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Age- and sex-related changes in the normal human ear

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ABSTRACT

The objective of this study was to supply information about: (1) normal sex-related dimensions of ears (linear distances and ratios, area); (2) left–right symmetry; and (3) growth changes between childhood and old age. The three-dimensional coordinates of several soft-tissue landmarks on the ears and face were obtained by a non-invasive, computerized electromagnetic digitizer in 497 male and 346 female healthy subjects aged 4–73 years. From the landmarks, paired ear width and length, the relevant ratios, ear areas and angles relative to the facial midline, as well as indices of left–right symmetry, were calculated, and averaged for age and sex. Comparisons were performed by factorial analysis of variance. All ear dimensions were significantly larger in men than in women ($p < 0.001$). A significant effect of age was found ($p < 0.001$), with larger values in older individuals. The ear width-to-length ratio and the sagittal angle of the auricle significantly decreased as a function of age ($p < 0.001$) but without sex-related differences. On average, the three-dimensional position of ears was symmetric, with symmetry coefficients ranging between 92% and 96%. Asymmetry was found in the sagittal angle of the auricle (both sexes), in the ear width-to-length ratio and ear width (men only). Data collected in the present investigation could serve as a data base for the quantitative description of human ear morphology and position during normal growth, development and aging. Forensic applications (evaluations of traumas, craniofacial alterations, teratogenic-induced conditions, facial reconstruction, aging of living and dead persons, personal identification) may also benefit from age- and sex-based data banks.

1. Introduction

According to a Chinese belief, long ears indicate longevity [1,2]. Indeed, the ears are among those body structures that continue to grow along entire lifetime, well beyond the end of their organogenesis [3], and the attainment of skeletal maturity [2,4–12]. Therefore, as shown by both cross-sectional and longitudinal studies, older people tend to possess bigger ears [2,4–12]. Unfortunately, the observation of the coexistence of two conditions is not sufficient to demonstrate their association.

Nevertheless, the age-related changes in ear dimensions and position are being widely investigated across all ethnic groups. Apart from anatomical and anthropometric descriptions, knowledge of the qualitative and quantitative normal ear morphology can help in the clinical diagnosis of several developmental alterations. Postnatal abnormalities in ear dimensions and position are common findings in several alterations of the human chromosomes and karyotype, and in developmental defects of the first and second branchial arches [3,10,11,13–21]. For instance, in persons with Down's syndrome ear length and width are reduced, the earlobe is often more protruding from head surface, and there is an increased right–left asymmetry [10,11,13–16,19,22]. In contrast, wide ears can be found in Apert and Crouzon syndromes [1,10,19]. Low-set ears can be found in persons with Noonan syndrome [17,20], and with trisomy 13 and 18 [10]; prominent ears can be found in Turner syndrome [22]. Such modifications can be detected even during intrauterine life, and ear length has been recently, tentatively proposed as a further marker for ultrasound-based prenatal screening of aneuploidy [14,22,23].

Knowledge of the normal ear dimensions, position and symmetry is also necessary for the timing of surgical reconstructions [24–26], when the contralateral organ cannot be used as a template [1,4,5,10,12], and for the design of hearing aid instruments [1,10,26,27]. Additionally, earprints have a potential for personal identification, and reference anthropometric data that consider the age-related modifications are necessary. Sex-, age- and ethnic-related data banks may therefore be produced, supplying reference information for multiple diagnostic and forensic procedures (aging of both living and dead persons, personal identification, facial reconstruction) [2,9,27].

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Overall, quantitative data on the age-related changes in ear dimensions during growth, development and aging have been recently reported for Dutch Caucasian [2], German Caucasian [9], Italian Caucasian [6,7,11], North American Caucasian [5,28], Turkish Caucasian [1,19,26,27,29], Indian [10,12,30], Ashkenazi and Sephardi Jew [4], Japanese [8], healthy persons of both sexes.

In contrast, data about ear position and symmetry in European Caucasians are still scanty. For instance, ear position was investigated only between childhood and mid-adulthood [5,6,11,28]. Ear symmetry is often stated, but actual data were reported only between the second and the sixth decades of life [4,6,11]. Indeed, in contemporary western society, not only the number of aged persons is increasing, but also forensic investigations are currently performed on a wider age range than before, thus needing new reference data on each ethnic group.

