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Research Paper
Imaging

The average three-dimensional face for different sex and age groups in a Dutch population

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Abstract. The increasing use of three-dimensional imaging calls for reference models representing large parts of the population. The aim of this prospective study was to create templates depicting facial maturation in the younger age groups. Healthy Dutch volunteers were captured, without selection of inclusions. Three-dimensional average faces were created using MATLAB, for both genders in four age groups (4–8 years, 8–12 years, 12–16 years, and ≥16 years). Variation within the groups was calculated and depicted on an average face with a green to red colour scale, corresponding to standard deviations between 0 and ≥ 3 mm, respectively. Measurements of the distances of eight perioral landmarks were provided as ratios. The statistical analysis was performed using ANOVA and Tukey's test. Three-dimensional reconstructions of the average face and their first principal component were created for each gender and age group. The first principal component comprised the facial width for each group, and the variation of landmarks was low. All ratios showed an increasing trend with increasing age, except for the ratio of philtrum width to mouth width. This study is novel in comparing facial morphology by means of ratios and in creating average faces for the different young age groups. These data provide useful insights into facial maturation, which might be beneficial for facial surgeons.

Keywords: Reference standards; Face; Three-dimensional imaging; Principal component analysis; Age groups.

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In facial surgery, one should strive for an aesthetically pleasing outcome, but the specific features that make a face attractive are still debated. The Fibonacci ratio, also commonly referred to as 'the golden ratio', is used to describe the ideal proportions of a face: dividing it into fifths horizontally and thirds vertically.[1] Several studies, however, have observed three candidates for biology-based preference: symmetry, sexual dimorphism, and averageness.[2] Although highly attractive faces are not average,[3] 'new' golden ratios match those of an average face.[4] To realize an aesthetically pleasing outcome, features of attractiveness should be taken into account during preoperative planning. In unilateral facial surgery, the other side of the face can be used as a guide to achieve symmetry. In bilateral facial surgery, for instance a Le Fort I osteotomy, this guidance is not provided and the surgeon must rely on their own experience to obtain an aesthetic surgical outcome. For these surgical procedures, reference models with data on sexual dimorphism and averageness could be useful.

As clinical appearance is usually difficult to describe in words, pictures and photographs are convenient tools. Three-dimensional (3D) imaging would be particularly suitable, since it provides more consistent measurements than two-dimensional (2D) imaging,[5] and has the advantage of measuring soft tissue volumetric data and surface topography.[6,7] Three-dimensional techniques have also enabled the creation of 3D reconstructions of average faces for different gender and age groups.[8–12] A study by Lambros[9] made visual 3D reconstructions of the ageing face and its alterations. Although the significant differences between genders and the changes in facial morphology during ageing have been researched extensively, data on the maturation of the face for younger age groups are limited. A study by Ferrario et al.[13] gathered data from over 2000 children aged 6 years and older. Three-dimensional measurements were compared between boys and girls, but maturation or age-dependent growth was not investigated, nor was a visual representation of 3D faces created.

Three-dimensional surface imaging is now ubiquitous in the domain of facial reconstruction, for example in maxillofacial surgery,[14,15] plastic surgery,[16] and orthodontics.[17] This calls for reference models representing large parts of the population of a hospital's catchment area. It appears that there are as yet no templates of average faces for the younger age groups. The aim of this study was to create templates of average faces for different age groups, and to depict the alterations in facial morphology during growth. These templates could be used as comparison material, as well as in the development of guidelines to enhance the aesthetic outcomes of facial surgery according to the age of the patient.

