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Reference values for three-dimensional surface cephalometry in children aged 3–6 years

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Structured Abstract

Objective – This prospective cross-sectional study design was performed to define reference values for the facial surfaces of 3–6-year-old boys and girls using three-dimensional surface cephalometry.

Material and Methods – A total of 2290 standardized three-dimensional facial images from 3 to 6-year-old preschool children were separated by gender and assigned to four age categories. All children were Caucasian and revealed no evidence of dentofacial abnormalities. On each image, 31 cephalometric landmarks were marked, resulting in 35 (19 frontal, six lateral, 10 paired) distances and eight angles. Differences between age groups and genders were calculated and significances detected.

Results – A base table with reference values was compiled, which indicated that boys showed higher values than age-matched girls and that measured distances increased with age.

Conclusion – The mean values from this study could be compiled as a reference table for three-dimensional facial analysis in Caucasian children aged 3–6 years. Such a reference table could be used in comparative studies with other populations or children with craniofacial malformations.

Key words: 3–6-year-olds; imaging; morphometric

Introduction

Orthodontic treatment in the primary dentition is usually indicated in cases of pronounced skeletal dysgnathia, which has a tendency to progress. At initiation of therapy during primary dentition, history of the disease, extra- and intraoral symptoms as well as functional impairment and model analysis build the basis for a detailed therapy plan. In complex diagnostic cases, radiographic images can be helpful (1).

There are various reasons why few reference values exist for 3–6-year-olds (2). Examinations are more difficult to perform at this age because of lack of compliance (3). Also, there is a high degree of interindividual variation in this age group, and the growth pattern cannot be defined with certainty (4). Therefore, even in complex diagnostic cases of 3–6-year-olds, reliable imaging techniques are needed which show the craniofacial morphology without skeletal structures and thus do not need ionizing radiation. Additionally, these imaging techniques should be quick, exact and valid. Reference values should be up to date and need to do justice to variables such as age groups, genders and ethnic backgrounds (5–7). Reference values for children aged 3–6 years are needed to ensure that the progression of any abnormalities can be appropriately judged. Furthermore, any facial deformities and asymmetries should be analysed for their severity, thus making it possible to determine the correct time and scope for any surgical reconstructions that may be required (8).

Three-dimensional surface cephalometry offers a fast and accurate way of obtaining important data about craniofacial morphology (9). Its advantages over radiographic cephalometry include three-dimensional results, no exposure to radiation and ease of use. Moreover, it supplies accurate and valid results for a wide variety of potential applications (10). These advantages have the potential of largely eliminating the need for successive cephalograms, thereby reducing the doses of radiation to which young orthodontic patients will be exposed in the future.

With these considerations in mind, we designed a prospective cross-sectional study to determine facial reference values for children 3–6 years of age, broken down by gender. The data obtained were to be analysed for significant differences between boys and girls and between age groups.

Material and methods

3D stereophotogrammetric images of 2524 healthy children, aged 3–6 years, from 201 preschool facilities were taken with a three-dimensional digital system (faceSCAN II®; Breuckmann, Meersburg, Germany) during 2007 and 2008. Two digital cameras with standardized distances captured pictures simultaneously from two different angles at a resolution of 640 × 480 pixels within 0.8 s, the shutter time is 0.3 s. The root mean square accuracy of the faceSCAN II is 0.3 mm (± 0.2 mm). Data were transferred to a high-performance image processing system and reproduced as a textured three-dimensional image using an SQL-based client/server Windows application (OnyxCeph3™®; Image Instruments, Chemnitz, Germany).

All images of preschool children included were obtained under standardized conditions: The children were casually looking forward as the images were taken, with their ears uncovered and the lips closed in a relaxed way, involving no tenseness of the perioral muscles.

The study population covered a wide variety of social backgrounds. Children were included if they were between 3 and 6-years-old, had no history of orthodontic treatment, and were of Caucasian descent. Parental consent to participation in the study was another requirement. Exclusion criteria included any syndromes and resultant craniofacial malformations, previous tooth extractions or lack of compliance. Between 10 and 30 children were included on a daily basis.

Approval of the study protocol was obtained from the institutional ethics commission (project number 345/2005).

A total of 234 images were not evaluated either because of poor image quality or because the children were not Caucasian, showed poor oral health (previous extractions) or exhibited considerable functional abnormalities. The remaining 2290 children were grouped by age: 3-year-olds (3–3 years and 11 months), 4-year-olds (4–4 years and 11 months), 5-year-olds (5–5 years and 11 months) and 6-year-olds (6–6 years and 11 months). Table 1 shows the age and gender distribution.

Two experienced investigators marked 31 measuring points as defined by Farkas (11) and Hajeer et al. (12) on the three-dimensional images of the faces by using OnyxCeph3™® (Table 2). Thirteen of these points were located along the median/sagittal plane, while the other 18 points were paired configurations located symmetrically to the left and right of the facial centre. The reproducibility of these points was investigated in

Table 1. **Distribution of male and female individuals across age groups**

	Age			
Gender	3 years	4 years	5 years	6 years
Male	121	440	435	210
Female	107	383	416	178

a previous study (13). Consequently, because of bad reproducibility, the vertex landmark was excluded from analysis, because the hair at the vertex was responsible for the inaccurate analysis. Furthermore, Gonion landmark (GO) was constructed as the point where the line to the posterior border of the ramus intersects with the mandibular plane. All these points were used to calculate 35 (19 frontal, six lateral, 10 paired) distances and 8 angles (Table 3, Figs 1, 2, and 3).