For instance, personal identification greatly depends on facial characteristics [31], and the definition of age-, sex- and ethnic-specific data bases may help in the identification of those individual features that best discriminate among persons [32,33]. Additionally, there is an urgent need for age-related facial dimensions that may help in the aging of victims from pedo-pornography. Facial reconstructions also need data collected from living persons of the widest possible age span, supplying information that may assist in simulating the modifications of facial features during normal growth and aging [7,34,35].

In the current study, information about: (1) normal sex-related dimensions of ears (linear distances and ratios, area); (2) left–right symmetry; and (3) growth changes between childhood and old age, were provided. Data were collected non-invasively using digital anthropometry in healthy Italian Caucasians aged 4–73 years.

2. Materials and methods

2.1. Subjects

Data on 843 healthy white Italians aged 4–73 years were collected. The subjects were divided into several non-overlapping age groups (Table 1): for children and preadolescent subjects, 2-year spans were used, while larger intervals were used for adolescent and adult subjects.

Subjects with a previous history of craniofacial trauma, ear diseases, congenital anomalies or surgery were not included in the sample. They were previously informed about all the adopted procedures, and gave their consent to the investigation. Informed consent was also obtained from the parents/legal guardians of the subjects underage. The study protocol was approved by the local ethic committee.

The data collection procedure used in the current study is non-invasive, not potentially harmful, do not provoke pain and do not use any instrument or energy currently considered to be potentially dangerous to the present or future health of the subjects or of her/his offspring [6,11,36]. Additionally, great care was taken to use procedures provoking the minimal disturbance to the subject.

Part of the current data was previously published [6,11].

2.2. Collection of three-dimensional facial landmarks

The data collection procedure took place in two separate steps, and it was followed by off-line calculations [21,36]. At first, for each subject, a set of 50 soft-tissue landmarks was located by inspection and palpation [36], and marked on the cutaneous surface using a quick-drying, black, liquid eye-liner. The brush of the eye-liner leaves a small mark (about 1 mm in diameter), it is not toxic, and it can be cleaned out very easily. During landmark marking, the subjects sat relaxed with a natural head position.

Table 1
Subjects analyzed in the current study.

Age (years)	Males	Females
4–5	19	11
6–7	27	29
8–9	45	23
10–11	40	39
12–14	87	51
15–17	54	63
18–30	126	66
31–40	66	28
41–50	11	11
51–64	15	18
65–80	7	7
Total	497	346

In the second step, the three-dimensional (*x*, *y*, *z*) coordinates of the facial landmarks were obtained with a three-dimensional computerized electromagnetic digitizer (3Draw, Polhemus Inc., Colchester, VT). The system has an accuracy of 0.025 cm, a resolution of 0.013 cm/cm of range, and it supplies actual metric data independent from external reference systems. Digitization of landmarks was performed by a single operator.

During data collection, the subjects sat in a natural head position in a chair with a backrest, where a cephalostat allows to fix the subject's head. Vertically and horizontally movable systems allow to accommodate for different sitting heights and head dimensions. To obtain the natural head position, the subjects were asked to look at the reflected image of their eyes in a mirror positioned at eye level at approximately 2 m of distance. They were asked to close their eyes, to keep their teeth in contact (centric occlusion), and to not move for the duration of the data collection. Data collection takes approximately 1 min. Before discharging the subject, the computer performed a fast reconstruction of facial morphology using the three-dimensional coordinates of the collected landmarks, and a check between the video image and the face of the subject was made to assess the correct sequence of landmarks, and any motion artifact. The procedure was repeated immediately if necessary, and this occurred in 1% of acquisitions.

The reproducibility of landmark identification, marker positioning and the reproducibility of the data collection procedure were previously reported, and found to be reliable [11]. In men, Dahlberg's error on the coordinates of 50 landmarks was 1.20 mm; in women, it was 0.95 mm. The two values were practically identical when expressed as a percentage of the relevant nasion-mid tragion distances (respectively, 1.04% and 1.05%). The complete set of 50 landmarks allowed for the quantitative study of head, face, orbits, nose, lips and mouth, ears in the living human subjects [36].

In the present study, from the complete set of 50 landmarks the following paired soft-tissue landmarks were further considered (right and left side noted r and l): n, nasion; ex_r, ex_l, exocanthion; t_r, t_l, tragion; pra_r, pra_l, preaurale; sa_r, sa_l, superaurale; pa_r, pa_l, postaurale; sba_r, sba_l, subaurale (Fig. 1).