Materials and methods

Population

Approval for this prospective study was provided by the Medical Ethics Review Committee (METC) UMC Utrecht (study number 14/652). Between December 2016 and January 2017, 3D images of healthy Dutch individuals visiting the University Museum Utrecht were captured with the two pod 3dMD system (3dMDface; 3dMD, Atlanta, GA, USA). All visitors were invited to participate, without using inclusion criteria, and all visitors who wished to participate were enrolled. Informed consent was obtained from all participants, as well as the parents or guardians of those aged < 16 years. Each subject was captured in the neutral face condition. The 3dMD system was placed in a windowless room used for daily clinical 3D imaging, illuminated with 100% LED lighting. The subjects were grouped into age categories of 4 years. Due to the small number of participants in the 16–20 years age group (six female, one male), it was decided to combine the older groups into one adult group, age ≥ 16 years. This resulted in the following age groups: 4–8 years, 8–12 years, 12–16 years, and ≥ 16 years. A separate average face was created for each age category and gender, defining eight groups in total.

Analyses

Four analyses were performed for each group. First, all faces in a group were combined to create a template of the average face. Second, principal component analysis (PCA) was performed, analysing the most common variable in a group. This was depicted as a linear function. Third, for all faces, the absolute distance of the paired landmark between each subject's original face and the averaged face was measured in millimetres (mm), and the standard deviation (SD) was calculated. The SDs of each landmark were depicted on the average face using a green to red colour scale corresponding to SDs between 0 and ≥ 3 mm, respectively. Fourth, eight ratios of the face were analysed. The distances between facial landmarks were determined as ratios in order to correct for the size of the head. The mathematic environment MATLAB (MATLAB R2020b; The MathWorks, Inc., Natick, MA, USA) was used to process and analyse the images, and to calculate distances and ratios. A further explanation of the techniques applied is provided below.

Analysis 1: average face

To create an average face from multiple 3D images, each individual 3D image had to be re-meshed, after which the subject-specific templates could be combined into one average face. For the re-meshing process, the following method was applied, with each step depicted in a flowchart in Fig. 1. First, the 3D images were pre-processed by automatically filling holes in the mesh. This was followed by a subsampling to create a uniform mesh with an average vertex distance of 1.0 mm. Next, the following six anatomical landmarks were placed manually on the uniformly distributed mesh: the left and right pupil, pronasale, left and right cheilion, and pogonion (step 1). These six landmarks were used in the Procrustes algorithm. This algorithm uses the landmarks to align the 3D image to a general template with facial contours, without scaling (step 2). By doing this, all 3D images had the correct rotation and orientation. For each age group, the general face template was scaled according to the six landmarks, in order to account for the variation in head size between the different age groups. Also, the 3D image was cropped based on the outer boundary of the face template. Subjects for which the forehead was not visible had to be excluded due to technical matching difficulties (step 3).

After the initial alignment and cropping of the 3D image, the landmark-guided coherent point drift (CPD) algorithm was used for the non-rigid deformation of the general face template towards the 3D image. The manually placed left and right pupil, left and right cheilion, and pronasale were used as the landmarks to guide the CPD (step 4). Subsequently, a ray-cast was applied from the vertices of the face template towards the 3D image, where every vertex from the face template was mapped onto the 3D image. Finally, all 3D images were aligned towards the facial template with the Procrustes algorithm using all vertices, by means of rigid registration (step 5). This resulted in every 3D image having the same position and rotation as the general face template, without scaling the face, in order to preserve the true facial measurements. Additionally, all of the processed 3D images had the same number of vertices with the same corresponding mesh, resulting in an aligned, subject-specific template. These subject-specific templates were averaged to create an average face for each of the four age groups of both genders.