Finally, the values obtained were compared and analysed for any statistically significant differences between the various age groups and both sexes.

Statistical analysis

The results were analysed with statistics software (JMP 8.0.1; SAS Institute Inc., Cary, NC, USA). The issue of reproducibility of the results, and hence the systematic error involved in the measuring points, was investigated in a previous study (13). The statistical measurement error (relative measurement error) was determined based on the standard deviation of the entire population, the mean absolute error of the mean value and the relative error of the mean value.

Intergroup comparisons were performed on the basis of mean values. The Shapiro–Wilk test was used to verify the presence of a normal distribution. Even though the vast majority of groups were found to exhibit a normal distribution, all groups were nevertheless analysed with the nonparametric Wilcoxon's test to ensure commonality of the statistical approach.

The level of significance was defined as $p < 0.05$. Any statistical significances thus found were additionally subjected to Bonferroni's correction at $p = 0.001$.

Results

Tables 4–8 summarize the mean values for measurements performed on boys and girls aged 3, 4, 5 and 6 years. All mean values are listed along with one standard deviation and their mean relative errors. The *p*-values listed indicate the presence or absence of statistically significant changes between the various age groups (listed separately for girls and boys) and statistically significant differences between genders.

All analyses showed unequivocally that the variables were influenced by age and sex. Boys would

Table 2. **Cephalometric landmarks**

Median Landmarks	Abbreviation	Paired Landmarks	Abbreviation
Trichion	TR	Eurion left + right	EUl + EUr
Glabella	GL	Exocanthion left + right	EXCl + EXCr
Nasion	N	Orbitale left + right	ORl + ORr
Pronasale	PRN	Endocanthion left + right	ENCl + ENCr
Tangent to Columella	COTG	Tragion left + right	Tl + Tr
Subnasale	SN	Zygion left + right	ZYGl + ZYGr
Superior labial sulcus	SLS	Alare left + right	ALl + ALr
Labrale superius	LS	Gonion left + right	GOl + GOr
Stomion	STO	Cheilion left + right	CHl + CHr
Labrale inferius	LI		
Inferior labial sulcus	ILS		
Pogonion	POG		
Menton	ME		

Table 3. **Cephalometric variables: 35 distances (19 frontal, six lateral, 10 paired) and eight angles**

Measurements	Definitions	Unit
Frontal measurements		
EU-EU	Head width	mm
T-T	Cranial base width	mm
ZYG-ZYG	Upper face width	mm
GO-GO	Lower face width	mm
ENC-ENC	Upper nose width	mm
EXC-EXC	Outer canthi distance	mm
AL-Al	Lower nose width	mm
CH-CH	Mouth width	mm
T-SN-T	Maxillary arch	mm
T-ME-T	Mandibular arch	mm
TR-N	Upper face length	mm
TR-ME	Total face length	mm
N-STO	Middle face length	mm
SN-ME	Lower face length	mm
STO-ME	Mandibular height	mm
N-SN	Nasal structure	mm
SN-STO	Upper lip length	mm
LS-STO	Upper lip width	mm
STO-LI	Upper lip thickness	mm
Lateral measurements		
LS-GLPOG	Distance upper lip to vertical profile line	mm
LI-GLPOG	Distance lower lip to vertical profile line	mm
LS-COTGPOG	Distance upper lip to Steiner's line	mm
LI-COTGPOG	Distance lower lip to Steiner's line	mm
LS-PRNPOG	Distance upper lip to aesthetic line	mm
LI-PRNPOG	Distance lower lip to aesthetic line	mm
Paired measurements		
T-N	Facial depth of right upper face	mm
T-N	Facial depth of left upper face	mm
T-SN	Facial depth of right middle face	mm
T-SN	Facial depth of left middle face	mm
T-ME	Facial depth of right lower face	mm
T-ME	Facial depth of left lower face	mm
EN-NME	Distance right eye to centre of face	mm
EN-NME	Distance left eye to centre of face	mm
CH-STO	Distance right corner to centre of mouth	mm
CH-STO	Distance left corner to centre of mouth	mm
Angles		
COTG-SN to SN-LS	Nasolabial angle	°
GL-N to N-PRN	Frontonasal angle	°
N-PRN to COTG-SN	Nose tip angle	°
SLS-LS to ILS-LI	Interlabial angle	°
GL-SN to SN-POG	Total face angle	°
LS-GL to GL-POG	Upper lip angle	°
LI-GL to GL-POG	Lower lip angle	°
LI-ILS to ILS-POG	Labiomental angle	°

Fig. 1. Reference points for the 35 (19 frontal, six lateral, 10 paired) distances and 8 angles measured.