2.3. Data analysis

For all three cartesian coordinates *x*, *y*, *z*, errors were about 2 mm for duplicate landmark identification and marker positioning, and about 0.1 mm for duplicate collection of the same marker set.

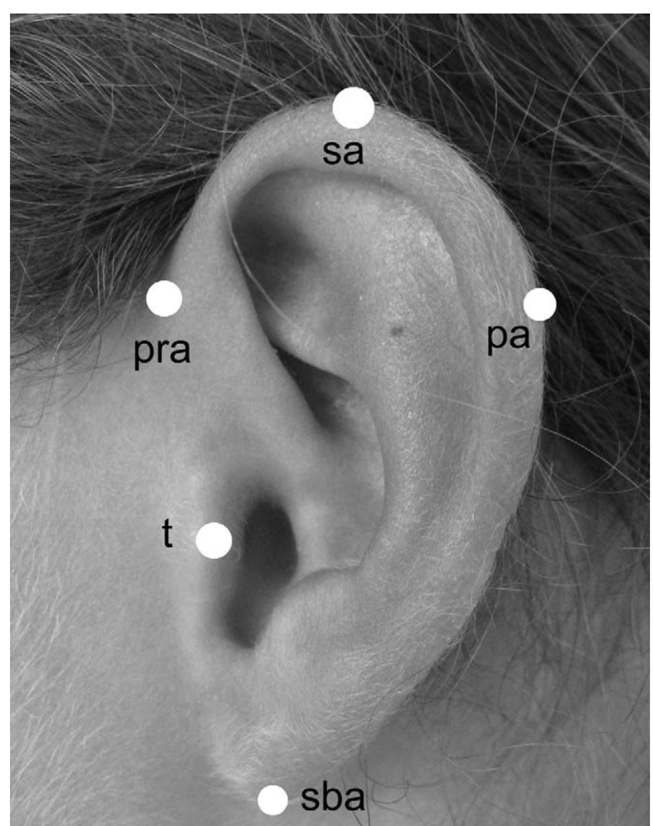

Fig. 1. Digitized three-dimensional soft-tissue ear landmarks used in the current study: t, tragion; pra, preaurale; sa, superaurale; pa, postaurale; sba, subaurale.

The *x*, *y*, *z* coordinates of the landmarks obtained on each subject were used to calculate the following measurements [6,11]:

- linear distances (unit: mm): right and left ear width (pra-pa); right and left ear length (sa-sba); tragion sagittal symmetry: absolute (signless) difference between the anteroposterior coordinates of right and left tragion; tragion vertical symmetry: absolute (signless) difference between the craniocaudal coordinates of right and left tragion;
- ratios (unit: percentage): right and left ear width to ear length (pra-pa/sa-sba $\times$ 100);
- areas (unit: cm^2): right and left ear area (area of the polygon between pra, sa, pa, sba, t);
- angles (unit: degrees): right and left angle of the auricle versus the facial midplane, computed as the angle between the t-pa line and the sagittal midplane passing through nasion and perpendicular to the ex_r–ex_l line;
- index (unit: percentage): three-dimensional symmetry index. For each ear, the spatial position of the center of gravity was computed from the *x*, *y*, *z* coordinates of pra, sa, pa, sba, t, and the distances of the same five landmarks from the relevant center of gravity calculated. The ten distances were summed. The differences between the positions of each pair (right and left) of landmarks were also assessed, and the sum of the five absolute (signless) differences obtained. The index was computed as 100 minus the percentage ratio between the sum of the differences and the sum of the distances. This index ranges between 100% (perfect symmetry) and 0% (no symmetry).

All measurements were performed in the three-dimensional space, *i.e.*, the position of landmarks relative to all the three planes (frontal, lateral and horizontal) was considered at the same time (no projections).

Descriptive statistics (mean and standard deviation) for each measurement were computed within sex and age group. Statistics of the angular measurements were computed by using the rectangular components of each angle.

Mean values between sexes and age groups were compared using two-way factorial analyses of variance. Mean right–left side values within sex and age groups were compared using two-way factorial analyses of variance. Significance was set at 1% ($p \leq 0.01$), with two-tail statistical tests used in all analyses. To identify different growth patterns before and after the attainment of skeletal maturity, data at each age group were expressed as a percentage of the value recorded in the 18–30-year-old subjects [9].

