Normal growth and development of the lips: a 3-dimensional study from 6 years to adulthood using a geometric model

VIRGILIO F. FERRARIO, CHIARELLA SFORZA, JOHANNES H. SCHMITZ, VERONICA CIUSA AND ANNA COLOMBO

Laboratorio di Anatomia Funzionale dell'Apparato Stomatognatico (LAFAS), Functional Anatomy Research Center (FARC); Istituto di Anatomia Umana Normale, Facoltà di Medicina e Chirurgia, Università degli Studi di Milano, Milano, Italy

(*Accepted 3 December 1999*)

ABSTRACT

A 3-dimensional computerised system with landmark representation of the soft-tissue facial surface allows noninvasive and fast quantitative study of facial growth. The aims of the present investigation were (1) to provide reference data for selected dimensions of lips (linear distances and ratios, vermilion area, volume); (2) to quantify the relevant growth changes; and (3) to evaluate sex differences in growth patterns. The 3-dimensional coordinates of 6 soft-tissue landmarks on the lips were obtained by an optoelectronic instrument in a mixed longitudinal and cross-sectional study (2023 examinations in 1348 healthy subjects between 6 y of age and young adulthood). From the landmarks, several linear distances (mouth width, total vermilion height, total lip height, upper lip height), the vermilion height-to-mouth width ratio, some areas (vermilion of the upper lip, vermilion of the lower lip, total vermilion) and volumes (upper lip volume, lower lip volume, total lip volume) were calculated and averaged for age and sex. Male values were compared with female values by means of Student's t test. Within each age group all lip dimensions (distances, areas, volumes) were significantly larger in boys than in girls ($P < 0.05$), with some exceptions in the first age groups and coinciding with the earlier female growth spurt, whereas the vermilion height-to-mouth width ratio did not show a corresponding sexual dimorphism. Linear distances in girls had almost reached adult dimensions in the 13–14 y age group, while in boys a large increase was still to occur. The attainment of adult dimensions was faster in the upper than in the lower lip, especially in girls. The method used in the present investigation allowed the noninvasive evaluation of a large sample of nonpatient subjects, leading to the definition of 3-dimensional normative data. Data collected in the present study could represent a data base for the quantitative description of human lip morphology from childhood to young adulthood.

Key words: Anthropometry; face; optoelectronic systems; lips.

INTRODUCTION

The dimensions of the facial soft-tissue structures (nose, lips, chin), their reciprocal spatial positions, and their relative proportions, are important components in the description of human morphology as well as in the clinical analysis of orthodontic, maxillofacial and plastic surgery patients. Apart from conventional 2-dimensional evaluations performed on radiographic films (Mamandras, 1984, 1988; Genecov et al. 1990; Lundström et al. 1992; Zylinski et al. 1992; Skinazi et al. 1994; Nanda & Ghosh, 1995; Prahl-Andersen et al. 1995; Ferrario & Sforza, 1997), several 3-dimensional (3-D) analyses of the facial surface through stereophotogrammetry, moiré stripes, range-camera techniques, laser scanning, optoelectronic systems, or even CT have been proposed (Burke & Hughes-Lawson, 1989; Bush & Antonyshyn, 1996; Ferrario et al. 1996*b*, 1998*d*, 1999*a*; Ras et al. 1996; Strömland et al. 1999). Specifically, the optoelectronic systems detect the 3-D coordinates of selected soft-tissue facial landmarks by using infrared sensitive cameras. In the 3-Dimensional Facial Morphometry method, recently introduced by Ferrario et al. (1996*b*, 1998*d*, 1999*a*), the 3-D landmark data thus collected can be used both in a

Correspondence to Prof. Virgilio F. Ferrario, Istituto di Anatomia Umana Normale, via Mangiagalli 31, I-20133 Milano, Italy. Tel.: +39 02 706 46 228/02 706 46 213; fax: +39 02 23 64 082/02 706 46 246; e-mail: farc@unimi.it

conventional metric approach (angles, distances and ratios similar to conventional anthropometry and cephalometrics) or with other morphometric techniques.

The system has already been applied to the quantitative study of normal soft-tissue facial growth. In particular, nasal growth and development (Ferrario et al. 1997*b*), the modifications of facial volumes from childhood through adolescence into adulthood (Ferrario et al. 1998*b*), as well as the growth patterns of selected linear and angular facial dimensions (Ferrario et al. 1998*c*, 1999*a*), and the age-related modifications of facial proportions (Ferrario et al. 1999*b*) have been evaluated. Moreover, the quantitative relationships between facial morphology and attractiveness (Ferrario et al. 1997*a*), and facial morphology and headform (Ferrario et al. 1997*c*) have been investigated in selected groups of normal children.

The 3-D approach allows the collection of data independent of head posture and projection errors (Ferrario et al. 1996*b*) and the use of noninvasive procedures allows the investigation of large samples of nonpatient children. Both characteristics make the optoelectronic systems particularly suitable for the study of the normal growth patterns of the lips. Indeed, a geometric model for the calculation of lip areas and volumes, as well as of lip linear dimensions, starting from the coordinates of 3-D soft tissue landmarks, has recently been devised. Data on lip morphology in a first group of young adults have already been reported (Ferrario et al. 1999*c*).

Conversely, no recent quantitative analyses about the normal 3-D growth patterns of lips have been published, apart from the linear distances and angles collected by direct anthropometry (Farkas & Posnick, 1992; Farkas et al. 1994), and a first set of values (mouth width and upper lip length) measured on white Scandinavian children (Strömland et al. 1999). Indeed, previous investigations analysed only 2-D radiographic projections, and only data about lip length (vertical dimension), thickness (anteroposterior dimension), and areas (Mamandras, 1984, 1988; Genecov et al. 1990; Nanda & Ghosh, 1995; Prahl-Andersen et al. 1995) are available. The cephalometric studies have a further shortcoming, because the soft tissues of the lips had been most often analysed together with the underlying hard tissues, and only their combined modifications during growth are thus available.