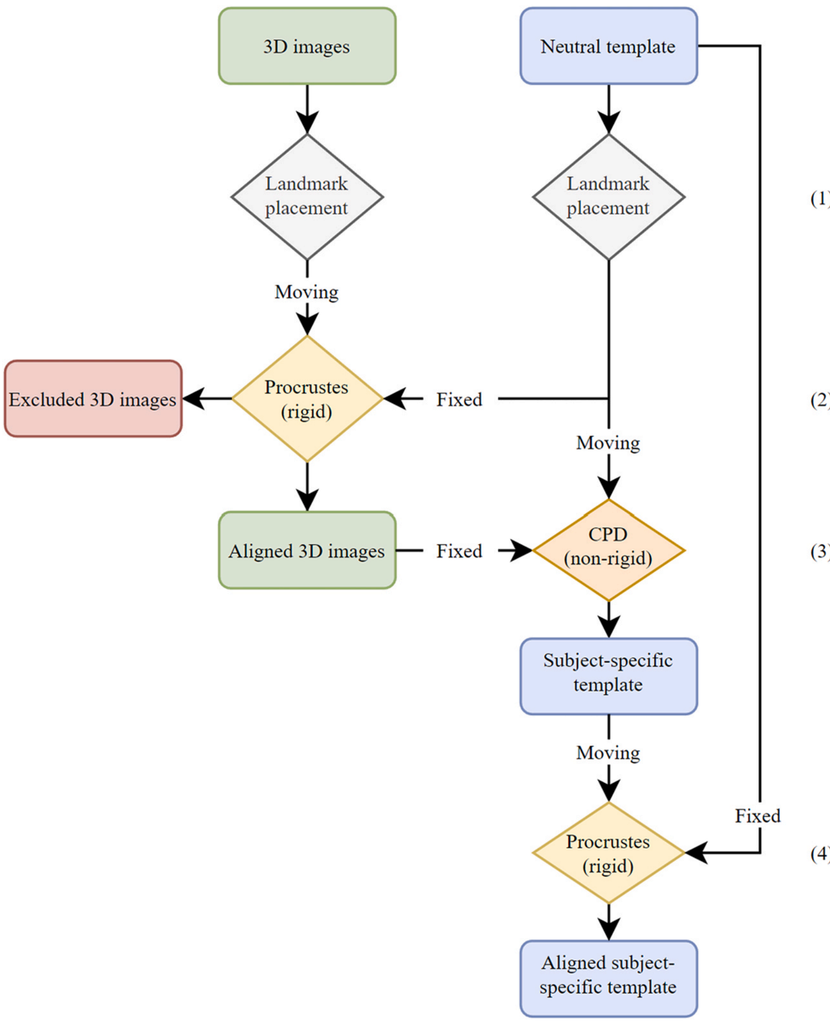

Fig. 1. Flowchart of the re-meshing process: summary of all steps that were executed to process the original 3D images into a subject-specific template. These subject-specific templates can be averaged into an average face. CPD, coherent point drift.

Analysis 2: PCA

The variations in facial morphology within a certain group were analysed by principal component analysis. PCA analyses the variation within a group, with the first principal component (PC) being the most common variable. This variable is depicted as a linear function, with the average at '0′ and the two extremes at '− 2′ and '+ 2′. For example, when the most common variation from the average is the length of the face, the shortest and longest face are shown at − 2 and + 2, with the average face in between, at 0. These are also called 'eigenfaces'. The first PC is the eigenface that covers the most common variable in the dataset. More information about the technical aspects of PCA and eigenfaces can be found online.[18]

Analysis 3: SD analysis

A total of 20 facial landmarks were analysed; the abbreviations for these landmarks are listed in Table 1. For each average face, the SD was calculated for each landmark, showing the distance of the paired landmarks between each subject's original face and the averaged face. Each landmark was depicted on the average face with a green to red colour scale corresponding to SDs between 0 and ≥ 3 mm, respectively.

Table 1. Facial landmarks.

al	Alare
ch	Cheilion
cph	Crista philtri
en	Endocanthion
ex	Exocanthion
gn	Gnathion
li	Labiale inferius
ls	Labiale superius
n	Nasion
pg	Pogonion
pn	Pronasale
sbal	Subalare
sn	Subnasale
sto	Stomion

Analysis 4: ratio analysis

Eight ratios of the face were also analysed. Seven distances were compared to the intercanthal width (ICW; left to right endocanthion): nose width (left to right ala), philtrum width (left to right crista philtri), mouth width (left to right cheilion), crista philtri to labiale superius, philtrum length (subnasale to labiale superius), left cheilion to left crista philtri, and right cheilion to right crista philtri. For crista philtri to labiale superius, the average of the left and right crista philtri to labiale superius was used. Regarding the eighth ratio, the width of the philtrum (left to right crista philtri) was compared to the width of the mouth (left to right cheilion). The ICW was chosen as the reference distance, since the maturation of this distance is reached at 8 years in females and 11 years in males, with 44% of the absolute total growth increment occurring between 3 and 4 years of age.[19]

