Research Article

Facial Growth in Children from 1 Month to 7 Years: A Biometric Approach by Image Processing

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Abstract

The facial growth rate before 7 years remains largely unknown because only radiographic measures allow precise calculations. We developed software to calculate the different facial dimensions without iatrogenic effects from photographs of children under 7 years. Thirty-seven facial landmarks adapted to the face of children were selected to quantify facial dimensions as a ratio. Results show that the height of the upper area is reduced according to age, with significant sex effects. The median facial area increases with age and without sex effects. The lower facial area also grows in relation to age, again with a significant sex effect. This first non- iatrogenic quantification of children's facial growth must be repeated with more efficient techniques. The upper and median facial areas present early on ratios similar to those observed in adults, while the lower area remains smaller with a development more pronounced in boys than girls.

Keywords: Facial growth; Children; Face recognition; Image processing

Introduction

In the international literature, there are no standards relating to facial growth in children. Only the facial relationships between three facial areas (upper, median, lower) at birth and those at adulthood exist. Conventional approaches are radiological in nature for children with dental joint disorders or significant dysmorphisms. Ethically, it is impossible to irradiate a cohort of children to obtain a quantification by age. For the past ten years, facial recognition software has allowed quantification of adult facial surfaces, but there is no such software adapted to children. Face photography is commonplace and has no iatrogenic effects, thus permitting its use to establish facial growth rate in children, and to propose the first quantification of a control population.

Materials and Methods

Population

The study was based on face photographs of children under 7 years of age. These photos were collected with the consent of the parents in a child maxillofacial surgery department and in a specialized service for the care of children. A total of 681 photographs were taken with frontal views of the children's faces. The parents were present when the photographs were taken and signed informed consent for their use in this study. All images were recorded with a thermal color palette making the child's face unidentifiable. The sample of images collected include diverse ethnic origins including Caucasian, Asian, North African and Sub-Saharan African.

Inclusion criteria

Initially, only 427 of the 681 images collected were selected. We eliminated all photos where the mouth was open or where upper and lower teeth were not in direct contact. We also eliminated photographs where the child's head was rotated, retracted or extended. We kept the images where the child had a slight inclination of the neck, because the software developed allows for straightening from the bi-pupillary axis. Premature children were excluded from the sample. Children with significant craniofacial syndromes, such as microsomia, Goldenard syndrome, or Francheschetti syndrome, were also excluded.

In children, facial development depends on various factors such as the development of respiratory functions, sucking and swallowing functions and eating. This growth also depends on the eruption of temporary teeth and the progressive growth of eyeballs. Finally, the development of the face is closely linked to the growth of the cranial perimeter. The growth of the head circumference is an asymptote whose slope is slightly different according to sex, but whose evolution is perfectly documented [1]. Between birth and the first month of life the average growth is 25 mm. This average growth is 30 mn between the 2nd and 3rd month, then 27 mm between the 4th and 6th month. The average growth then decreases gradually to 23.5 mm from 7 to 10 months, to 22.5 mm from 11 to 20 months, to 20.5 mm from 21 to 40 months, to 12 mm from 41 to 60 months and finally around 10 mm from 61 to 84 months. Based on the evolution of the cranial perimeter, we defined 7 age classes for this study. In the end, 312 photos of the participants were able to undergo automated analysis. The 312 children (106 girls and 206 boys) were affected into 7 age classes (Table 1), defined on the basis of criteria for growth standards of the Cranial Perimeter (CP).

Face analysis software

The Face software was developed entirely within the CHArt laboratory by the second author (FJ), using Red programming language and the redCV library for image processing (Figure 1).

