9 9–11 11–13 13–15 7–15	2.41 2.34 2.29 1.58 8.61	0.91 0.94 1.21 1.12 2.11	1.35 0.34 0.09 -0.51 5.96	3.97 3.77 3.74 2.98 12.51	1.74 1.24 1.39 1.15 5.52	0.63 0.93 1.20 1.53 1.79	1.04 -0.17 -0.77 -1.22 3.00	2.40 2.56 3.37 3.16 7.91	0.14 0.029 0.10 0.63 0.005
Nasal width	7–9	2.08	1.40	0.34	5.16	1.22	0.58	0.14	2.00	0.14
	9–11	1.33	0.64	0.00	2.61	1.14	0.38	0.49	1.56	0.69
	11–13	1.79	0.75	0.40	2.99	0.97	0.63	-0.14	1.80	0.037
	13–15	1.69	0.71	0.58	2.76	0.88	0.43	0.23	1.38	0.019
	7–15	6.89	1.79	4.37	10.30	4.21	0.91	2.86	5.80	0.002
Bigonial width	7–9	2.56	1.14	0.12	3.99	3.04	0.99	1.48	4.38	0.40
	9–11	3.49	1.05	1.48	5.46	3.16	0.66	2.08	3.95	0.31
	11–13	3.90	1.35	2.19	5.62	3.19	0.54	2.38	3.79	0.35
	13–15	4.19	1.48	1.33	6.09	1.68	1.37	-0.37	4.11	0.005
	7–15	14.14	2.79	8.37	17.26	11.06	2.05	7.69	13.62	0.023
Biantegonial width	7–9	2.65	1.34	0.87	4.72	2.99	0.68	2.26	3.99	0.51
	9–11	2.69	1.62	0.54	5.14	3.06	0.73	2.22	4.21	0.35
	11–13	2.42	1.19	0.61	4.98	2.06	0.86	1.10	3.58	0.51
	13–15	3.45	1.14	1.18	5.20	1.79	0.94	0.72	3.42	0.009
	7–15	11.22	2.44	5.78	13.95	9.90	1.44	8.28	12.38	0.083
Maxillary intermolar width	7–9 9–11 11–13 13–15 7–15	0.87 0.81 0.56 0.21 2.44	0.46 0.78 0.79 0.83 0.91	$0.50 \\ -0.75 \\ -0.60 \\ -1.37 \\ 0.31$	1.92 1.93 1.86 1.14 3.31	0.83 0.97 -0.11 -0.30 1.39	0.78 0.50 0.74 0.50 0.94	-0.16 0.07 -1.23 -1.28 0.50	1.92 1.51 1.04 0.13 3.08	0.79 0.69 0.12 0.23 0.046
Mandibular intermolar width	7–9 9–11 11–13 13–15 7–15	0.96 0.66 0.37 0.11 2.09	0.47 0.61 0.54 0.83 1.18	0.41 -0.61 -0.35 -1.34 0.22	1.73 1.26 1.12 1.43 3.64	$\begin{array}{c} 0.82 \\ 0.65 \\ -0.10 \\ -0.52 \\ 0.84 \end{array}$	0.74 0.48 0.89 0.57 1.50	0.08 0.09 -1.26 -1.67 -1.46	2.39 1.54 1.56 0.06 2.77	0.35 0.66 0.20 0.056 0.069

**Table 4** Descriptive statistics for the growth increments in the 2 year intervals and during 7–15 years of age (in mm); positive values indicate an increase, negative values indicate a decrease. *P*-values indicate gender differences.

SD, standard deviation.

With respect to the skeletal changes occurring with age in males, the increases in width were statistically significant at all 2 yearly intervals. With only a few exceptions, the same significant difference was found for the increases in skeletal widths in females. Among males, the maxillary and mandibular intermolar widths increased in a statistically significant manner between 7 and 9 and 9 and 11 years of age, but the growth changes were not significant between 11 and 13 and 13 and 15 years of age. Among females, a significant increase in both intermolar widths was found between 7 and 9 and 9 and 11 years of age. During 11–13 and 13–15 years of age, females did not show significant growth in the maxillary intermolar width. For the mandibular intermolar width, females demonstrated a slight, statistically insignificant decrease between 11 and 13 years of age, followed by a statistically significant decrease between 13 and 15 years of age.