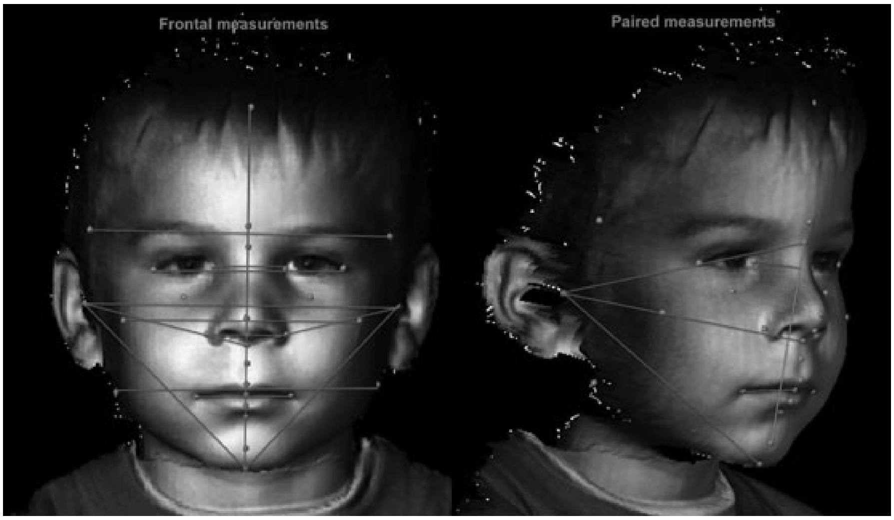

Fig. 2. Frontal measurements and paired measurements.

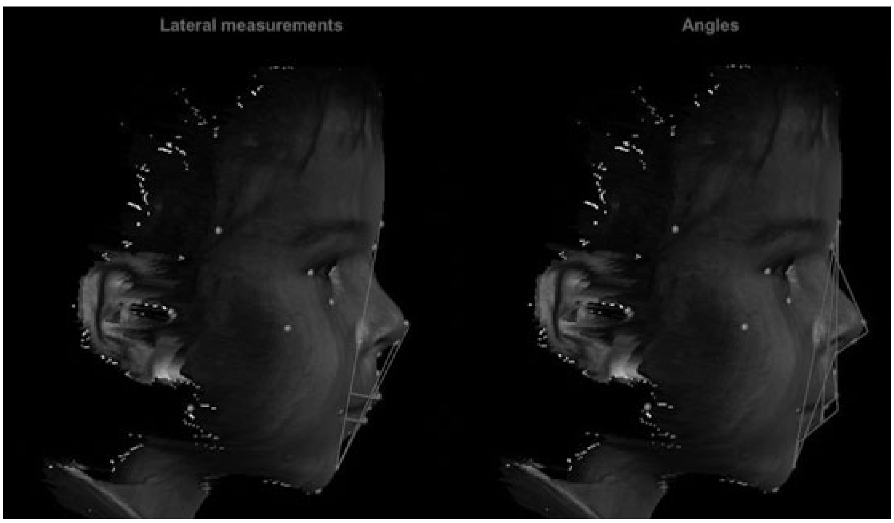

Fig. 3. Lateral measurements and angles.

usually show higher values than age-matched girls, and the measured distances increased with age.

Parameters for the mouth (Table 4) showed that the upper and lower lips of boys were located more anterior relative to the vertical profile line (LS/LI-GLPOG) compared with girls. This difference was significant in some age groups. Relative to the Steiner‘s line (LS/LI-COTGPOG)

Table 4. **Mean values (MV), standard deviation (SD) and relative error (relE) for all measurements of the mouth divided into age and gender**

Mouth												
Female							Male					
Age	Pa	MV	± SD	relE	n	Pg	Age	Pa	MV	± SD	relE	n
Distance upper lip to vertical profile line (LS-GLPOG)												
3		7.4	2.0	0.027	107		3		8.0	2.2	0.024	119
4		7.4	2.2	0.015	381	*	4		8.0	2.2	0.013	440
5		7.5	2.1	0.014	415		5		7.9	2.4	0.015	435
6		7.3	2.4	0.025	176	*	6		8.3	2.4	0.020	210
Distance lower lip to vertical profile line (LI-GLPOG)												
3		4.3	1.9	0.042	107		3		4.8	1.9	0.037	120
4		4.2	1.8	0.022	382	*	4		4.7	1.8	0.018	440
5		4.2	1.8	0.021	415	*	5		4.7	2.0	0.021	435
6		3.9	1.9	0.035	176	*	6		4.8	2.2	0.031	210
Distance upper lip to Steiner's line (LS-COTGPOG)												
3		1.5	1.0	0.064	107		3		1.6	1.1	0.061	119
4		1.6	1.0	0.032	383		4		1.7	1.0	0.029	438
5	*	1.5	1.0	0.032	415		5		1.6	1.1	0.032	435
6	*	1.8	1.1	0.048	178		6		1.7	1.1	0.044	210
Distance lower lip to Steiner's line (LI-COTGPOG)												
3		1.8	1.0	0.056	107		3		1.6	1.0	0.060	118
4		1.7	1.1	0.033	382		4		1.7	1.1	0.031	438
5	*	1.8	1.1	0.031	415		5		1.9	1.3	0.033	435
6	*	2.1	1.4	0.050	178		6		1.9	1.3	0.047	210
Distance upper lip to aesthetic line (LS-PRNPOG)												
3		1.5	1.0	0.062	107		3		1.5	1.0	0.059	119
4		1.6	1.1	0.034	383		4		1.7	1.1	0.030	438
5	*	1.7	1.1	0.032	415		5		1.7	1.2	0.032	435
6	*	2.1	1.4	0.050	178		6		1.8	1.2	0.047	210
Distance lower lip to aesthetic line (LI-PRNPOG)												
3		1.9	1.1	0.059	107		3		1.7	1.0	0.056	118
4		1.8	1.1	0.032	383		4		1.8	1.2	0.031	438
5	*	2.0	1.2	0.030	415		5		2.0	1.4	0.033	435
6	*	2.4	1.5	0.048	178		6		2.1	1.4	0.047	210
Mouth width (CHr-CHl)												
3		35.1	3.5	0.010	107		3		35.9	3.9	0.010	121
4	*	36.0	3.8	0.005	382		4		36.6	3.7	0.005	440
5	*	37.0	3.9	0.005	416		5		37.4	3.8	0.005	435
6		37.7	3.9	0.008	178		6		38.2	4.1	0.007	209
Upper lip thickness (LS-STO)												
3		5.5	1.4	0.025	107		3		5.6	1.4	0.023	119
4		5.5	1.3	0.012	382		4		5.7	1.4	0.012	439
5		5.6	1.3	0.011	416		5		5.8	1.4	0.012	435
6		5.8	1.4	0.018	178		6		5.9	1.4	0.016	210