Face software also uses the DLib c++ library for facial recognition. The first step in recognizing a face concerns the identification of its location among other aspect of the photograph. The function implemented by Dlib to perform this task uses the HOG (Histogram of Oriented Gradient) descriptor. This descriptor is based on the fact that the appearance and shape of an object can be described by the distribution of gradient intensity and by the orientation of the contours [2]. Once the face is located, it is necessary to find distinctive points of the face (facial landmarks). These points include the corners of the eyes, nose, mouth, eyebrows and other landmarks. The method used by Dlib for the detection of facial landmarks involves the implementation of the

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algorithm proposed by [3]. This method consists of semi-supervised learning of a cascade of regressors from a data set. The images in the dataset are annotated manually, specifying the coordinates (x,y) of each feature. The method also considers the distance probability between two pairs of points. The cascade of regressors is then trained from the annotated data to estimate the position of the facial features directly from the pixel intensity. The predictive detector used by Dlib allows the location of 68 landmarks that represent the structure of a face [4,5]. The data for learning comes from the iBUG 300-W dataset . This dataset contains many facial images in different orientations, lighting, and other characteristics that allow effective facial recognition.

Although DLib is very effective for real-time and accurate face recognition in adults, we made some adjustments to adapt the algorithm to facial recognition in children. First, we selected 37 facial landmarks that were particularly adapted to face recognition in infants and children. In addition to the 2 pupillary landmarks, the selected facial landmarks are divided into 7 markers for the facial symmetry line, and 28 markers for the two hemifaces. In order to accurately quantify facial growth, the recognition of bone relief is fundamental. We therefore chose to modify the automatic location of some landmarks, such as placing the lower palpebral landmarks as the suborbital landmarks, and by adding four landmarks that we felt were essential:

- The trichion, on the median line, delimiting the hairline with the forehead with the ophryon located at the intersection of the upper eyebrow and the median line, which allows the height of the upper facial area to be measured.
- The 2 pterions temporal landmarks, at the crossroads of bones (frontal, parietal, sphenoid and temporal), as important landmarks to measure the growth of the upper and middle facial areas in children.
- The facial landmarks used in this study are as follows (Figure 2):
- 7 markers on the median line, from the top to the bottom of the face: trichion [69,M1], ophryon [71,M2], nasion [28,M3], nasal [33,M4], sub-nasal [51,M5], gnathion [8,M6], as well as stomion [66,S1] for the bilabial center.
- 14 markers on each hemiface (R: located on the right hemiface, L: on the left)
- 5 markers for the hemifacial contour: the pterion [68-R1 / 70-L1], the root of the auricular horn [0-R2 / 16-L2], the root of the lobule [2-R3 / 14-L3], the gonion [4-R40 / 12-L4], the external chin strap [6-R5 / 10-L5],
- for the orbit: 3 eyebrow markers: the root [21-R8 / 22-L8], the apex [19-R7 / 24-L7], and the eyebrow tail [17-R6 / 26-L6], the 2 internal [39-R10 / 42-L10], and external [36-R9 / 45-L9] canthi, 2 internal infraorbital landmarks [40- R11 / 47-L11], and external infraorbital [41-R12 / 46-L12],
- The alare for the nasal base [31-R 13 / 35-L13],
- The cheilion for the lip corner [48-R 14 / 54-L14] (Figure 2).

Data analysis

Given human morphological variability, it was impossible to directly compare facial dimensions and surfaces among all children. To allow a correct inter-child comparison, the measurements were computed as ratios.

- For the height dimension: the height of each facial area (upper, median, lower) was divided by the total facial height of the participant.
- For surfaces: the surface of hemi-faces, facial, orbital, jugo-mandibular, sub-nasal areas, and chin strap is divided by the total facial surface of the participant, the total surface of the hemi-faces, the surface of facial areas or the surface of different spaces.
- The axes of the eyes (bi-canthi) were calculated in relation to the horizontal and allow for defining the orientation of the eyes.
- The axes defined by the 2 external canthi and the bi-cheilion axis allow for objectifying their orthogonality or non-orthogonality with respect to the vertical axis of facial symmetry.

A total of 37 facial measurements could be calculated for each child. In addition to the sex of the children, we also collected the following information: age in days at the time of the examination and the number of weeks of amenorrhea at birth. For the statistical analysis of the data we used R to calculate the different two-factor analyses of variance with age and sex as grouping factors. The normality of the distributions was first verified by the Shapiro-Wilk test and the homogeneity of the distributions by the Levene test.