The objectives of this study were (1) to provide reference data for selected dimensions of lips (linear distances and ratios, vermilion area, volume) in a large sample of healthy subjects aged from 6 y into young adulthood using a 3-D noninvasive landmark-based method (Ferrario et al. 1996*b*, 1999*a*, *c*), (2) to quantify the relevant growth changes, and (3) to evaluate sex differences in growth patterns.

MATERIALS AND METHODS

Sample

Data from a total of 2023 examinations (928 observations on males, 1095 on females on a total of 1347 white northern Italians) performed on 4 different samples using the Three-Dimensional Facial Morphometry (3DFM) method (Ferrario et al. 1996*b*, 1998*d*, 1999*a*) were included in this mixed longitudinal and cross-sectional study. The composition of the samples has already been detailed by Ferrario et al. (1999*a*). In brief, the first sample (191 male and 200 female children aged 6–12 y) and the second sample (72 male and 71 female children aged 11–15 y) were examined during 2 longitudinal growth studies. The third sample (240 male and 383 female adolescents aged 13–17 y) and the fourth sample (105 men and 96 women aged 18–32 y, mean 21 y) were examined once only. Subjects with previous history of craniofacial trauma or congenital anomalies, as well as those with an overjet larger than 5 mm, were not included in the sample. The adult subjects and the parents of the children were previously informed about all the

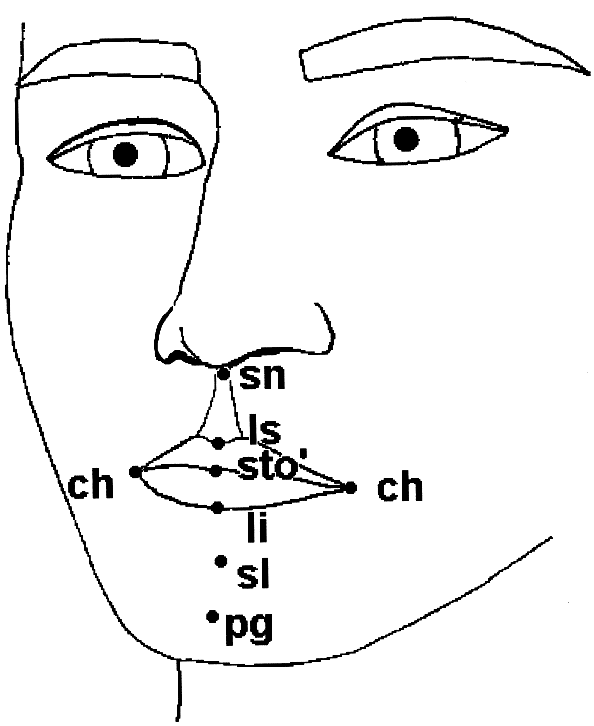

Fig. 1. Digitised soft-tissue 3-D landmarks: sn, subnasale; ls, labiale superius; li, labiale inferius; sl, sublabiale; ch, left and right cheilion.

adopted procedures, and gave their consent to the investigation. The subjects were divided into non-overlapping age classes, all rounded to the nearest 6 mo.

Collection of 3-dimensional facial landmarks

For each subject, a single operator located the landmarks by careful inspection or palpation and marked them on the skin surface. A 2 mm hemispheric reflective marker was fixed on the centre of each point using double-sided adhesive plaster. Two high resolution infrared sensitive CCD video cameras coupled with a video processor (ELITE, BTS, Milan, Italy) provided the 3-D coordinates of the centre of gravity of the markers. The Three-Dimensional Facial Morphometry method has been described in detail elsewhere (Ferrario et al. 1996*b*). In brief, the subjects were asked to stand with their head in a natural position (natural head position). To obtain the natural head position, a 25×25 cm mirror was positioned at eye level at a distance of about 1.5 m, and the subject was invited to look at the reflection of his/her pupils. For each subject, an acquisition of 0.1 s was collected with a sampling rate of 50 Hz.

The reproducibility of landmark identification, marker positioning and the reproducibility of the data collection procedure (ELITE system and mathematical reconstruction of point coordinates) were previously reported, and found to be reliable (Ferrario et al. 1996*b*, 1999*a*). In the present study, only the following soft-tissue landmarks were considered (Ferrario et al. 1999*c*) (Fig. 1).

1. Median points: sn, subnasale; ls, labiale superius (outermost point of the upper lip); li, labiale inferius (outermost point of the lower lip); sl, sublabiale.

2. Lateral points (right and left side noted r and l): ch_r, ch_l, cheilion (labial commissura).

Landmark positions were defined according to Farkas (1994). As detailed by Ferrario et al. (1999*c*), to approximate for the position of stomion, a further point was also derived mathematically as *sto′*. This point had x (left–right) and z (anteroposterior) coordinates positioned at middistance between labiale superius and labiale inferius, while its y coordinate (craniocaudal) corresponded to the axis joining the 2 cheilion landmarks. According to Ferrario et al. (1999*c*), the approximation given by this derived landmark was not completely consistent with literature findings. Nevertheless, it was deemed to be the best analogue that could be produced with the current set of landmark data, and it was also used in the present study.