Statistical analysis

The statistical analysis was performed using GraphPad Prism version 8.3.0 for Windows (GraphPad Software, San Diego, CA, USA; www.graphpad.com). The normality of the data distribution was tested using Q–Q plots. Normally distributed data were expressed as the mean with SD. For each gender, differences between the age groups were analysed using one-way analysis of variance (ANOVA). A statistically significant difference was considered at a P-value < 0.05. For statistically significant differences, multiple comparisons analysis was performed between all groups, using the Tukey post hoc test.

Results

Characteristics of the study subjects

In total, 406 healthy subjects were captured. The forehead was not visible in

Table 2. Characteristics of the study participants.

Age group (years)	Female (*n*)	Age (years)		Male (*n*)	Age (years)	
		Mean (SD)	Range		Mean (SD)	Range
4–8	13	6.4 (1.0)	4–7	17	6.2 (0.7)	5–7
8–12	60	9.5 (1.1)	8–11	58	9.5 (1.1)	8–11
12–16	17	12.8 (0.9)	12–15	22	12.9 (1.0)	12–15
≥ 16	78	40.9 (14.0)	16–74	63	45.3 (10.4)	18–75

SD, standard deviation.

78 of them and they had to be excluded due to technical matching difficulties. The remaining 328 subjects were divided into groups based on gender and age. The characteristics of the study participants are given in Table 2. All except seven of the participants in the total cohort were White.

Average faces, group variation, and first principal component (PC)

The average faces of each gender and age group and their first PCs are shown in Fig. 2 (females) and Fig. 3 (males). These figures also provide an overview of the SDs of all the landmarks of each group, indicated on a colour scale from green to red, where the brightest green represents an SD of 0 mm and the brightest red an SD of ≥ 3 mm.

For all groups, the first PC was the width of the face. Analysis of the SD of the landmarks showed low variation for the average faces. For both males and females, in all age groups, higher SDs were seen for left and right cheilion, pronasale, gnathion, and pogonion.

Analysis of ratios

Table 3 reports the mean ratios in the different age and gender groups. The results of the statistical tests, comparing the mean values between the age groups for each gender, are reported in Table 4. Graphs depicting the ratio in each age group for each gender are shown in Figs. 4–11. Additionally, the measurements of the ICW and comparisons between the age groups are provided in Tables 3 and 4, and as a graph in Fig. 12. The ICW was significantly increased in the older age groups when compared to the younger age groups.

All ratios showed an increasing trend with increasing age, except for the ratio philtrum width to mouth width (Fig. 7). There was no significant difference in

Fig. 2. Females—average faces for the female participants in the different age groups. The first principal component (PC) for each face is provided; the largest variable of each group is depicted as a linear function (−2 to 2). On the right side of the figure, the facial landmarks are indicated with coloured dots depicting the standard deviation of the corresponding landmark in the group.

Fig. 3. Males—average faces for the male participants in the different age groups. The first principal component (PC) for each face is provided; the largest variable of each group is depicted as a linear function (−2 to 2). On the right side of the figure, the facial landmarks are indicated with coloured dots depicting the standard deviation of the corresponding landmark in the group.

this ratio between the age groups for either the female or male subjects. For females, the nose width/intercanthal width ratio showed no significant difference across the age groups. The length of the philtrum in both females and males appeared to show a slight decrease for the age group 12–16 years (Fig. 9); however, the philtrum length to intercanthal width ratio did not differ significantly between this age group and the younger age groups (Table 4). Moreover, the philtrum length to intercanthal width ratio increased significantly for the age group ≥ 16 years.