***Table 4.* Continued.**

Mouth												
Female							Male					
Age	Pa	MV	± SD	relE	n	Pg	Age	Pa	MV	± SD	relE	n
Lower lip thickness (STO-LI)												
3		5.1	1.4	0.027	107		3		5.2	1.2	0.022	119
4		5.1	1.2	0.012	381	*	4		5.4	1.4	0.013	439
5		5.3	1.3	0.012	416		5		5.5	1.4	0.012	435
6		5.3	1.5	0.021	178		6		5.5	1.3	0.016	210
Distance right corner to centre of mouth (CHr-STO)												
3		19.0	2.2	0.011	107		3		19.4	2.5	0.012	119
4	*	19.4	2.4	0.006	381		4	*	19.7	2.3	0.006	438
5	*	20.1	2.5	0.006	416		5	*	20.3	2.3	0.005	435
6		20.5	2.4	0.009	178		6		20.6	2.5	0.008	209
Distance left corner to centre of mouth (CHl-STO)												
3		19.1	2.2	0.011	107		3		19.6	2.5	0.012	119
4		19.8	2.4	0.006	381		4		20.0	2.4	0.006	438
5		20.1	2.4	0.006	416		5		20.4	2.6	0.006	435
6		20.6	2.6	0.009	178		6		21.0	2.7	0.009	209
Interlabial angle (SLS-LS-LI-ILS)												
3		130.3	17.6	0.013	107		3		130.7	16.3	0.011	120
4		133.7	16.2	0.006	381		4		131.6	16.9	0.006	440
5		136.6	15.6	0.006	416	*	5		132.6	17.0	0.006	435
6		138.7	16.0	0.009	178		6		134.9	16.6	0.009	210
Upper lip angle (LS-GL-POG)												
3		7.5	2.2	0.029	107		3	7.8	2.1	0.024	120	
4		7.2	2.1	0.015	382		4	7.5	2.1	0.013	440	
5		7.1	2.0	0.014	415		5	7.2	2.2	0.015	435	
6		6.7	2.2	0.025	176	*	6	7.4	2.1	0.020	210	
Lower lip angle (LI-GL-POG)												
3		3.7	1.6	0.042	107		3		4.0	1.6	0.037	120
4		3.5	1.5	0.021	382	*	4		3.9	1.5	0.018	440
5		3.5	1.5	0.021	415		5		3.7	1.6	0.021	435
6		3.1	1.5	0.035	176	*	6		3.7	1.6	0.030	210
Labiomental angle (LI-ILS-POG)												
3		148.0	12.8	0.008	107		3		147.7	13.0	0.008	120
4		148.6	13.3	0.005	383		4		148.1	12.9	0.004	440
5		150.7	12.6	0.004	416	*	5		147.7	12.3	0.004	435
6		151.2	11.8	0.006	178		6		150.3	13.7	0.006	210

Significant differences (*, Pa < 0.05) between the age groups shown separately for girls and boys. The central column indicates significant differences (*****, Pg < 0.05) between boys and girls for the respective age groups.

and aesthetic line (LS/LI-PRNPOG), only the group of 5- and 6-year-old girls showed significant differences. The 6-year-old girls showed more protrusive lip profiles than the 5-year-olds.