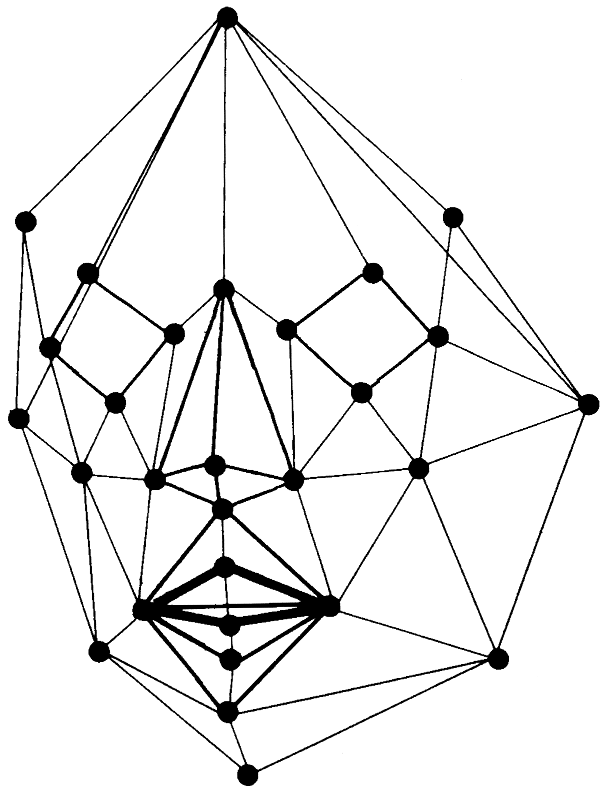

Fig. 2. Three-dimensional reconstruction of the human face according to the 3DFM method.

Data analysis

According to a geometric model of the face (Fig. 2), the x, y, z coordinates of the 6 points obtained on each subject were used to calculate the following parameters.

1. Linear distances (unit: mm): mouth width ($ch_r - ch_l$); total vermilion height (ls − li); total lip height (sn − sl); upper lip height (sn − sto′);

2. Ratio (unit: percentage): vermilion height-to-mouth width ($ls - li/ch_r - ch_l \times 100$);

3. Areas (unit: cm^2): vermilion of the upper lip (area of the quadrilateral between ch_r, ls, ch_l, sto′); vermilion of the lower lip (area of the quadrilateral between ch_r, li, ch_l, sto′); total vermilion (area of the quadrilateral between ch_r, ls, ch_l, li);

4. Volumes (unit: cm^3): upper lip volume (approximated from the volumes of 2 tetrahedra: the first tetrahedron had the plane ch_r, ch_l, ls as its base and vertex in sn, the second had the plane ch_r, ch_l, ls as its base and vertex in sto′); lower lip volume (as above, first tetrahedron with the plane ch_r, ch_l, li as its base and vertex in sl, the second with the plane ch_r, ch_l, li as its base and vertex in sto′); total lip volume (sum of the 4 tetrahedra).

All measurements were performed in 3-D space, i.e. the position of the points relative to all the 3 planes (frontal, lateral and horizontal) was considered at the

Table 1. *Three-dimensional lip morphometry in normal children and young adults* (*mean and* S.E.M.)

Age group		6–7 y		7–8 y		8–9 y		9–10 y		10–11 y		11–12 y		12–13 y	
Sex		M	F	M	F	M	F	M	F	M	F	M	F	M	F
Number		40	45	54	45	82	88	106	126	109	118	63	64	55	57
Parameter	Unit														
Total lip volume	cm^3	3.02	2.73	3.43	2.98	3.65	3.02	3.87	3.33	4.09	3.64	4.20	3.80	4.50	4.07
		(0.12)	(0.09)	(0.12)	(0.10)	(0.09)	(0.09)	(0.09)	(0.06)	(0.93)	(0.07)	(0.11)	(0.11)	(0.13)	(0.12)
Upper lip volume	cm^3	1.86	1.60	2.07	1.77	2.17	1.73	2.27	1.90	2.34	2.05	2.32	2.05	2.49	2.17
		(0.08)	(0.06)	(0.07)	(0.06)	(0.06)	(0.05)	(0.07)	(0.04)	(0.06)	(0.04)	(0.07)	(0.07)	(0.08)	(0.07)
Lower lip volume	cm^3	1.16	1.13	1.40	1.21	1.47	1.28	1.59	1.43	1.75	1.60	1.88	1.75	2.00	1.90
		(0.07)	(0.05)	(0.06)	(0.05)	(0.04)	(0.05)	(0.05)	(0.03)	(0.04)	(0.04)	(0.06)	(0.06)	(0.08)	(0.07)
Total vermilion area	cm^2	3.74	3.49	4.14	3.81	4.24	3.73	4.40	3.95	4.64	4.28	4.53	4.29	4.79	4.64
		(0.10)	(0.10)	(0.12)	(0.11)	(0.10)	(0.08)	(0.10)	(0.06)	(0.09)	(0.07)	(0.10)	(0.10)	(0.12)	(0.13)
Upper lip vermilion area	cm^2	2.04	1.91	2.22	2.12	2.18	1.92	2.28	2.03	2.26	2.12	2.12	2.00	2.20	2.15
		(0.09)	(0.08)	(0.09)	(0.08)	(0.07)	(0.05)	(0.06)	(0.04)	(0.06)	(0.05)	(0.08)	(0.08)	(0.08)	(0.08)
Lower lip vermilion area	cm^2	1.70	1.59	1.92	1.70	2.06	1.80	2.12	1.92	2.38	2.16	2.41	2.30	2.60	2.49
		(0.08)	(0.06)	(0.08)	(0.08)	(0.06)	(0.06)	(0.06)	(0.04)	(0.05)	(0.06)	(0.08)	(0.08)	(0.10)	(0.09)
Mouth width (ch_r-ch_l)	mm	45.27	44.27	47.23	45.41	46.54	45.36	47.67	46.89	48.78	48.02	49.54	48.20	50.66	50.28
		(0.56)	(0.84)	(0.64)	(0.52)	(0.49)	(0.38)	(0.37)	(0.27)	(0.33)	(0.32)	(0.51)	(0.44)	(0.43)	(0.42)
Total vermilion height (ls − li)	mm	15.11	14.36	16.04	15.31	16.50	15.03	16.80	15.31	17.22	16.08	16.51	15.93	17.07	16.53
		(0.36)	(0.35)	(0.46)	(0.38)	(0.30)	(0.31)	(0.35)	(0.24)	(0.29)	(0.25)	(0.31)	(0.33)	(0.37)	(0.38)
Vermilion height to mouth width ratio	%	33.62	33.08	34.32	33.83	35.73	33.31	35.41	32.83	35.50	33.62	33.55	33.16	33.73	32.88
		(0.92)	(1.09)	(1.17)	(0.84)	(0.75)	(0.74)	(0.77)	(0.59)	(0.65)	(0.57)	(0.73)	(0.74)	(0.72)	(0.71)
Total lip height (sn − sl)	mm	34.70	33.37	35.57	34.09	36.41	34.28	36.77	34.12	37.16	34.63	37.08	35.04	37.54	35.02
		(0.36)	(0.38)	(0.47)	(0.46)	(0.31)	(0.32)	(0.28)	(0.27)	(0.52)	(0.28)	(0.40)	(0.40)	(0.51)	(0.43)
Upper lip height (sn − sto′)	mm	14.67	13.89	14.92	14.29	16.02	14.76	16.65	15.23	17.10	15.93	17.15	16.21	17.59	16.70
		(0.29)	(0.29)	(0.30)	(0.32)	(0.24)	(0.25)	(0.23)	(0.18)	(0.20)	(0.21)	(0.28)	(0.26)	(0.36)	(0.33)