3. Results

On average, a significant effect of sex was found for all distances and areas (all measurements larger in men than in women of corresponding age), while no differences were found for the angles, the ratios and the symmetry indices (Tables 2–4). Age significantly influenced all analyzed measurements: linear distances, areas and symmetry increased from childhood to old age, while the sagittal angles of the auricle and the width-to-length ratios decreased as a function of age. In all occasions, men and women had different age-related patterns, with significant sex $\times$ age interactions.

At 4–5 years of age, ear length was approximately 90% (girls) and 84–86% (boys) of the relevant values recorded in the 18–30-year-old subjects; hereafter, the age-related increment was gradual in boys (Fig. 2). In contrast, in the 15–17 years old girls ear length was somewhat larger than in the reference "adult" group (Fig. 3). During adult aging, further gradual age-related increments were observed, and ear length reached 115% (51–64-year-old women) and 118–120% (65–80-year-old men) of the relevant mean value of the 18–30-year-old subjects. In the first age group, ear width was about 89% of the value recorded in the reference "adult" group, with subsequent increments up to 107% (women) and 108% (men) in the last age group. Similar trends were found for ear area, that started from 80% (boys) and 86% (girls), and reached 129% (men) and 126% (women) of its values recorded in the 18–30 years age subjects.

Table 2
Three-dimensional ear morphometry in healthy men.

Measurement	Unit	Age (years)	4–5	6–7	8–9	10–11	12–14	15–17	18–30	31–40	41–50	51–64	65–80
3D symmetry index	%	Mean	93.82	94.42	94.46	94.41	94.71	94.85	95.32	95.71	95.47	95.28	95.51
		SD	2.69	2.28	2.22	2.01	2.06	2.13	1.81	1.50	2.33	1.69	1.50
t sagittal symmetry	mm	Mean	6.03	2.11	2.28	3.62	2.74	2.79	3.28	3.95	3.53	2.77	4.76
		SD	3.40	1.94	1.47	2.67	2.02	2.15	2.37	2.68	2.25	2.18	4.34
t vertical symmetry	mm	Mean	10.02	2.73	3.17	3.51	3.02	2.88	2.28	3.10	3.38	3.58	3.98
		SD	3.36	2.09	2.36	2.52	2.05	2.08	1.63	2.46	2.70	2.41	2.02
Right side													
Ear width (pra-pa)	mm	Mean	34.16	34.95	35.95	36.91	36.91	36.37	37.54	39.15	39.99	38.99	40.53
		SD	2.27	2.46	2.51	3.42	2.97	2.83	3.36	3.03	3.22	3.75	4.51
Ear length (sa-sba)	mm	Mean	53.30	54.95	57.07	58.94	59.60	61.09	61.93	64.38	65.96	67.28	74.16
		SD	3.42	3.17	3.28	3.64	3.72	3.98	4.06	3.81	3.32	4.40	4.89
Pra-pa/sa-sba	%	Mean	64.18	63.66	63.06	62.70	62.04	59.63	60.70	60.90	60.69	57.93	54.56
		SD	3.84	3.89	4.07	5.19	4.80	4.18	4.69	4.54	4.76	3.83	3.55
Ear area	mm^2	Mean	919.16	939.91	988.88	1015.61	1057.62	1073.02	1117.09	1197.50	1260.42	1271.26	1451.66
		SD	105.49	95.58	100.48	140.31	133.19	134.67	137.44	136.15	133.3	184.72	213.61
Angle of the auricle	deg	Mean	35.36	35.78	35.87	31.38	32.36	32.95	32.12	27.39	34.56	29.89	30.12
		SD	8.03	6.19	9.08	7.73	7.73	7.09	6.67	7.35	2.92	7.68	7.69
Left side													
Ear width (pra-pa)	mm	Mean	31.93	34.86	35.71	36.38	35.84	35.93	36.67	38.73	39.12	38.62	39.74
		SD	3.04	2.72	2.46	3.44	2.91	3.05	3.52	3.25	2.86	4.30	4.33
Ear length (sa-sba)	mm	Mean	52.74	54.85	57.74	58.91	59.60	62.18	62.19	64.88	65.77	66.70	73.13
		SD	3.69	2.91	2.69	3.59	3.80	5.09	4.08	3.74	3.70	5.25	6.00
Pra-pa/sa-sba	%	Mean	60.58	63.63	61.93	61.81	60.26	57.98	59.04	59.76	59.57	57.94	54.29
		SD	4.63	4.72	4.60	5.16	4.96	5.22	5.03	4.59	4.42	5.11	2.65
Ear area	mm^2	Mean	850.44	926.96	995.02	1017.13	1039.9	1088.27	1104.03	1192.94	1237.46	1275.22	1411.80
		SD	128.37	97.00	92.67	130.62	117.59	141.60	141.34	135.34	147.88	212.70	274.60
Angle of the auricle	deg	Mean	43.06	39.69	40.30	33.29	35.21	36.20	34.42	30.52	34.88	32.60	28.89
		SD	8.86	6.64	8.04	7.70	7.50	6.55	7.38	7.14	6.43	7.72	5.82