The various anatomical regions differed concerning their growth pattern: for bizygomatic, mid-facial, bigonial and biantegonial widths, males seemed to be characterized by accelerated growth during the last time interval (13–15 years of age) which was not observed in the female group (Figure 4). This pattern was similar to the growth curves for standing height, where sexual dimorphism became apparent at 13 years of age. In contrast, for maxillary and mandibular intermolar widths, the increments were marked by a slight deceleration between 13 and 15 years of age in males. For females, the highest values were found at 11 years of age, with a subsequent slight decrease in width. Finally, the cranial width again showed different growth dynamics, where growth was rather linear in both sexes with comparatively small increments at all time intervals.

Figure 5 displays the increases in the eight skeletal variables during 7 and 15 years of age and, additionally, illustrates the incremental changes at the different topographical strata of the craniofacial skeleton. In males, the total transverse increases between 7 and 15 years of age ranged from 4 to 7 mm for cranial and bifrontotemporal widths, 7–9 mm for nasal and maxillary skeletal base widths, over 11–14 mm for bigonial and biantegonial widths to 15–17 mm for the mid-facial variables, i.e. mid-facial and bizygomatic widths. For males, the total increments in the intermolar widths (not depicted in Figure 5) were in the range of 2–3 mm. Smaller changes were found among females.

#### Percentile attainments of the transverse dimensions

The percentile attainments for the various transverse measurements are illustrated in Figure 6. They give insight into the remaining growth at the various stages when compared with the state at 15 years of age. The exact values are given in Table 3. The cranial width showed, at 7 years of age, percentile attainments of



**Figure 5** Illustration of the increases in the eight skeletal variables during the total observation period (7–15 years of age). For each dimension, the male value is given above the line and the female value is given below the line.



**Figure 6** Percentile attainments for the cranial and mid-facial dimensions (upper graph) and the maxillo-mandibular dimensions (lower graph) relative to the absolute size at 15.5 years of age in (a) males and (b) females.

97-98 per cent, indicating that growth was nearly complete at an early developmental stage. The growth potential found for the bifrontotemporal width was just slightly larger. A different growth behaviour with a greater remaining growth potential was found for midfacial, bizygomatic and skeletal maxillo-mandibular widths with percentile attainments at 7 years of age in the range of 84-87 per cent for males and 87-91 per cent for females. The nasal width showed the greatest remaining growth with only 80 per cent growth attained at 7 years of age in males and 86 per cent in females. Intermolar widths again showed a different pattern of growth; at 7 years of age, approximately 95 per cent (maxilla) or 96 per cent (mandible) in males and approximately 97 per cent (maxilla) or 98 per cent (mandible) of their size at 15 years of age in females had been attained.

## Discussion

## Depressed PA view—selection of landmarks

In the present study, radiographs taken in a modified PA projection, the so-called depressed PA view, were analysed. According to Adams (1962), this modified

projection permits good depiction of the bigonial width due to a view over the whole mandible, as well as the zygomatic arches. Additionally, the temporal line is clearly visible, allowing precise analysis of the bifrontotemporal width representing the smallest width of the forehead (Martin and Saller, 1957). However, the orbital structures are difficult to identify in this modified projection. In addition, bicondylar and bimastoidal widths were omitted in the present study due to uncertain landmark identification in the depressed PA view (Richardson, 1967).

# Transverse growth pattern of the various anatomical regions

In the present investigation, all transverse dimensions, with the exception of mandibular intermolar widths, increased progressively during the whole period of observation, which is in agreement with Athanasiou *et al.* (1992).

*Cranial width.* Snodell *et al.* (1993) found, for the cranial width, that at 6 years of age the cranium had reached 94–95 per cent of the width at 18 years of age, indicating that it followed the neural growth pattern. With the majority of growth completed by 6 years of age there is accordance with the results of the present study

which demonstrated, during an 8 year period, that the cranial width increased by 4.1 mm in males and 3.5 mm in females.