same time (no projections). Data on lip morphology in young adults have already been reported in part by Ferrario et al. (1999*c*).

Descriptive statistics (mean and standard error of the mean, S.E.M.) for each measurement and ratio were computed within sex and age class. Mean values between sexes were compared using Student's *t* test for independent samples. Significance was set at 5% ($P \leqslant 0.05$), with 2-tail statistical tests used in all analyses.

For each variable and age class, the attainment of adult dimensions was calculated within sex as the percentage ratio of child value to adult value.

RESULTS

Mean and standard error of the mean for each of the parameters measured at each age for both sexes are presented in Table 1. The relevant statistical comparisons between boys and girls are reported in Table 2. As an example, the growth changes of total lip volume are graphically illustrated in Figure 3, where the percentage attainment of adult dimensions at each age is also reported.

On average, within each age group, lip areas, volumes and linear distances were significantly larger in boys than in girls with some exceptions in the first age classes (6–8 y of age) and in coincidence with the earlier female peripubertal growth spurt (between 11 and 14 y of age), whereas the vermilion height-to-mouth width ratio did not show a corresponding sex-related pattern.

Between 6 y of age and young adulthood, the growth patterns of the analysed variables can be approximately classified into 3 groups. While some dimensions almost doubled their value (total lip volume, from 3 to 6 cm^3 in boys, and from 2.7 to 4.5 cm^3 in girls, Fig. 3; lower lip volume and vermilion area), the increment was of only one third in others (total vermilion area, upper lip volume), and limited

Table. 1 (*cont.*)

Age group		13–14 y		14–15 y		15–16 y		16–17 y		17–18 y		Adults	
Sex		M	F	M	F	M	F	M	F	M	F	M	F
Number		60	61	79	104	58	101	67	98	60	92	95	96
Parameter	Unit												
Total lip volume	cm^3	4.83 (0.16)	4.05 (0.12)	5.16 (0.14)	4.19 (0.09)	5.57 (0.15)	4.45 (0.10)	5.66 (0.15)	4.56 (0.11)	5.64 (0.14)	4.74 (0.10)	6.00 (0.12)	4.46 (0.10)
Upper lip volume	cm^3	2.65 (0.08)	2.19 (0.07)	2.83 (0.08)	2.23 (0.05)	2.95 (0.09)	2.32 (0.05)	3.02 (0.08)	2.37 (0.06)	2.92 (0.08)	2.53 (0.06)	3.15 (0.06)	2.31 (0.06)
Lower lip volume	cm^3	2.18 (0.10)	1.87 (0.07)	2.33 (0.08)	1.96 (0.05)	2.63 (0.09)	2.13 (0.05)	2.64 (0.09)	2.19 (0.06)	2.72 (0.07)	2.21 (0.06)	2.85 (0.08)	2.15 (0.06)
Total vermilon area	cm^2	4.82 (0.15)	4.59 (0.12)	5.17 (0.12)	4.74 (0.08)	5.50 (0.02)	4.84 (0.10)	5.57 (0.16)	4.82 (0.09)	5.58 (0.14)	5.13 (0.11)	5.59 (0.10)	4.80 (0.09)
Upper lip vermilion area	cm^2	2.21 (0.08)	2.13 (0.08)	2.40 (0.07)	2.19 (0.05)	2.37 (0.09)	2.16 (0.07)	2.47 (0.10)	2.12 (0.05)	2.39 (0.10)	2.40 (0.07)	2.44 (0.08)	2.12 (0.07)
Lower lip vermilion area	cm^2	2.61 (0.11)	2.45 (0.08)	2.78 (0.09)	2.54 (0.06)	3.13 (0.10)	2.68 (0.07)	3.10 (0.12)	2.69 (0.07)	3.18 (0.09)	2.73 (0.08)	3.15 (0.08)	2.68 (0.07)
Mouth width (ch_r-ch_l)	mm	51.53 (0.70)	50.13 (0.41)	52.40 (0.43)	49.94 (0.32)	53.15 (0.49)	50.60 (0.34)	54.34 (0.50)	51.24 (0.35)	54.27 (0.47)	51.29 (0.36)	55.60 (0.39)	50.89 (0.38)
Total vermilion height (ls − li)	mm	16.81 (0.42)	16.44 (0.39)	17.70 (0.35)	16.98 (0.25)	18.42 (0.38)	17.10 (0.34)	18.30 (0.48)	16.79 (0.29)	18.33 (0.42)	17.76 (0.34)	17.91 (0.31)	16.75 (0.27)
Vermilion height to mouth width ratio	%	33.00 (0.97)	32.85 (0.79)	33.90 (0.70)	34.13 (0.53)	34.76 (0.73)	33.89 (0.68)	33.86 (0.95)	32.92 (0.60)	33.93 (0.82)	34.71 (0.66)	32.41 (0.64)	33.07 (0.58)
Total lip height (sn − sl)	mm	38.40 (0.48)	35.25 (0.42)	39.44 (0.48)	36.32 (0.31)	40.40 (0.42)	37.03 (0.36)	39.98 (0.50)	36.57 (0.38)	40.23 (0.46)	37.73 (0.40)	40.66 (0.36)	36.63 (0.31)
Upper lip height (sn − sto′)	mm	17.59 (0.37)	16.79 (0.29)	18.02 (0.29)	17.10 (0.20)	18.78 (0.31)	17.40 (0.23)	18.69 (0.37)	17.38 (0.26)	18.66 (0.27)	17.77 (0.26)	18.73 (0.24)	17.48 (0.20)