Table 3
Three-dimensional ear morphometry in healthy women.

Measurement	Unit	Age (years)	4–5	6–7	8–9	10–11	12–14	15–17	18–30	31–40	41–50	51–64	65–80
3D symmetry index	%	Mean	91.75	95.10	94.53	95.45	94.38	94.81	94.62	95.41	95.30	95.42	94.18
		SD	1.85	1.86	2.14	1.72	1.85	2.06	2.15	1.64	1.26	1.51	2.96
t sagittal symmetry	mm	Mean	4.96	2.45	2.69	1.99	3.29	2.94	3.14	3.07	2.71	4.17	2.88
		SD	3.47	1.87	2.36	1.71	2.92	2.17	2.30	2.32	2.14	2.77	1.97
t vertical symmetry	mm	Mean	7.22	3.54	2.67	2.51	2.89	2.75	2.30	2.34	1.90	3.26	3.68
		SD	3.85	1.96	2.03	1.96	2.43	2.05	1.77	1.68	1.34	2.04	1.12
Right side													
Ear width (pra-pa)	mm	Mean	31.99	33.17	33.22	33.78	34.41	35.74	34.51	35.72	35.70	35.32	36.13
		SD	1.71	2.56	3.50	2.97	2.89	3.12	2.96	2.78	3.65	3.45	2.62
Ear length (sa-sba)	mm	Mean	50.30	52.84	53.40	54.97	57.00	60.26	56.11	58.43	61.57	64.80	64.02
		SD	3.05	3.73	3.38	3.69	3.65	4.34	4.31	2.79	2.96	3.80	5.03
Pra-pa/sa-sba	%	Mean	63.85	62.92	62.17	61.58	60.46	59.38	61.67	61.20	57.95	54.54	56.60
		SD	5.65	4.68	4.97	5.25	4.73	4.05	4.95	4.74	4.65	4.76	4.24
Ear area	mm^2	Mean	828.94	857.34	879.57	896.29	938.91	1042.54	927.30	973.43	1039.01	1092.19	1146.05
		SD	77.18	103.60	131.35	115.15	123.26	148.88	121.73	91.17	161.22	135.83	106.37
Angle of the auricle	deg	Mean	31.22	35.52	37.98	36.75	30.61	33.25	32.30	30.56	27.67	29.43	18.43
		SD	5.13	9.54	6.95	7.58	7.43	7.05	7.61	8.35	8.20	5.45	6.69
Left side													
Ear width (pra-pa)	mm	Mean	29.55	33.33	32.79	34.09	33.98	35.55	34.42	34.91	36.57	35.54	37.57
		SD	2.29	1.66	2.64	2.71	3.03	3.21	3.05	3.09	3.35	3.17	3.67
Ear length (sa-sba)	mm	Mean	50.63	52.84	54.04	55.52	56.99	61.38	56.36	58.89	60.91	64.91	64.70
		SD	2.64	3.33	2.88	3.49	3.76	5.22	4.05	2.89	1.91	3.51	5.09
Pra-pa/sa-sba	%	Mean	58.52	63.26	60.69	61.46	59.71	58.10	61.19	59.29	60.01	54.85	58.27
		SD	5.48	4.17	3.79	4.23	4.97	5.04	4.92	4.73	4.71	5.11	6.50
Ear area	mm^2	Mean	762.09	849.37	871.70	912.48	938.90	1060.07	932.25	953.66	1037.54	1116.42	1188.91
		SD	58.99	75.26	108.75	113.89	117.48	154.35	115.92	109.81	134.28	145.25	138.36
Angle of the auricle	deg	Mean	33.48	40.37	40.25	40.10	35.69	36.22	32.37	30.93	27.28	29.69	25.41
		SD	5.67	7.38	7.82	6.33	8.27	6.42	6.87	9.00	6.28	7.04	4.93

In boys, the angle of the auricle decreased during the analyzed time span, starting at 4–5 years from 110 (right side) and 125% (left side) of the relevant adult "reference" value, and reaching 94 (right side) and 84% (left side) in the oldest men (Fig. 4). In girls, the pattern was more scattered, with a gradual increment in the first age groups, and subsequent reductions (Fig. 5).