Mouth width (CHr-CHl), distance right and left corner to centre of mouth (CHr/CHl-STO) and upper and lower lip thicknesses (LS/LI-STO) enlarged with increasing age where this increase

Table 5. **Mean values (MV), standard deviation (SD) and relative error (relE) for all measurements of the head divided into age and gender**

Head												
Female							Male					
Age	Pa	MV	± SD	relE	n	Pg	Age	Pa	MV	± SD	relE	n
Head width (EUr-EUl)												
3		119.5	12.2	0.010	93		3		119.7	±11.6	0.009	111
4		118.4	13.1	0.006	334	*	4	*	120.8	12.1	0.005	411
5		119.6	12.7	0.005	338	*	5	*	122.6	12.7	0.005	405
6		118.7	13.0	0.008	147		6		118.9	11.0	0.006	184
Cranial base width (Tr-Tl)												
3		125.9	5.0	0.004	17		3		129.4	5.4	0.004	32
4		127.0	4.1	0.002	95	*	4		128.3	11.5	0.004	103
5		128.2	4.3	0.002	99	*	5		131.8	5.2	0.002	133
6		130.2	4.8	0.003	37		6		132.5	5.2	0.003	75

Significant differences (*, Pa < 0.05) between the age groups shown separately for girls and boys. The central column indicates significant differences (*, Pg < 0.05) between boys and girls for the respective age groups.

was only significant between age groups. Overall for these parameters, boys showed greater values than girls with significant differences for the lower lip thickness (LI-STO) between 4-year-old boys and girls.

The angles for the oral region revealed significant differences between 5-year-old boys and girls for the interlabial angle (SLS-LS-LI-ILS) and the labiomental angle (LI-ILS-POG). Furthermore, there was a significant difference for the upper lip angle (LS-GL-POG) between 6-year-old boys and girls and for the lower lip angle (LI-GL-POG) between the 4- and 6-year-olds.

Parameters raised for the head (EUr-EUl, Tr-Tl) (Table 5) showed that boys of all age groups had greater mean values than girls. This difference was significant between the 4- and 5-year-olds.

Also the parameters for the face (Table 6) revealed some significant differences: the 3-, 4- and 5-year-old boys showed significantly greater mean values for the lower and upper jaws (Tr-SN-Tl, Tr-ME-Tl) than the age-matched girls, and the 5-year-old boys and girls had significantly greater values for these parameters than the 4-year-olds. Furthermore, 6-year-old girls showed greater values for both jaws than 5-year-olds.

The measurement of the single halves of the face (Tr-N, Tl-N, Tr-SN, Tl-SN, Tr-Me, Tl-ME) revealed that boys always had significantly greater values than the girls, except for the group of 6-year-olds, where the differences for the left upper, middle and lower face (Tl-N, Tl-SN, Tl-ME) were not significant. In general, the values of the single halves of the face increased annually in both gender groups.

Boys showed significantly greater values for the middle face length (N-STO) than girls. Furthermore, this mean value increased significantly every year in both gender groups. Also for the lower face length and height (STO-ME, SN-ME), boys had greater mean values than girls. For both gender groups, face length and height (STO-ME, SN-ME) increased with age: girls revealed significant differences between the 3- and 4-year-olds and between the 4- and 5-year-olds, boys between the 4- and 5-year-olds and between the 5- and 6-year-olds. The values of the total face length (TR-ME) for 4- and 5-year-old boys were significantly greater than the values for age-matched girls. This parameter increased yearly in all gender groups with a significant difference between 4- and 5- and 5- and 6-year-old girls and a significant difference between 4- and 5-year-old boys.

Parameters raised for the eyes (ENCr-ENCl, EXCr-EXCl, ENCr-NME, ENCl-NME) (Table 7)

***Table 6.* Mean values (MV), standard deviation (SD) and relative error (relE) for all measurements of the face divided into age and gender**