M, males; F, females.

to one fifth in the remaining ones (upper vermilion area, mouth width, total vermilion height, total and upper lip heights).

For most variables, about 95% of the relevant adult value was obtained by 13–14 y of age in girls, but only by 15–18 y in boys. When the individual dimensions were analysed, it appeared that the total vermilion height gained the adult value earlier than the mouth width, thus giving almost constant values for the relevant ratio (between 32.4 and 35.7% in boys, between 32.8 and 34.7% in girls). The attainment of adult dimensions was faster in the upper than in the lower lip, especially in girls. For instance, in the 7 to 8-y-old girls the upper vermilion area had the same mean value measured in the young adult women, and after 12 y of age no further modifications were observed. Conversely, the similar value calculated for the lower lip gained 95% of the adult dimension only by 15 y of age.

DISCUSSION

The facial soft tissues both for healthy subjects and for maxillofacial, plastic surgery and orthodontic patients are best analysed through a 3-D approach (Burke & Hughes-Lawson, 1989; Farkas & Posnick, 1992; Farkas et al. 1994; Bush & Antonyshyn, 1996; Ferrario et al. 1996*b*, 1998*d*, 1999*a*; Ras et al. 1996; Strömland et al. 1999). Indeed, the actual appearance of a patient's face is the composite result of several widths, depths and heights, and all 3 spatial planes should be considered together. This seems particularly appropriate in the study of mouth and lips during growth and development (Mamandras, 1984). Postural changes may also affect lip morphology, and mask actual growth (Mamandras, 1984).

The imaging system used in the present investigation is independent of head posture (Ferrario et al. 1996*b*). Indeed, the use of natural head position in the

Table 2. *Sex differences in 3-dimensional lip morphometry in normal children and young adults*

Age group Degrees of freedom	6–7 y 83	7–8 y 97	8–9 y 168	9–10 y 230	10–11 y 225	11–12 y 125	12–13 y 110	13–14 y 119	14–15 y 181	15–16 y 157	16–17 y 163	17–18 y 150	Adults 189
Total lip volume	n.s.	0.010	0.001	0.001	0.001	0.025	0.025	0.001	0.001	0.001	0.001	0.001	0.001
Upper lip volume	0.010	0.005	0.001	0.001	0.001	0.010	0.005	0.001	0.001	0.001	0.001	0.001	0.001
Lower lip volume	n.s.	0.025	0.005	0.005	0.025	n.s.	n.s.	0.025	0.001	0.001	0.001	0.001	0.001
Total vermilion area	n.s.	n.s.	0.001	0.001	0.005	n.s.	n.s.	n.s.	0.005	0.001	0.001	0.025	0.001
Upper lip vermilion area	n.s.	n.s.	0.005	0.001	n.s.	n.s.	n.s.	n.s.	0.025	n.s.	0.001	n.s.	0.005
Lower lip vermilion area	n.s.	n.s.	0.005	0.010	0.010	n.s.	n.s.	n.s.	0.025	0.001	0.005	0.001	0.001
Mouth width ($ch_r - ch_l$)	n.s.	0.050	n.s.	n.s.	n.s.	0.050	n.s.	n.s.	0.001	0.001	0.001	0.001	0.001
Total vermilion height (ls − li)	n.s.	n.s.	0.001	0.001	0.005	n.s.	n.s.	n.s.	n.s.	0.025	0.005	n.s.	0.010
Vermilion height to mouth width ratio	n.s.	n.s.	0.025	0.010	0.050	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Total lip height (sn − sl)	0.025	0.050	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Upper lip height (sn − sto′)	n.s.	n.s.	0.001	0.001	0.001	0.025	n.s.	n.s.	0.010	0.001	0.005	0.025	0.001

n.s., not significant ($P > 0.05$).
P values for male vs female comparisons by Student's *t* test for independent samples are given.

quantitative analysis of the facial hard and soft tissues is presently being advocated by several researchers (a recent review is given by Ferrario et al. 1996*a*), for its lower variability and larger significance in everyday true life appearance when compared with conventional intracranial reference planes. Moreover, intracranial planes cannot be assessed by noninvasive landmark or surface based procedure used for the study of facial soft tissues (Bush & Antonyshyn, 1996; Ferrario et al. 1996*b*, 1998*d*, 1999*a*; Ras et al. 1996; Strömland et al. 1999). The system used in the current investigation provides absolute measurements which, in this perspective, are similar to those obtained by direct anthropometry. All the problems of projection of 3-D structures into a 2-D plane are therefore abolished. A detailed discussion of this point can be found in Ferrario et al. (1996*b*).