*Mid-facial/maxillary development.* Woods (1950) found that the bizygomatic width increased from 110.5 to 124.7 mm in males and from 107.8 to 120.6 mm in females between 7 and 15 years of age. Basyouni and Nanda (2000) described an increase of 15.9 mm for males and 15.2 mm for females between 7 and 15 years of age. The increases in the bizygomatic width between 7 and 15 years of age in the present study, i.e. 17.1 mm in males and 13.5 mm in females, correspond well with Woods (1950) and Basyouni and Nanda (2000).

As regards the maxillary skeletal base width, Basyouni and Nanda (2000) found an increase of 11.3 mm in males and 9.7 mm in females between 7 and 15 years of age. For boys and girls pooled together, Athanasiou et al. (1992) described an increase of 5.4 mm in the maxillary width between 7 and 15 years of age, similar to Cortella et al. (1997), who determined an increase of 5.3 mm. The total increases in the present study, 8.6 mm in males and 5.5 mm in females, are within these ranges. The maxillary sizes at 15 years of age in the present study of 63.8 mm in males and 58.5 mm in females are close to the corrected value of 59.1 mm reported by Cortella et al. (1997). Nevertheless, it should be kept in mind that this landmark, which is an intersection of two anatomical lines, may be located slightly differently in the depressed view. The gender differences for the maxillary skeletal base width are also consistent with the findings of Basyouni and Nanda (2000) and Wei (1970).

The transverse development of the mid-facial width, i.e. the distance between the zygomaxillary sutures, was investigated by Singh and Savara (1966) and Savara and Singh (1968). They found an increase of 7.8 mm from 81.5 to 89.3 mm for girls and an increase of 11.9 mm from 82.0 to 93.9 mm for boys between 7 and 15 years of age. Although larger total increases were found in the present study (14.9 mm in males and 9.6 mm in females), the corrected values for the mid-facial widths are of similar magnitudes.

*Mandibular development.* Woods (1950) reported an increase in the bigonial width between 7 and 15 years of age of 13.7 mm in males and 10.4 mm in females. In the study of Basyouni and Nanda (2000), for the same interval, the bigonial width increased 13.7 mm in males and 12.9 mm in females. Those increases are very similar to the results of the present study, where on average the bigonial width increased 14.1 mm in males and 11.1 mm in females. With respect to the size of the bigonial width, the male values are very close to the corrected values of Woods (1950), whereas the female values are 3–4 mm larger.

Athanasiou et al. (1992) found, between 7 and 15 years of age, an increase in the biantegonial width of 12.1 mm

and Cortella *et al.* (1997) determined an increase of 9.4 mm. Ricketts (1981) detected, at 8 years of age, a mean antegonial width of 75 mm, with a subsequent increase of 1.35 mm/year resulting in 88.5 mm at 18 years of age. The increases found in the present study, 11.2 mm in males and 9.9 mm in females, lie between those of Athanasiou *et al.* (1992) and Cortella *et al.* (1997), and correspond quite well with Ricketts' (1981) norm values and increments. When interpreting the results clinically, for analysis of the basal mandibular width, Ricketts (1981) favours the use of the biantegonial area is closer to the dentition and undistorted by muscle attachments.

Transverse development of the dental arches. For transverse development of the dental arches, the results of the present study were compared in a tabular form with those of previous investigations (Table 5). Growth changes instead of absolute arch widths were compared, because previous studies used different measurement points and different techniques, e.g. PA radiographs with or without magnification correction or dental casts. Nevertheless, the results are in keeping with the findings of most investigators and the review of Lee (1999), namely: (1) a larger increase in the intermolar width in the maxilla than in the mandible. (2) a larger increase in the intermolar width in males than in females, (3) a minimal increase or even decrease in the mandibular width between 11 and 15 years of age, especially in females. When interpreting these results, it should be considered that this relatively small increase in arch width may be in part due to mesial movement of the molars. This combined change in arch width as well as arch depth, which decreases over time, has been described in detail by DeKock (1972).