Face												
Female							Male					
Age	Pa	MV	± SD	relE	n	Pg	Age	Pa	MV	± SD	relE	n
Upper face width (ZYGr-ZYGl)												
3		87.3	10.0	0.011	101		3		87.9	9.1	0.009	121
4		88.8	8.5	0.005	370		4		90.5	10.6	0.006	416
5		89.7	8.6	0.005	398		5		90.7	8.3	0.004	425
6		90.4	8.6	0.007	175		6		91.9	8.5	0.006	204
Lower face width (GOr-GOl)												
3		94.2	7.0	0.007	6		3		99.4	6.0	0.005	8
4		99.6	9.1	0.005	26		4		99.9	9.7	0.005	31
5		102.9	9.1	0.004	22		5		101.4	9.0	0.004	34
6		101.0	5.8	0.004	9		6		100.0	8.9	0.006	11
Maxillary arch (Tr-SN-Tl)												
3		202.7	9.9	0.005	17	*	3		211.8	9.5	0.004	32
4	*	205.6	10.7	0.003	95	*	4	*	211.4	8.5	0.002	104
5	*	209.8	9.8	0.002	99	*	5	*	216.7	8.6	0.002	133
6	*	215.0	9.5	0.003	37		6		217.6	8.7	0.003	75
Mandibular arch (Tr-ME-Tl)												
3		214.4	11.8	0.005	17	*	3		222.2	12.4	0.005	32
4	*	217.0	11.1	0.003	95	*	4	*	221.6	10.2	0.002	104
5	*	222.1	9.7	0.002	99	*	5	*	228.4	9.9	0.002	133
6	*	229.3	10.0	0.003	37		6		231.5	10.4	0.003	75
Facial depth of right upper face (Tr-N)												
3		98.2	4.3	0.004	49	*	3		102.7	4.8	0.004	60
4	*	98.6	5.6	0.003	202	*	4	*	102.2	5.7	0.003	241
5	*	101.7	4.3	0.002	233	*	5	*	105.0	4.5	0.002	254
6		102.7	4.3	0.003	96	*	6		105.4	4.3	0.003	126
Facial depth of left upper face (Tl-N)												
3		100.1	4.6	0.004	27	*	3		104.1	5.0	0.004	56
4		101.7	5.2	0.003	149	*	4	*	104.5	4.9	0.002	165
5	*	102.7	5.2	0.002	157	*	5	*	106.2	4.4	0.002	184
6	*	105.9	5.3	0.004	62		6		107.5	4.8	0.003	107
Facial depth of right middle face (Tr-SN)												
3		100.1	5.3	0.005	48	*	3		104.6	5.1	0.004	60
4	*	100.8	5.4	0.003	201	*	4	*	104.4	6.3	0.003	240
5	*	104.1	4.7	0.002	233	*	5	*	107.3	4.8	0.002	254
6		105.5	4.7	0.003	96	*	6		107.8	4.1	0.003	126
Facial depth of left middle face (Tl-SN)												
3		102.4	5.1	0.005	27	*	3		106.4	5.9	0.005	56
4		104.4	6.0	0.003	149	*	4	*	107.2	5.2	0.002	165
5	*	105.5	6.1	0.003	157	*	5	*	109.1	4.7	0.002	184
6	*	109.3	5.9	0.004	62		6	*	110.7	5.1	0.003	107

***Table 6.* Continued**

Face												
Female							Male					
Age	Pa	MV	± SD	relE	n	Pg	Age	Pa	MV	± SD	relE	n
Facial depth of right lower face (Tr-ME)												
3		106.0	8.1	0.007	48	*	3		109.8	6.3	0.005	60
4	*	107.5	5.9	0.003	201	*	4	*	110.5	7.5	0.003	239
5	*	110.6	5.2	0.002	233	*	5	*	113.5	5.5	0.002	253
6	*	112.8	5.0	0.003	95	*	6		114.9	4.6	0.003	125
Facial depth of left lower face (Tl-ME)												
3		108.0	5.5	0.005	27	*	3		111.6	6.7	0.005	56
4		110.1	6.5	0.003	147	*	4	*	112.3	6.0	0.003	167
5	*	111.8	6.6	0.003	157	*	5	*	115.0	5.4	0.002	184
6	*	115.8	6.5	0.004	62		6	*	117.6	6.2	0.004	107
Upper face length (TR-N)												
3		68.0	8.1	0.012	85		3		67.0	10.1	0.014	79
4		65.5	8.7	0.007	292		4		66.8	9.8	0.007	276
5		65.9	8.3	0.006	332		5		66.7	9.6	0.007	272
6		67.5	8.5	0.009	130		6		65.8	8.3	0.009	112
Total face length (TR-ME)												
3		150.4	7.3	0.005	84		3		9.7	0.006	75	
4	*	150.8	8.5	0.003	287	*	4	*	9.2	0.003	272	
5	*	153.7	8.5	0.003	331	*	5	*	9.5	0.003	269	
6	*	156.9	8.4	0.004	129		6		8.4	0.004	112	
Middle face length (N-STO)												
3	*	51.1	3.5	0.007	107	*	3	*	3.9	0.007	119	
4	*	52.8	3.7	0.004	382	*	4	*	3.7	0.003	439	
5	*	54.5	4.0	0.004	416	*	5	*	3.8	0.003	435	
6	*	55.9	3.7	0.005	178	*	6	*	4.3	0.005	210	
Lower face height (SN-ME)												
3	*	53.3	3.6	0.006	106	*	3		55.8	4.5	0.007	117
4	*	54.6	4.3	0.004	376	*	4	*	56.0	3.9	0.003	435
5	*	55.7	4.0	0.004	415	*	5	*	57.2	3.9	0.003	432
6		56.1	4.2	0.006	177	*	6	*	58.3	4.3	0.005	209
Lower face length (STO-ME)												
3	*	35.5	2.9	0.008	106	*	3	*	37.6	3.8	0.009	116
4	*	36.5	3.5	0.005	377	*	4	*	37.3	3.4	0.004	435
5	*	37.3	3.3	0.004	415	*	5	*	38.0	3.3	0.004	432
6	*	37.5	3.5	0.007	177	*	6	*	39.0	3.5	0.006	209
Total face angle (GL-SN-POG)												
3		162.8	5.5	0.003	107		3		162.3	5.1	0.003	121
4		162.3	5.3	0.002	380		4		161.5	5.1	0.001	439
5		161.8	5.2	0.002	415		5		161.6	5.4	0.002	435
6		161.7	5.1	0.002	176		6		161.0	5.0	0.002	210

Significant differences (*, Pa < 0.05) between the age groups shown separately for girls and boys. The central column indicates significant differences (*, Pg < 0.05) between boys and girls for the respective age groups.