The present study used a geometric model of the lips, where only some discrete landmarks have been sampled (Figs 1, 2). While this approach can give a good approximation of linear distances (Ferrario et al. 1996*b*), the calculation of areas and volumes may be inadequate (Ferrario et al. 1997*b*, 1998*b*). Indeed, the surfaces lying between contiguous landmarks, actually curved, have been approximated by linear planes. Therefore the calculations cannot provide the actual lip volume or area, but only an approximation of their values, as extensively discussed by Ferrario et al. (1997*b*, 1998*b*, 1999*c*). A better approximation could be given using a larger number of landmarks describing the curved surface, as provided by laser scanning systems (Bush & Antonyshyn, 1996). Unfortunately, the homologous landmarks are not readily detected in this way, and the use of geometric models is difficult. It has to be mentioned that the geometric models allow the quantitative analysis and comparison of different subjects starting from homologous landmarks which possess a well-defined anatomical localisation (Ferrario et al. 1996*b*).

As stated in Materials and Methods, the present study did not assess the actual position of landmark stomion, but derived it from the coordinates of labiale superius and labiale inferius (left–right and anteroposterior positions) and left and right cheilion (craniocaudal position). This landmark definition was adopted because the optoelectronic system could not

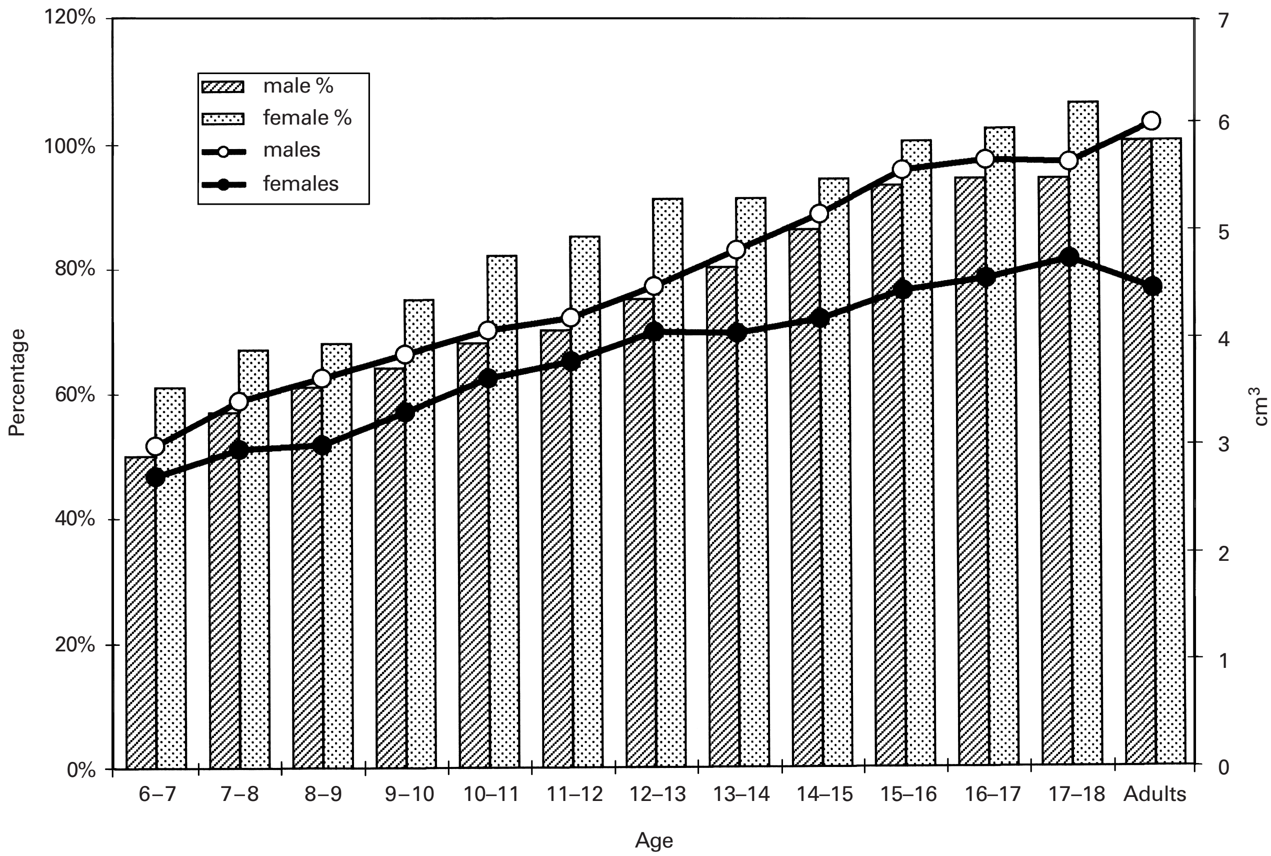

Fig. 3. Total lip volume (cm^3), male (open circles) and female (closed circles) mean values as a function of age. At each age class, the percentage attainment of the adult dimension is also reported (males, striped bars; females, dotted bars).

detect the actual landmark (a double-sided adhesive marker had to be positioned on the point). As discussed by Ferrario et al. (1999*c*), and according to literature data, the approximation was inadequate (at least in young adult subjects), as the upper lip was too short. Nevertheless, this derived stomion was deemed to be the best analogue that could be produced with the current set of landmark data, and it was also used in the present study. A different approach for data collection, where the single landmarks were not previously identified by markers, could provide the actual x, y and z data for stomion. For instance, the use of an electromagnetic 3-D digitiser may overcome this limitation (Ferrario et al. 1998*a*). Indeed, in the study of lip abnormalities (such as cleft lip), the actual detection of landmark stomion is obviously essential. Likewise, upper lip morphology could best be analysed by a larger set of landmarks also describing the philtral crests as well as the nasolabial fold (Farkas, 1994). Unfortunately, these landmarks are too close to be accurately detected by the opto-electronic system used in the present investigation because the images from the different markers partially superimpose. As already noted for landmark stomion, the addition of these landmarks to the present geometric model may be performed using a different approach for data collection, such as an electromagnetic 3-D digitiser (Ferrario et al. 1998*a*).