In both sexes, ear length increased more than ear width (approximately, 3.2 times more in women, and 2.8 times in men); in the first age groups, the width-to-length ratios were larger than those recorded in the 18–30-year-old subjects (up to 103% in girls, 106–108% in boys), and decreased to 90% of the relevant reference values in the oldest subjects.

In women, right and left side linear distances, area and ratio were symmetric ($p > 0.01$ in all occasions), while the left side angle of the auricle was significantly larger than the right side angle. In men, a significant asymmetry was found for ear width, the angle of the auricle (for both variables, the left side was larger than the right side) and the width-to-length ratio (right side larger than left side).

On average, the tragion vertical symmetry (relative vertical position between the left and the right side tragi) was somewhat larger than the tragion sagittal symmetry (relative anteroposterior position between the left and right tragi), but the difference was particularly evident in the first age group. Indeed, the 4–5 years old children had the largest absolute asymmetry in both sexes (up to

Table 4
p-values from the two-way factorial analyses of variance.

Measurement	Sex	Age	Sex × age
3D symmetry index	NS	<0.001	<0.001
Tragion sagittal symmetry	NS	<0.001	<0.001
Tragion vertical symmetry	NS	<0.001	<0.001
Right side			
Ear width (pra-pa)	<0.001	<0.001	<0.001
Ear length (sa-sba)	<0.001	<0.001	<0.001
Ear width to ear length	NS	<0.001	<0.001
Ear area	<0.001	<0.001	<0.001
Sagittal angle of the auricle	NS	<0.001	<0.001
Left side			
Ear width (pra-pa)	<0.001	<0.001	<0.001
Ear length (sa-sba)	<0.001	<0.001	<0.001
Ear width to ear length	NS	<0.001	<0.001
Ear area	<0.001	<0.001	<0.001
Sagittal angle of the auricle	NS	<0.001	<0.001

Degrees of freedom: Sex 1821; Age 10,821; Sex × age 10,821. NS: Not significant ($p > 0.01$).

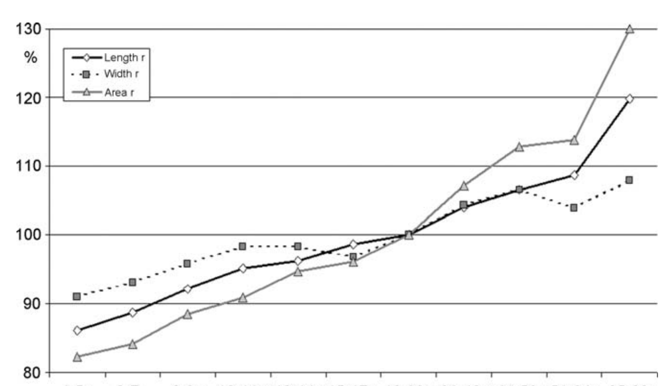

Fig. 2. Age-related modifications in male auricular dimensions (right side). All values are expressed as a percentage of the mean value in the 18–30 years age group.

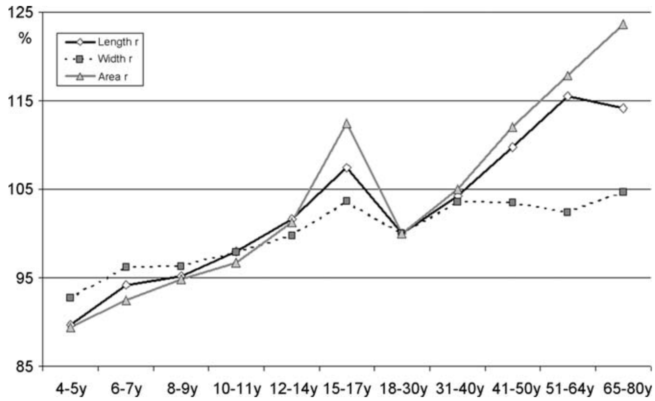

Fig. 3. Age-related modifications in female auricular dimensions (right side). All values are expressed as a percentage of the mean value in the 18–30 years age group.