Results

In this preliminary study, we focused on the three facial areas (upper, middle, lower). Total facial height of each participant was defined by the difference of y coordinates of the trichion and the gnathion landmarks. Upper facial height was computed as the difference between trichion and ophryon y coordinates. Median facial height was calculated as the difference between ophryon and sub-nasal landmarks y coordinates. Lower facial height was estimated as the difference between sub-nasal and gnathion y coordinates. To allow comparisons across participants, 3 ratios were calculated:

- UFA: upper facial height / total facial height
- MFA: median facial height / total facial height
- LFA: lower facial height / total facial height

Upper Facial Area (UFA)

As illustrated in Figure 3, an ANOVA demonstrated a significant effect of age: $F(6, 298) = 14.715$, $p < .001$, $\eta 2 = .223$ and $\omega 2 = .208$. The height of the UFA decreases according to the age of the participants. This analysis also revealed a significant sex effect: $F(1, 298) = 4.107$, $p < .05$, $\eta 2 = .010$ and $\omega 2 = .008$. In comparison to total facial height, the upper area has smaller proportions for girls than for boys. Finally, there is no significant interaction between age and sex, indicating that the decrease in UFA height is similar for girls and boys (Figure 3).

Median Facial Area (MFA)

An ANOVA demonstrated a significant effect of age: $F(6, 298) = 7.192$, $p < .001$, $\eta 2 = .129$ and $\omega 2 = .106$, but with no significant sex effect. Finally, there was no significant interaction between age and sex, indicating that the decrease in MFA height is comparable in girls and boys. These results are illustrated in (Figure 4).

Lower Facial Area (LFA)

As illustrated by Figure 5, an ANOVA again demonstrated a significant age effect: $F(6, 298) = 4.746$, $p < .001$, $\eta 2 = .085$, and $\omega 2 = .067$, as the height of the LFA increased with the age of the participants. This analysis also revealed a significant sex effect: $F(1,298) = 5.852$, $p < .02$, $\eta 2 = .017$ and $\omega 2 = .014$. In relation to total facial height, the LFA has higher proportions for girls than for boys. However, no significant interaction between the age and sex were observed, as the increases in the height of the LFA were of the same nature for girls and boys.

Discussion

It has been established that the height of the upper facial area at birth is equal to half the facial height and that the median and lower areas are divided into the remaining two quarters [6-11]. The data

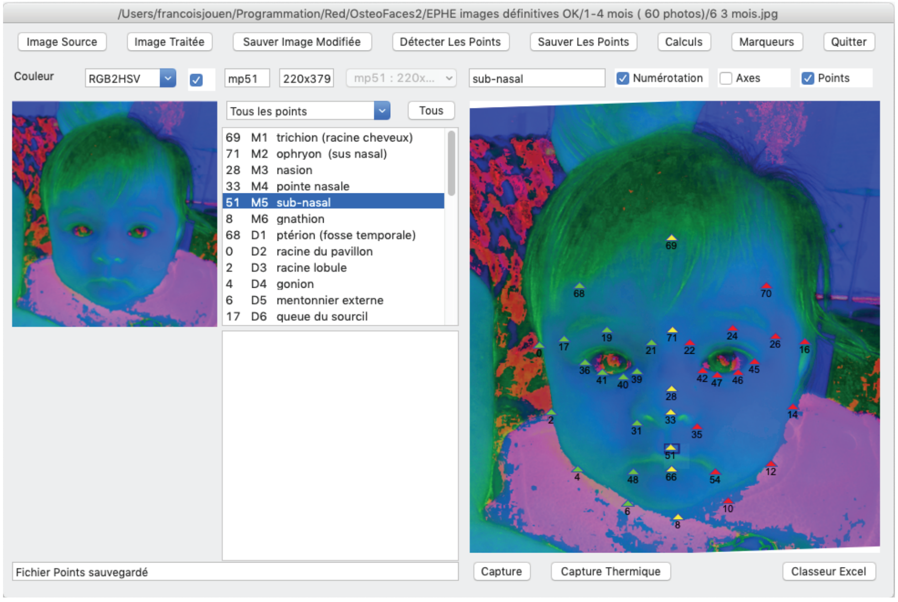

Figure 1: Software interface.