In most age classes, a statistically significant sexual dimorphism was found in all linear, surface and volume measurements, male values being larger than female values. Exceptions were found in the first age classes and in coincidence with the earlier female peripubertal growth spurt. Moreover, the growth patterns of the different measurements also showed sex-related characteristics. Generally, girls grew earlier and faster than boys, gaining adult dimensions approximately 2 to 5 y earlier. The present sexual dimorphism (dimensions and timing) is similar to that found for most other facial soft and hard structures (Mauchamp & Sassouni, 1973; Mamandras, 1984; Genecov et al. 1990; Nanda et al. 1990; Farkas & Posnick, 1992; Farkas et al. 1994; Nanda & Ghosh, 1995; Prahl-Andersen et al. 1995; Ferrario et al. 1997*b*, 1998*b*, *c*, 1999*a*, *b*; Foley & Duncan, 1997).

Both in boys and girls, some of the volumes, areas and distances measured in the older age groups were somewhat larger than the corresponding values measured in the young adults (for instance, total lip volume and upper lip vermilion area in 17 to 18-y-old girls, total vermilion height in 15 to 16-y-old boys). Two considerations arise: first, such fluctuations in the mean values are to be expected in a cross-sectional study; second, the mean ± 1 S.D. of these measurements are well superimposed. Similar trends could also be observed in the data reported by Farkas & Posnick (1992) and by Farkas et al. (1994). Pure longitudinal studies are obviously more likely to be exempt from such effects.

Direct measurements of mouth width (ch – ch) performed by Farkas et al. (1994) were similar to the present data, while the values reported by Strömland et al. (1999) were about 2–3 mm smaller than the present ones, especially in boys. Data on total lip height (sn – sl) and on total vermilion height (ls – li) were not found in the literature, but derived measurements from 3-D direct anthropometry (Farkas et al. 1994) were in good agreement with the present mean values.

The upper lip height sn – sto measured on cephalometric radiographs by Genecov et al. (1990) in a longitudinal growth study between 7.5 and 17 y was about 4–6 mm larger than the present measurements at comparable ages in both girls and boys. Similar differences can be calculated from the data reported by Zylinski et al. (1992) for preadolescent boys, and by Burstone (1967) for adolescent boys and girls. All studies differ from the present investigation in at least 3 points: first, 2-D data were used; second, apparently no correction for the magnification of the radiographs was performed; third, the landmark stomion was actually measured and not derived as in the present study. The last consideration could also explain the 4 mm difference between the present upper lip height and that directly measured by Peck & Peck (1995) in orthodontic patients aged 15.5 y on average. Similar differences can be observed between the current upper lip height and the direct anthropometric measurements reported by Farkas & Posnick (1992) and by Farkas et al. (1994) for children aged 6 to 18 y and young adults. Also the 3-D computerised data collected by Strömland et al. (1999) on Scandinavian children of comparable age were about 3–5 mm larger than the present values. Nevertheless, when the growth patterns of the upper and lower lips were compared, findings similar to those reported in the present study were found, with the lower lip growing more and for a longer time than the upper lip (Mamandras, 1988; Genecov et al. 1990; Zylinski et al. 1992; Nanda & Ghosh, 1995). In particular, the growth patterns (attainment of adult dimensions) reported by Nanda & Ghosh (1995) are comparable to the present patterns in both sexes.

No literature comparisons could be made for lip volumes and areas. Indeed, in the investigation by Mamandras (1984) some lip areas were measured from lateral head radiographs, but those areas combined hard and soft tissue structures and cannot be compared with the present 3-D cutaneous data.

In the present study, no selections for the different occlusal (Angle) Classes were performed, and only individuals with a previous history of craniofacial trauma or congenital anomalies, as well as those with an overjet larger than 5 mm, were not included in the sample. Further studies may analyse the effect of different Angle Classes on lip dimensions, but it has to be mentioned that Burstone (1967) found no differences in lip dimensions between adolescents with 'normal' faces and adolescents with Angle Class II, division 1 malocclusion.

The number of subjects in each age and sex class was comparable to that found in classic anthropometric cross-sectional studies (Farkas & Posnick, 1992; Farkas et al. 1994), and it was 2 to 10 times larger than that reported by more recent 3-D computerised investigations (Strömland et al. 1999). Data collected in the present investigation could therefore represent a first data base for the quantitative description of human lip morphology in normal children and adolescents. For instance, they can be used in computerised simulations of the surgical or orthodontic treatments. Moreover, the same protocol could be applied to patients with craniofacial alterations, where a modification of the set of soft tissue landmarks may be required.

REFERENCES

BURKE PH, HUGHES-LAWSON CA (1989) Stereophotogrammetric study of growth and development of the nose. *American Journal of Orthodontics and Dentofacial Orthopedics* **96**, 144–151.

BURSTONE CJ (1967) Lip posture and its significance in treatment planning. *American Journal of Orthodontics* **53**, 262–284.

BUSH K, ANTONYSHYN O (1996) Three-dimensional facial anthropometry using a laser surface scanner: validation of the technique. *Plastic and Reconstructive Surgery* **98**, 226–235.

FARKAS LG (1994) Examination. In *Anthropometry of the Head and Face* (ed. Farkas LG), 2nd edn, pp. 3–56. New York: Raven Press.

FARKAS LG, POSNICK JC (1992) Growth and development of regional units in the head and face based on anthropometric measurements. *Cleft Palate-Craniofacial Journal* **29**, 301–329.

FARKAS LG, HRECZKO TA, KATIC MJ (1994) Craniofacial norms in North American Caucasians from birth (one year) to young adulthood. In *Anthropometry of the Head and Face* (ed. Farkas LG), 2nd edn, pp. 241–335. New York: Raven Press.