#### Percentile changes

Basyouni and Nanda (2000) also used percentile changes to compare the different relative rates of growth between the various transverse dimensions. They found that the bilateral orbitale width was the first transverse dimension to complete growth. This is in agreement with the present findings where the cranial parameters related to the neural growth pattern, i.e. cranial and bifrontotemporal widths, also showed, beside the intermolar widths, the highest percentile attainments at 7 years of age. In agreement with Basyouni and Nanda (2000), the bizygomatic width in the present study also demonstrated a slightly earlier completion of growth than the bigonial width. Finally, the large remaining growth potential of the nasal width is also in agreement with Snodell et al. (1993) and Basyouni and Nanda (2000).

Authors	Age*	Maxillary inte	ermolar width	Mandibular in	Mandibular intermolar width		
		Males	Females	Males	Females		
Woods, 1950	7–15	+2.56	+2.47	-0.59	-0.78		
DeKock, 1972	12–15	+1.20	-0.1	+0.6	+0.2		
Movers et al., 1976	7–15	+4.02	+3.07	+2.44	+1.35		
Sinclair and Little, 1983	9-13			+0.30	-0.41		
Athanasiou et al., 1992	7–15	+2	2.66	+0.	+0.74		
Snodell et al., 1993	6-18	+6.28	+2.0	+0.12	-0.38		
Bishara et al., 1997	8-13	+2.4	+2.0	+1.3	+0.9		
Present study	7–15	+2.44	+1.39	+2.09	+0.84		

**Table 5** Comparison of the increases in maxillary and mandibular intermolar widths in previous studies with the presentfindings (in mm).

\*Age periods in the cited investigations were selected with respect to the period 7-15 years in the present study.

## Limitations

Snodell *et al.* (1993) and Basyouni and Nanda (2000) demonstrated that for a number of craniofacial width dimensions, especially in males, growth of the craniofacial width continues past 15 years of age. However, due to the absence of radiographs beyond 15.5 years of age, it was not possible to include measurements beyond this age.

The small sample size must be taken into account. Although the Belfast Growth Study comprised the longitudinal records of 300 subjects, only 18 fulfilled the inclusion criteria of a Class I with good occlusion, which is similar to Kerr's (1979) study. Nevertheless, only subjects with a good occlusion were selected in the present study as previous investigations have shown that transverse development may be affected by the presence of a malocclusion such as an open bite (Hsu, 1998) or a Class II division 1 malocclusion (Staley *et al.*, 1985; Tollaro *et al.*, 1996).

#### Conclusions

Craniofacial widths were larger for males than females. At 7 years of age, gender differences were minimal. In contrast, at 15 years of age, for all variables, gender differences concerning craniofacial widths were more pronounced and statistically significant for bizygomatic, mid-facial, nasal, maxillary skeletal base and intermolar widths. Correspondingly, growth increments were larger in the male group, especially in the time interval of 13–15 years of age.

Anatomical regions differ concerning their respective transverse growth patterns. For bizygomatic, mid-facial, bigonial and biantegonial widths, males seem to show an acceleration in growth between 13 and 15 years of age not present in the female group. By contrast, for maxillary and mandibular intermolar widths, males exhibit a deceleration in the increases after 11 years of age and females show a stagnation or a slight decrease in intermolar width beyond 11 years of age. In general, there seems to be a greater increase in the intermolar width in the maxilla than in the mandible and a greater increase in males than in females. The cranial width again shows different growth dynamics, where growth is rather linear, with comparatively small increments at all time intervals.

The remaining growth potential of the various craniofacial regions differs greatly. For the cranial width, growth is nearly complete at an early developmental stage. For mid-facial, bizygomatic and skeletal maxillo-mandibular widths, percentile attainments in the range of 84–91 per cent suggest a greater remaining growth potential at 7 years of age. The nasal width shows the greatest remaining growth potential of all investigated dimensions. Intermolar widths show a different growth behaviour, where at 7 years of age more than 95 per cent of their size at 15 years of age has been attained. Orthodontists should be aware of these physiological limitations concerning the transverse development of the dental arches, notably after the eruption of the permanent canines and premolars beyond 11 years of age.

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#### Acknowledgement

We wish to express our thanks to the German Orthodontic Society (Deutsche Gesellschaft für Kieferorthopädie) for providing financial support for this project.

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