Table 7. **Mean values (MV), standard deviation (SD) and relative error (relE) for all measurements of the eyes divided into age and gender**

Eyes												
Female							Male					
Age	Pa	MV	± SD	relE	n	Pg	Age	Pa	MV	± SD	relE	n
Internal eye distance = upper nose width (ENCr-ENCl)												
3		30.1	1.9	0.006	105		3	*	30.4	2.3	0.007	120
4	*	30.5	2.3	0.004	380	*	4	*	31.2	2.3	0.004	438
5	*	31.0	2.4	0.004	414	*	5		31.5	2.3	0.004	433
6		31.4	2.3	0.006	175		6		31.7	2.4	0.005	209
Outer canthi distance (EXCr-EXCl)												
3	*	80.1	3.8	0.005	104	*	3	*	82.3	4.4	0.005	119
4	*	81.5	4.0	0.003	381	*	4	*	83.5	3.9	0.002	434
5	*	82.7	4.0	0.002	411	*	5	*	84.5	4.0	0.002	430
6	*	83.8	4.4	0.004	175	*	6		84.9	4.1	0.003	209
Distance right eye to centre of face (ENCr-NME)												
3		18.2	1.7	0.009	106		3	*	18.2	2.0	0.010	116
4	*	18.3	1.8	0.005	376	*	4	*	19.0	1.9	0.005	435
5	*	18.8	1.8	0.005	413	*	5		19.2	2.0	0.005	431
6		19.2	1.8	0.007	175		6		19.4	1.9	0.007	208
Distance left eye to centre of face (ENCl-NME)												
3	*	18.5	1.7	0.009	105	*	3		19.1	2.0	0.010	116
4	*	19.0	1.8	0.005	377	*	4	*	19.5	1.8	0.004	435
5	*	19.5	1.9	0.005	414	*	5	*	19.9	1.8	0.004	430
6		19.9	1.9	0.007	174		6		20.2	2.1	0.007	208

Significant differences (*, Pa < 0.05) between the age groups shown separately for girls and boys. The central column indicates significant differences (*, Pg < 0.05) between boys and girls for the respective age groups.

also showed significant differences between age and gender groups. Overall, it was obvious that the internal eye (ENCr-ENCl) and the outer canthi (EXCr-EXCl) distance increased with every year, and boys revealed greater mean values than girls.

Also in the region of the nose (Table 8), there were some significant differences: The nasal structure (N-SN) and the lower nose width (ALr-ALl) showed greater mean values for all boy groups of all ages compared with age-matched girls with the exception of 6-year-old boys. The nasal structure (N-SN) increased significantly every year in both genders. The lower nose width (ALr-ALl) only increased significantly from 4 to 5- and from 5- to 6-year-old girls.

The frontonasal (GL-N-PRN) angle revealed significant greater values for 3-year-old boys than for 3-year-old girls. This parameter increased yearly in both gender groups; thus, girls showed significant differences between 3- and 4- and 4- and 5-year-olds and boys showed significant differences between 4- and 5-year-olds.

Discussion

This study showed that boys showed higher values than age-matched girls and that measured distances increased with age. Significant alterations occurred in both sexes, predominantly in the area of the middle and lower face. The largest increases were seen in boys from age 4 to 5 and in girls both from age 4 to 5 and from age 5 to 6.

Table 8. **Mean values (MV), standard deviation (SD) and relative error (relE) for all measurements of the nose divided into age and gender**

Nose												
Female							Male					
Age	Pa	MV	± SD	relE	n	Pg	Age	Pa	MV	± SD	relE	n
Nasolabial angle (COTG-SN-LS)												
3		124.5	9.4	0.007	107		3		123.8	7.7	0.006	120
4		124.6	10.4	0.004	378		4		125.1	8.0	0.003	439
5		126.4	7.8	0.003	415		5		125.6	8.2	0.003	435
6		126.9	7.9	0.005	178		6		125.5	8.7	0.005	210
Frontonasal angle (GL-N-PRN)												
3	*	138.1	6.2	0.004	107	*	3		140.1	6.0	0.004	121
4	*	140.7	6.2	0.002	381		4	*	141.1	6.3	0.002	440
5	*	142.3	6.2	0.002	415		5	*	142.3	5.9	0.002	435
6		143.1	5.9	0.003	176		6		142.5	6.3	0.003	210
Nose tip angle (N-PRN-COTG-SN)												
3		96.9	6.5	0.006	107		3		97.2	6.4	0.006	121
4		96.6	5.9	0.003	381		4		96.4	6.1	0.003	439
5		96.9	5.9	0.003	415		5		96.3	5.9	0.003	435
6		95.9	5.6	0.004	178		6		95.6	6.3	0.005	210
Lower nose width (ALr-ALl)												
3		29.2	2.2	0.007	107	*	3		30.1	2.1	0.006	120
4	*	29.7	2.1	0.004	381	*	4		30.5	2.1	0.003	438
5	*	30.2	2.2	0.004	414	*	5		30.9	2.3	0.004	435
6	*	30.7	2.3	0.006	177		6		31.3	2.4	0.005	209
Nasal structure (N-SN)												
3	*	33.7	3.4	0.010	107	*	3	*	3.6	0.009	121	
4	*	35.3	3.2	0.005	381	*	4	*	3.5	0.005	439	
5	*	36.7	3.7	0.005	416	*	5	*	3.6	0.005	435	
6	*	38.1	3.6	0.007	178		6	*	4.1	0.007	210	

Significant differences (*, Pa < 0.05) between the age groups shown separately for girls and boys. The central column indicates significant differences (*, Pg < 0.05) between boys and girls for the respective age groups.