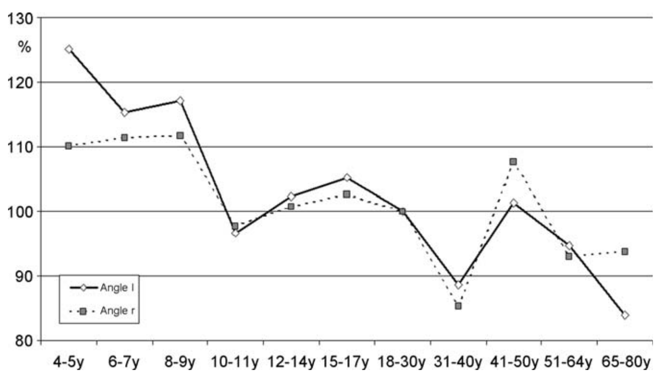

Fig. 4. Age-related modifications in male angle of the auricle. All values are expressed as a percentage of the mean value in the 18–30 years age group.

10 mm, vertical symmetry in boys). In all other age groups, values up to 4.8 mm were found.

At the same time, the three-dimensional symmetry index, which informs about the relative positions of the five ear landmarks, was larger than 94% in all age groups except the first one, showing a minimal asymmetry in both sexes and at all ages.

4. Discussion

A deep knowledge of the dimensions and relative positions of facial structures in the different age and ethnic groups, as well as in the two sexes, is necessary for a correct reconstruction of the global facial appearance, both for surgical and forensic purposes [4,12,21,24,25,35].

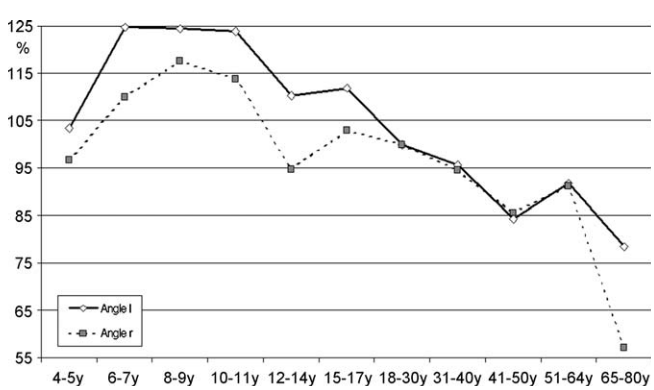

Fig. 5. Age-related modifications in female angle of the auricle. All values are expressed as a percentage of the mean value in the 18–30 years age group.

In the last 15 years, ear dimensions have been investigated in several ethnic groups, using both three-dimensional direct and indirect anthropometry, and photography [1,2,4–12,19,26–30]. Overall, notwithstanding ethnical variations in actual ear dimensions and position [2,4,10,12,17,20], all investigations found that the human auricle continues to grow well beyond the attainment of skeletal maturity.

With aging, progressive modifications of the microscopic structure of ear cartilage have been reported, with reductions in elastic fibers and in the density of cartilage cells [8]. Age-related reductions of skin elasticity and resilience were also mentioned [10]. Overall, the observed microscopic modifications may explain the macroscopic increments in ear dimensions.

Boys and men had larger ears than girls and women, a finding in accord with the previous studies [1,2,4–9,11,26,27,30]. The sexual dimorphism in ear dimensions appears to begin with postnatal growth: at birth, and within the first 24 months of life, similar dimensions in newborn and children boys and girls were found in almost all studies [17,19,20,26]. Only Agnihotri and Singh [30] reported significantly larger ears in Indian boys than in girls at birth and in the first months of life.

Because of significant sex and age interaction, differences were found in the patterns of increment between sexes. Similar findings were reported for adult Dutch and German Caucasians [2,9]. In Japanese subjects, Ito et al. [8] found that between birth and 99 years of age the increment was continuous in women, but it stopped around 50 (ear width) and 70 (ear length) years of age in men. The same finding was reported by Meijerman et al. [2], who stated that auricle expansion has a slower start in women than in men, but it continues to an older age.