Discussion

The aim of this study was to create templates of average faces for healthy individuals. This study is novel in examining the facial anthropometry by comparing facial ratios for and within different age groups. The data are cross-sectional, and therefore it must be noted that they do not represent true growth or ageing, but give an indication of facial ageing and trends in the measurements with increasing age.

The PCA, showing the largest variable in a dataset, revealed that the largest difference within each age group was the facial width. The SD analysis showed higher SDs for landmarks at the corners of the mouth (cheilion), tip of the nose (pronasale), and at the chin (gnathion and pogonion), indicating that these landmarks are the most variable within each group. Other landmarks showed low SD scores for all average faces, which indicates that there was little difference between the study subjects and the average facial templates. Therefore, these templates provide a very useful guide for clinicians, for example as a model to strive for in facial surgery, or in assessing the extent of deviation in facial deformities.

All measurement ratios showed a significant increase over the different age groups for both males and females, except the nose width/intercanthal width ratio in females. The only exception was the philtrum width to mouth width ratio, which remained static across all age groups. Yet, the philtrum width and mouth width compared to the ICW did show significant increases with increasing age. This indicates that the philtrum and mouth widen at similar rates with increasing age. The philtrum length to ICW ratio showed an interesting trend for both males and females. Up until the age of 16 years, this ratio did not change. In the age group ≥ 16 years, the ratio increased significantly. This indicates that philtrum growth until the age of 16 years is even less than ICW growth, but that it enlarges significantly after the age of 16 years. This is in agreement with a study by Ferrario et al.,[20] which reported that upper lip length shows only a limited increase from the age of 6 years until young adulthood. The increase in philtrum length at older ages has been confirmed previously.[8,9]

The previous literature has described changes in facial anthropometry across different age groups. Ferrario et al.[13] illustrated facial morphometry of boys and girls in age groups from 6 years to

Table 3. Analysis results: mean ratios.

Ratio		Age (years)			
		4–8	8–12	12–16	≥ 16
	Female	*n* = 13	*n* = 60	*n* = 17	*n* = 78
1	Nose width / intercanthal width	0.92	0.95	0.94	0.98
	SD	0.05	0.08	0.07	0.10
2	Philtrum width / intercanthal width	0.33	0.34	0.35	0.38
	SD	0.03	0.03	0.03	0.04
3	Mouth width / intercanthal width	1.34	1.40	1.48	1.55
	SD	0.10	0.14	0.15	0.15
4	Philtrum width / mouth width	0.24	0.24	0.24	0.24
	SD	0.02	0.02	0.02	0.02
5	Christa philtri–labiale superius / intercanthal width	0.16	0.17	0.18	0.19
	SD	0.02	0.02	0.02	0.02
6	Philtrum length / intercanthal width	0.41	0.42	0.40	0.46
	SD	0.04	0.04	0.04	0.07
7	Cheilion L–crista philtri L / intercanthal width	0.71	0.72	0.77	0.83
	SD	0.07	0.08	0.09	0.10
8	Cheilion R–crista philtri R / intercanthal width	0.70	0.72	0.76	0.80
	SD	0.06	0.08	0.09	0.09
	Intercanthal width (mm)	31.12	31.72	32.83	33.51
	SD	2.42	2.45	1.99	3.00
	Male	*n* = 17	*n* = 58	*n* = 22	*n* = 63
1	Nose width / intercanthal width	0.96	0.95	0.96	1.04
	SD	0.09	0.07	0.09	0.10
2	Philtrum width / intercanthal width	0.34	0.34	0.37	0.41
	SD	0.03	0.03	0.04	0.04
3	Mouth width / intercanthal width	1.32	1.38	1.46	1.58
	SD	0.14	0.15	0.12	0.16
4	Philtrum width / mouth width	0.25	0.25	0.25	0.26
	SD	0.02	0.02	0.02	0.02
5	Christa philtri–labiale superius / intercanthal width	0.17	0.17	0.19	0.21
	SD	0.02	0.02	0.02	0.02
6	Philtrum length / intercanthal width	0.44	0.44	0.43	0.48
	SD	0.05	0.04	0.04	0.06
7	Cheilion L–crista philtri L / intercanthal width	0.69	0.73	0.75	0.82
	SD	0.06	0.07	0.06	0.10
8	Cheilion R–crista philtri R / intercanthal width	0.68	0.71	0.74	0.83
	SD	0.09	0.08	0.05	0.09
	Intercanthal width (mm)	30.60	32.17	33.20	34.60
	SD	2.45	2.46	2.53	2.89