FERRARIO VF, SFORZA C, DALLOCA LL, DE FRANCO DJ (1996*a*) Assessment of facial form modifications in orthodontics. Proposal of modified computerized mesh diagram analysis. *American Journal of Orthodontics and Dentofacial Orthopedics* **109**, 263–270.

FERRARIO VF, SFORZA C, POGGIO CE, SERRAO G (1996*b*) Facial three-dimensional morphometry. *American Journal of Orthodontics and Dentofacial Orthopedics* **109**, 86–93.

FERRARIO VF, SFORZA C (1997) Size and shape of soft-tissue facial profile: effects of age, gender and skeletal class. *Cleft Palate-Craniofacial Journal* **34**, 498–504.

FERRARIO VF, SFORZA C, POGGIO CE, COLOMBO A, TARTAGLIA G (1997*a*) Facial three-dimensional morphometry in attractive versus non attractive children. *International Journal of Adult Orthodontics and Orthognathic Surgery* **12**, 145–152.

FERRARIO VF, SFORZA C, POGGIO CE, SCHMITZ JH (1997*b*) A three dimensional study of growth and development of the nose. *Cleft Palate-Craniofacial Journal* **34**, 309–317.

FERRARIO VF, SFORZA C, POGGIO CE, SCHMITZ JH, COLOMBO A (1997*c*) Soft tissue facial morphology related to headform: a three-dimensional quantitative analysis in childhood. *Journal of Craniofacial Genetics and Developmental Biology* **17**, 86–95.

FERRARIO VF, SFORZA C, POGGIO CE, COVA M, TARTAGLIA G (1998*a*) Preliminary evaluation of an electromagnetic three-dimensional digitizer in facial anthropometry. *Cleft Palate-Craniofacial Journal* **35**, 9–15.

FERRARIO VF, SFORZA C, POGGIO CE, SCHMITZ JH (1998*b*) Facial volume changes during normal human growth and development. *Anatomical Record* **250**, 480–487.

FERRARIO VF, SFORZA C, POGGIO CE, SCHMITZ JH (1998*c*) Craniofacial growth: a three-dimensional soft-tissue study from 6 years to adulthood. *Journal of Craniofacial Genetics and Developmental Biology* **18**, 138–149.

FERRARIO VF, SFORZA C, SCHMITZ JH, MIANI A JR, SERRAO G (1998*d*) A three-dimensional computerized mesh diagram analysis and its application in soft tissue facial morphometry. *American Journal of Orthodontics and Dentofacial Orthopedics* **114**, 404–413.

FERRARIO VF, SFORZA C, POGGIO CE, SCHMITZ JH (1999*a*) Soft tissue facial morphometry from 6 years to adulthood: a three-dimensional growth study using a new modeling. *Plastic and Reconstructive Surgery* **103**, 768–777.

FERRARIO VF, SFORZA C, SERRAO G, COLOMBO A, CIUSA V (1999*b*) Soft-tissue facial growth and development as assessed by the three-dimensional computerized mesh diagram analysis. *American Journal of Orthodontics and Dentofacial Orthopedics* **116**, 215–228.

FERRARIO VF, SFORZA C, SERRAO G (1999*c*) A three-dimensional quantitative analysis of lips in normal young adults. *Cleft Palate-Craniofacial Journal*, in press.

FOLEY TF, DUNCAN PG (1997) Soft tissue profile changes in late adolescent males. *The Angle Orthodontist* **67**, 373–380.

GENECOV JS, SINCLAIR PM, DECHOW PC (1990) Development of the nose and soft tissue profile. *The Angle Orthodontist* **60**, 191–198.

LUNDSTRÖM A, FORSBERG C-M, PECK S, McWILLIAM J (1992) A proportional analysis of the soft tissue facial profile in young adults with normal occlusion. *The Angle Orthodontist* **52**, 127–133.

MAMANDRAS AH (1984) Growth of lips in two dimensions: a serial cephalometric study. *American Journal of Orthodontics* **86**, 61–66.

MAMANDRAS AH (1988) Linear changes of the maxillary and mandibular lips. *American Journal of Orthodontics and Dentofacial Orthopedics* **94**, 405–410.

MAUCHAMP O, SASSOUNI V (1973) Growth and prediction of the skeletal and soft-tissue profile. *American Journal of Orthodontics* **64**, 83–94.

NANDA RS, GHOSH J (1995) Facial soft tissue harmony and growth in orthodontic treatment. *Seminars in Orthodontics* **1**, 67–81.

NANDA R, MENG H, KAPILA S, GOORHUIS J (1990) Growth changes in the soft tissue facial profile. *The Angle Orthodontist* **60**, 177–190.

PECK S, PECK L (1995) Selected aspects of the art and science of facial esthetics. *Seminars in Orthodontics* **1**, 105–126.

PRAHL-ANDERSEN B, LIGHTELM-BAKKER ASWMR, WATTEL E, NANDA R (1995) Adolescent growth changes in soft tissue profile. *American Journal of Orthodontics and Dentofacial Orthopedics* **107**, 476–483.

RAS FL, HABETS LMH, VAN GINKEL FC, PRAHL-ANDERSEN B (1996) Quantification of facial morphology using stereophotogrammetry—demonstration of a new concept. *Journal of Dentistry* **24**, 369–374.

SKINAZI GLS, LINDAUER SJ, ISAACSON RJ (1994) Chin, nose, and lips. Normal ratios in young men and women. *American Journal of Orthodontics and Dentofacial Orthopedics* **106**, 518–523.

STRÖMLAND K, CHEN Y, NORBERG T, WENNERSTROM K, MICHAEL G (1999) Reference values of facial features in Scandinavian children measured with a range-camera technique. *Scandinavian Journal of Plastic and Reconstructive Hand Surgery* **33**, 59–65.

ZYLINSKI CG, NANDA RS, KAPILA S (1992) Analysis of soft-tissue facial profile in white males. *American Journal of Orthodontics and Dentofacial Orthopedics* **101**, 514–518.