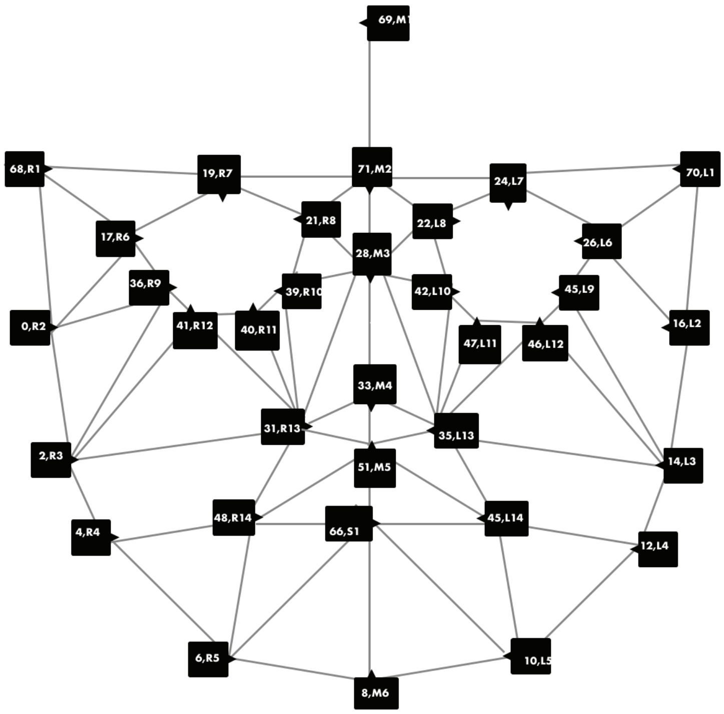

Figure 2: Facial landmarks for children.

collected from this group of 312 participants allowed us to document the rate of growth of facial areas up to 7 years of age, as illustrated by (Figure 6).

In proportion, the upper facial area decreases in height with respect to the development of the two other areas. However, not all areas grow at the same rate: the median area develops more rapidly than the lower area. Between 2 and 3 months, the relative height of the upper area represents 40 to 43% of the total facial height, and before 6 months this height will only be 35 to 40%. This height will then decrease proportionally and very gradually. However, for the last group (61-84 months), it decreases more sharply and ranges from 33% to 36%, which is very close to the relative value observed in adults. For the last group, the upper and median areas presented similar sizes (UFA: 33 to 36%, MFA: 33 to 35%) while the lower area remained proportionally smaller, between 30% and 32% of the total face height.

During the first year of life, it therefore appears that the lower area remains at a relatively small proportion but with considerable variability (26-31%) depending on the participants. This high variability can

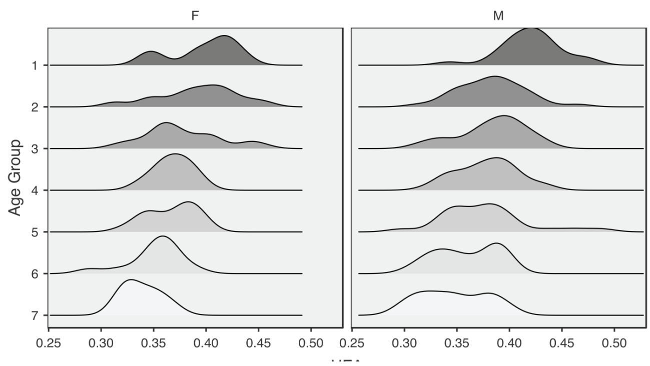

Figure 3: Evolution of Upper Facial Area according to age and sex.