SD, standard deviation.

adulthood. They examined the differences in linear and angular measurements between boys and girls. As in the present study, an increasing trend with increasing age was observed for the linear measurements. Yet, the significance of the age-related change was not mentioned in that previous study. Furthermore, the study by Ferrario et al.[13] described the modification of the facial measurements with increasing age. However, the study focused on linear or angular measurements, rather than ratios of facial measurements. When assessing facial attractiveness, however, most studies are searching for ideal ratios of the face, rather than absolute linear or angular measurements.[1,4] With the latter in mind, it is the authors' opinion that the present study provides more useful information for the clinician.

The linear measurements were presented as ratios compared to the intercanthal width, in order to correct for the size of the head. The ICW was chosen, since a vast part of its growth occurs between 3 and 4 years of age,[19] which is younger than the youngest age group included in the present study. However, significant differences in the ICW were observed between the age groups, revealing an increase at older ages. The current measurements for ICW are in line with previously reported measurements, as summarized by Sforza et al.[21] In that study, it was observed that ICW varies among ethnic groups and age groups. These age-

Table 4. Analysis results: significance of the differences in ratios and intercanthal width between the age groups, for the female and male participants (*P*-values).

	Ratio 1	Ratio 2	Ratio 3	Ratio 4	Ratio 5	Ratio 6	Ratio 7	Ratio 8	ICW
Female									
ANOVA	0.086	< 0.001 *	< 0.001 *	0.696	< 0.001 *	< 0.001 *	< 0.001 *	< 0.001 *	< 0.001 *
Tukey post hoc test									
4–8 vs 8–12	0.742	0.411	0.520	0.991	0.405	0.973	0.960	0.802	0.887
4–8 vs 12–16	0.936	0.142	0.053	0.948	0.145	0.984	0.243	0.241	0.313
4–8 vs ≥ 16	0.172	< 0.001 *	< 0.001 *	0.983	< 0.001 *	0.009 *	0.001 *	< 0.001 *	0.017 *
8–12 vs 12–16	0.986	0.655	0.221	0.717	0.669	0.770	0.207	0.432	0.434
8–12 vs ≥ 16	0.286	< 0.001 *	< 0.001 *	0.999	< 0.001 *	< 0.001 *	< 0.001 *	< 0.001 *	< 0.001 *
12–16 vs ≥ 16	0.445	0.027 *	0.280	0.654	0.039 *	< 0.001 *	0.104	0.180	0.775
Male									
ANOVA	< 0.001 *	< 0.001 *	< 0.001 *	0.141	< 0.001 *	< 0.001 *	< 0.001 *	< 0.001 *	< 0.001 *
Tukey post hoc test									
4–8 vs 8–12	0.987	0.846	0.472	0.870	0.839	0.998	0.301	0.602	0.142
4–8 vs 12–16	0.997	0.027 *	0.029 *	0.999	0.024 *	0.891	0.063	0.107	0.014 *
4–8 vs ≥ 16	0.003 *	< 0.001 *	< 0.001 *	0.860	< 0.001 *	0.028 *	< 0.001 *	< 0.001 *	< 0.001 *
8–12 vs 12–16	0.919	0.033 *	0.187	0.896	0.031 *	0.881	0.562	0.397	0.406
8–12 vs ≥ 16	< 0.001 *	< 0.001 *	< 0.001 *	0.093	< 0.001 *	< 0.001 *	< 0.001 *	< 0.001 *	< 0.001 *
12–16 vs ≥ 16	0.002 *	< 0.001 *	0.004 *	0.743	< 0.001 *	< 0.001 *	0.003 *	< 0.001 *	0.147

ANOVA, analysis of variance; ICW, intercanthal width. For ratios 1–8, see Table 3. *Statistically significant, *P* s < 0.05.