All measurements were collected as part of a prospective cross-sectional study. Advantages over longitudinal designs include fewer investigators, smaller intervals between measurements, and less time required for the study overall, which enhances quality and reduces costs. What is more, executing any longitudinal study design over several years is rendered next to impossible by the rapidly changing technologies used for computer-assisted recording.

In his 1996 guidelines for precise anthropometric measurements, Farkas (14) demanded that reference values should be defined on the basis of sufficiently large samples of volunteers and that all ethnic groups and different social backgrounds should be represented. Well-trained examiners should use sophisticated measurement tools and work with cooperative patients. All measurements should be performed by the same examiner and preferably, the measurements should be checked by another examiner. Finally, any standard values thus obtained should not be used for more than 20 years.

All these requirements were met in the present study. The points of measurements were investigated for reproducibility in a previous study (13).

It was found that the variability of seven points (right/left eurion, right/left gonion, right/left zygonion, trichion) was > 1 mm. In other words, these points were not shown to offer good reproducibility. This was mainly due to the reason that these points define soft tissues without corners or protrusions, which does not facilitate to determine defined positions. Furthermore, the decreased reproducibility of the point Trichion is based on the fact that the hair line is often covered by the hair itself, thus hiding the exact localization. Additionally, it has to be mentioned that the system (faceSCAN II®; Breuckmann, Meersburg, Germany) covers an area of 170°, leading to scanning of part of the head. Areas behind the ear lobe were missing completely and border areas were not always completely scanned. Therefore, the points GOr/GOl but also Tr/Tl could not always be marked reliably. Besides, image quality was not excellent: there were empty spaces in the area around the hair and ears which made locating the landmarks in that region difficult. These facts reduced the quality of calculated mean values generated from the points mentioned above.

However, because our study included a total of 2290 individuals, the relative error of the mean value was considerably smaller than 1 even for the seven points mentioned above (save a few exceptions in the group of 3-year-olds, which was the smallest group). Thus, to our opinion, even the quality of the mean value of the points known to offer less-than-ideal reproducibility is at least acceptable. Newer 3D imaging techniques will result in an even better quality of the image surfaces, and the investigator's spatial ability to accurately determine the landmarks will probably not be impaired any more.

As noted above, hardly any reports dealing with standard values in Caucasian children 3–6-years-old have been published. Because radiographic cephalometry of 3–6-year-olds results in only reduced information and exposure of the individuals to ionizing radiation (15, 16), for these age groups, reference values are needed that are generated without this exposure to ionizing radiation. Three-dimensional surface imaging appears to be an appropriate method to gather information on craniofacial morphology, especially in children (10). Nevertheless, this method only regards soft tissue measurements, and it remains to be seen whether facial analysis allows conclusions about sub-surface skeletal structures as well as antero-posterior and vertical malocclusions. Because of thickness variation of soft tissues, the relation between soft tissue lines and skeletal structures is not linear (17, 18). However, there are publications indicating a direct relationship between these two structures thus allowing the conclusion that soft tissues do indeed give an indication of underlying skeletal and dental anomalies (19–21).

Our own results can be compared with only a few studies in the literature. Farkas et al. (3, 22–24), Ferrario et al. (25) and Mori et al. (26) performed investigations with objectives similar to our study. Overall, the mean values found in all three of these studies were comparable to those found in our study, but Ferrario et al. and Mori et al. did not investigate individuals of 4 years or younger. All three studies concerned much smaller study populations than in our study. The determination of the absolute and relative error of the mean in addition to the standard deviation shows that the number of measurements has a crucial importance for the quality of the mean. The size of the measurement error is inversely dependent on the number of measurements, the larger the number of measurements, the smaller the measurement error and the higher the quality of the mean.

Furthermore, previously published studies investigated different ethnic groups. While the most comprehensive study by Farkas et al. did not use three-dimensional imaging because of historical reasons, the other two studies already employed this recent technique. So far, to our knowledge, our study provides the most comprehensive three-dimensional data on facial soft tissue structures of 3–6-year-old Caucasian children.

Conclusion

The mean values can be used as reference values for three-dimensional facial analysis in Caucasian children aged 3–6 years. These values can serve as reference for further studies, for example, into age-matched children with craniofacial anomalies.

Clinical relevance

Radiographic images for orthodontic diagnosis in 3–6-year-old children usually are contra-indicated and reference values for this age group from large data bases are rare. Three-dimensional surface imaging could provide reference values without radiation. Data from the present study could be compiled as a reference table for three-dimensional facial analysis in Caucasian children aged 3–6 years. These values can be used as reference, for example, for studies into other populations or into children with craniofacial malformations.

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