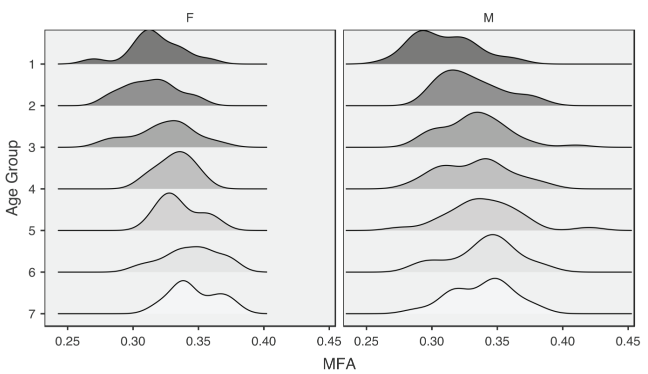

Figure 4: Evolution of Median Facial Area according to age and sex.

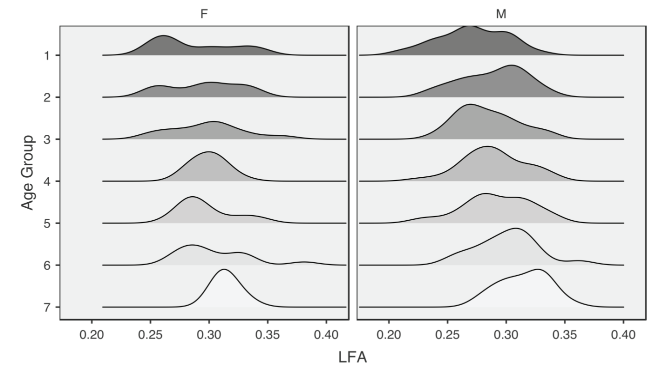

Figure 5: Evolution of Lower Facial Area according to age and sex.

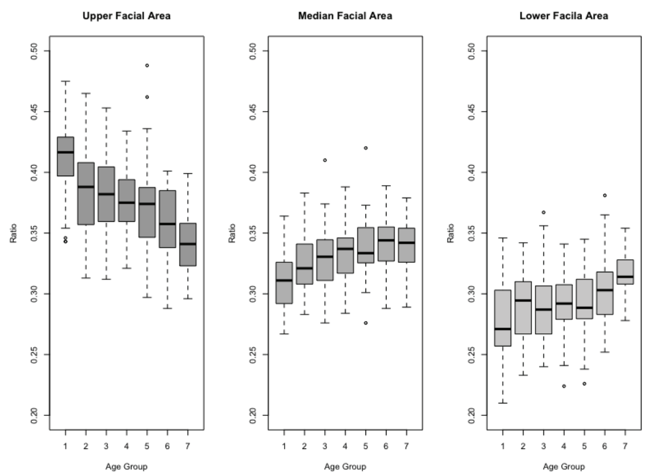

Figure 6: Evolution of the proportional growth of the 3 facial area between 1 month and 7 years.

be associated with the early or late emergence of temporary teeth as summarized in (Table 2).

Before birth, there is a fetal respiratory function that is normally greater than or equal to the frequency of several chest movements that are related to the inhalation of the amniotic fluid and its release with pulmonary fluid for a period of 3 s/min or greater. At birth, with the introduction of air breathing, the respiratory rate increases considerably; this rate raises from 20 to 40 cycles/minute up to 6 months, then from 20 to 30 cycles/minute up to 2 years, in relation to the pneumatization of the maxillary sinuses that begins around 18 months. This frequency will decrease from 16 to 25 cycles/min until 12 years, then from 12 to 20 cycles/min in adulthood. There is a great difference between fetal life frequency and that of the first months of life when this function is at its peak. It can be argued that the most important development of the median facial area is related to the onset of respiratory airway functions.

The lower facial area remains smaller than other areas up to 7 years. The sucking-swallowing function appears very early, around 9-11 weeks of pregnancy. At full-term birth, the child's sucking cycle consists of three coordinated actions: sucking, swallowing and breathing. The development of the lower area seems closely linked to that of the median facial area. Around 6 months, sometimes earlier, the emergence of temporary teeth begins with the eruption of the mandibular incisors; this phase will last up to about 33 months with the arrival of the 2nd temporary molars. The schedule for the onset of temporary teeth provides an averaged age for each tooth emergence. However, inter-individual variability could explain the large variation in height (26 to 31%) of the lower facial area during the 1st year of life.