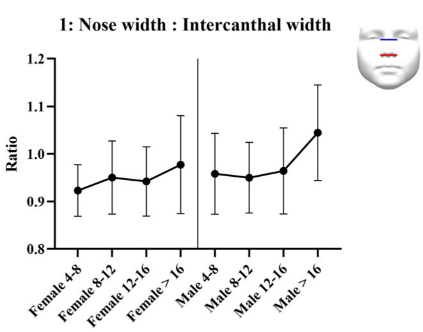

Fig. 4. Nose width (measured from left to right ala) to intercanthal width (measured from left to right endocanthion) ratio by age group (years).

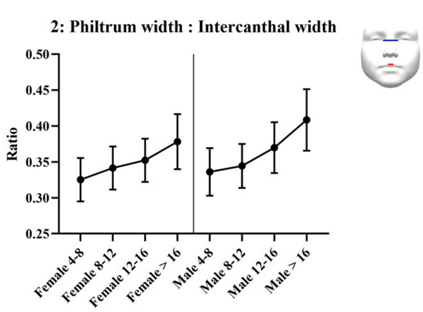

Fig. 5. Philtrum width (measured from left to right crista philtri) to intercanthal width (measured from left to right endocanthion) ratio by age group (years).

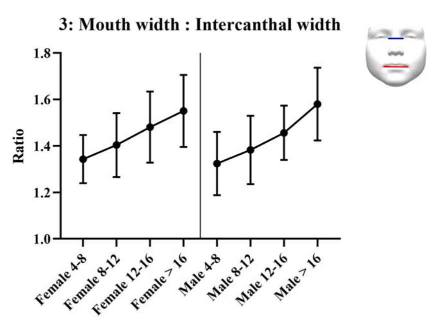

Fig. 6. Mouth width (measured from left to right cheilion) to intercanthal width (measured from left to right endocanthion) ratio by age group (years).

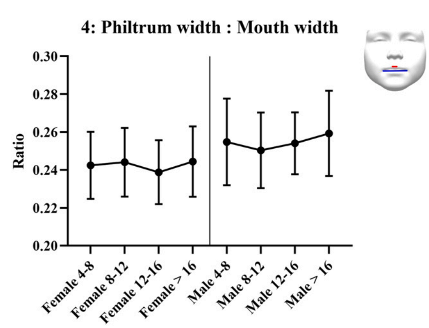

Fig. 7. Philtrum width (measured from left to right crista philtri) to mouth width (measured from left to right cheilion) ratio by age group (years).

related changes after adolescence might be explained by sagging of the skin.[22]

A point that must be addressed is the inevitable risk of inaccuracy resulting from the technical aspects of the present study. A small error can occur in all steps. For all images, the six landmarks for the Procrustes algorithm were placed manually. Manual placement of landmarks is accompanied by a small error which is generally clinically acceptable.[23,24] The remaining landmarks were placed automatically by CPD, which is proven to be deterministic,[25] meaning that there is no inter-observer error. It could be stated that the placement of landmarks should be checked manually in order to minimize the inaccuracy, but, as stated before, manual placement of landmarks entails an error. Besides, the clinical applicability would decrease substantially if landmark placement was required to be done manually for large numbers of photographs. The best effort was made to minimize measurement errors. However, it should be taken into account that all errors were added up, resulting in an inaccuracy of the final results. Therefore, the SD analysis of each average face does not merely show group variation, but also includes the analysis error.

To avoid bias, there was no selection of subjects in the present study. Therefore, the study population should accurately reflect the heterogeneous make-up of Dutch inhabitants of the Netherlands. However, this resulted in an unbalanced distribution of inclusions per group. For instance, the male group aged 16–20 years consisted of only one subject. It was, therefore, decided to combine all of the subjects aged ≥ 16 years into one group. Future studies could put effort into obtaining equal numbers of subjects in each age group, with the aim of achieving a more informative comparison for the older age groups.

These templates for average faces of different age groups, and the facial ratios,

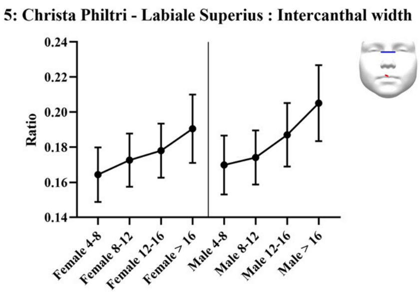

Fig. 8. Christa philtri to labiale superius (average of both left and right) to intercanthal width (measured from left to right endocanthion) ratio by age group (years).

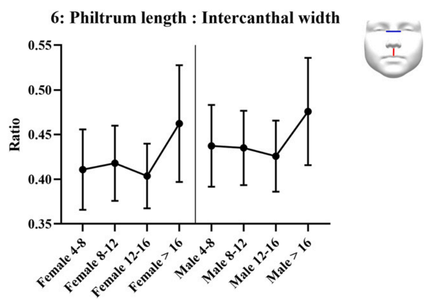

Fig. 9. Philtrum length (measured from subnasale to labiale superius) to intercanthal width (measured from left to right endocanthion) ratio by age group (years).

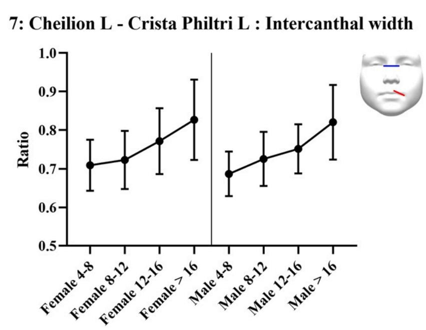

Fig. 10. Left cheilion to left crista philtri to intercanthal width (measured from left to right endocanthion) ratio by age group (years).

could be helpful for clinicians, providing an insight into the average faces, facial ratios for different parts of the face, and the changes during maturation. These templates could also be used to construct colour maps, depicting the deviation from the average face. Such colour maps have been used by Lambros[9] to give a visual representation of the differences between age groups.

In conclusion, the results of this study may be beneficial in facial surgery, for example in trauma,

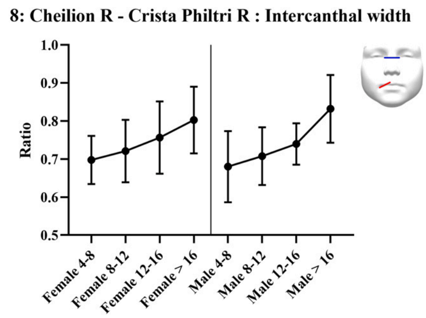

Fig. 11. Right cheilion to right crista philtri to intercanthal width (measured from left to right endocanthion) ratio by age group (years).

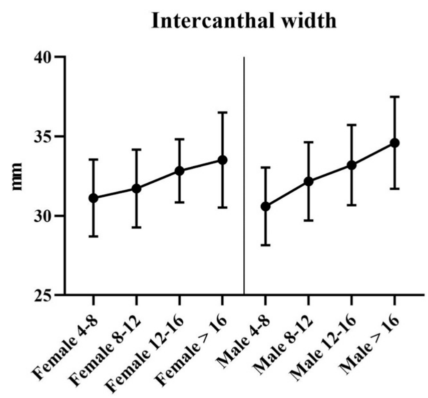

Fig. 12. Intercanthal width (measured from left to right endocanthion) in millimetres by age group (years).

orthognathic, plastic, or reconstructive cases, to obtain an expected outcome according to the age of the patient.

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Competing interests

None.

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Ethical approval

Ethical approval for the study was obtained from the Medical Ethics Review Committee (METC) UMC Utrecht (14/652).

Patient consent

Written informed consent was obtained for each study participant before enrolment in the study.

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