In relation to total facial height, the upper facial area has smaller proportions for girls than for boys. On the other hand, for the median and lower facial areas, the proportions are higher for girls than for boys. For the three facial areas, the relative variance of the groups has a higher percentage in the upper area (26%) than in the median (13%) or lower areas (11.4%). Conversely, the sex variance is lower for the upper area (1.4%) than for the lower area (25%). It would therefore appear that for the upper stage, whose growth is a consequence of the important development of the telencephalon (forebrain), sex has a slight influence. The development of the median facial area is not sex related. On the other hand, for the lower facial area, the sex factor has a significant effect.

During adolescence, the development of the lower area accentuates the differentiation between girls and boys. According to a recent study involving more than 550 participants (8.5 to 19.5-year-olds) and modeling mandibular growth (by cone-bean imaging), sexual characteristics are present as early as 9 years of age [12]. According to the authors, the male mandible changes more rapidly and over a longer period of time than the female mandible, whose growth peaks and declines earlier. Our study confirms that the differentiation by sexual characteristics plays a very precocious role in the growth of the lower facial area.

Table 1: Distribution by age and sex.

Groups	Age classes in month	Female			Male		
		N	Mean (in day)	S.D.	N	Mean (in day)	S.D.
1	~~3-Feb~~ 2-3	13	70.4	21.5	23	74.2	19.8
2	~~5-Apr~~ 4-5	14	143	17	30	146	19.8
3	~~10-Jun~~ 6-10	24	248	51.1	36	242	46.5
4	~~20-Nov~~ 11-20	15	476	61.6	37	436	98.9
5	21-40	18	850	183	26	919	161
6	41-60	14	1438	149	36	1499	185
7	61-84	8	2064	176	18	2129	210
		106			206		

Table 2: Onset of dentition in children.

TEMPORARY TEETH			
SUPERIOR TEETH	**Eruption Age in month**	**Eruption Order**	**Exfoliation in year**
central incisors	~~12-Aug~~ 8-12	1	7-Jun
lateral incisors	~~13-Sep~~ 11-13	2	8-Jul
1st molar	13-19	3	11-Sep
canines	16-22	4	12-Oct
2nd molar	21-40	5	12-Oct
INFERIOR TEETH	**Eruption Age in month**	**Eruption Order**	**Exfoliation in year**
central incisors	~~10-Jun~~ 6-10	1	7-Jun
lateral incisors	~~16-Oct~~ 10-16	2	8-Jul
1st molar	14-18	3	11-Sep
canines	17-23	4	12-Oct
2nd molar	23-31	5	12-Oct

Conclusion

According to [13], harmonious growth depends on genetic, hormonal and environmental (socio-economic) factors; however, considerable variation can be observed according to ethnicity and also between and within families. Our study demonstrates that the distribution of the upper and median facial areas (UFA: 33-36%, MFA: 33-35%) is very close to that of adults at a very early age. Only the lower area remains in smaller proportions. This allowed for the first non-iatrogenic approach to quantifying facial growth in children.

The median area develops intensely before 6 months, which is probably related to the powerful respiratory functions observed during the first months. In parallel, the lower area develops more gradually in relation to the emergence of temporary teeth. The lower facial area remains modest in proportion and will finish its development only with the progressive positioning of permanent teeth. Our study also reveals a differential sex effect on facial area growth. There is no effect of sex for the median facial area, and sex plays only a minor role for the upper area. However, sex has an important effect on the development of the lower area. Our results show that the growth of the lower area increases earlier in boys than in girls.

Our study provides the first quantification of facial growth in children without the use of any irradiation. The facial recognition software we developed allows for a non-iatrogenic approach to this issue. In order to obtain optimal results, this study should be replicated with more efficient techniques, either a quantification by stereophotogrammetry, or by software that allows the image to be aligned in the sagittal (flexion-extension) and horizontal (right/left rotation) planes.

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