In the present investigation, the post-maturity growth of ear dimensions continued in both sexes without apparent stops. Overall, in the different age groups of the current report ear length was somewhat smaller, especially in women, while ear width was larger, than that reported by Ito et al. [8]. Ear shape, therefore, seems different in the two ethnic groups; unfortunately, no other comparable measurements were found in the quoted study. Similar differences were observed in comparison with the photographic investigation performed by Meijerman et al. [2], and with the anthropometric studies made by Bozkir et al. [1] and Kalcioglu et al. [26].

In the current and in previous reports [2,7,9,10], the age-related modifications were not identical for all dimensions: ear length and area increased faster than ear width, with subsequent modifications in global ear shape (as assessed by the ear width-to-length ratio). In contrast, no age-related variations in auricular index were found in Indian men, who had on average smaller ears than the current men [10].

According to Brucker et al. [5], aging involves only modifications in auricular lobule, without actual increments in the other structures, but this finding was denied by subsequent studies [2,9,10]. Ear area [6,11,21] was proposed by Chang et al. [14] as prenatal, intrauterine marker of fetal aneuploidy, but it was not reported in other postnatal investigations, even if it could well discriminate between normal persons and persons with Down's syndrome [11].

The adult increments in auricular dimensions cannot be explained by natural selection: it is not true that persons with bigger ears live longer [1,2]. Gualdi-Russo [7] performed a longitudinal anthropometric study with a 10-year follow up period; at the second examination, persons were aged 31 to more than 60 years. Significant age-related increments in ear length were found, with smaller, not significant variations in ear width. Nevertheless, when the various age groups were considered all together (as in a cross-sectional investigation), between 21 and more than 60 years ear length increased by 8.7 mm in men and by

8 mm in women (both increments were statistically significant), and ear width increased by 2.9 mm (men; $p < 0.05$) and 1.9 mm (women).

As expected, childhood and adolescent growth patterns were on average faster than those reported during aging [8,9,12,26]. The growth patterns for ear dimensions before young adulthood reported by Farkas et al. [28] were practically identical to the present ones: between 12 and 14 years of age both ear dimensions have attained adult values in girls (about 98–100% of the values found at 18 years of age), while in boys the adolescent growth is not finished yet [19]. Indeed, the pattern is similar to that found for overall facial growth: at 13–14 years of age, while girls had almost reached adult values, in boys large increases were still to occur [36]. Overall, current ear linear dimensions in children and young adults were well comparable to the data reported by Farkas et al. [28].

A limited number of studies reported data on ear position, notwithstanding the importance of this information [3,24,26]. Among the others, the position relative to other facial reference landmarks [5,24,25], and the protrusion from the mastoid bone [1,10,19,26] were reported. Overall, in adult persons all these measurements did not seem to vary according to constant patterns, a finding contrasting with the present modifications in auricular angle relative to the facial midplane. In children, ear protrusion from the mastoid was found to increase from birth to approximately 6 years of age [26]. The use of angular values allows assessments independent from actual head dimensions, that are likely to change during growth. On average, all current values were within normal ranges [3,26], and decreased with age, as reported also by Meijerman et al. [2]. This information is important for a correct timing of surgical reconstruction, especially during growth.

Ear position, as assessed by the auricular angle, was significantly asymmetric in both sexes, a finding in accord with Lian et al. [20], who found a 5% difference in the vertical ear position at birth, and with Coward et al. [24], who found differences in ear position relative to midline facial landmarks. This value is in accord with the current tragion vertical asymmetry index. Overall, asymmetry in linear dimensions was found only in male ear width, and in the width-to-length ratio, while women were more symmetric. Only few previous studies reported ear asymmetry, and with contrasting findings: in adult Jews, the left lobule was found to be smaller than the right one [4], but in Indian men no side differences were reported [12]. Ear dimensions in adult Turkish Caucasians were symmetric [1], but asymmetry was found between 6 and 13 years of age [27]. Interestingly, boys were somewhat more asymmetric than girls: their ear was wider on the left than on the right side. Adult Indian men had somewhat larger right than left ears; the differences were significant especially for ear width [10]. Asymmetry in ear length was reported by Coward et al. [24].

When global ear asymmetry was assessed using the three-dimensional symmetry index, subjects of the present study seemed to possess symmetrically positioned ears. Children in the 4–5 years age group had the largest ear asymmetry (both when assessed three-dimensionally and in ear width), a finding of difficult explanation. In a cross-sectional study, Ferrario et al. found that facial asymmetry was larger in adolescents than in adults [37]: small growth imbalances between the two facial sides may be considered even in the current children. Considering the lack of detailed literature data on this topic, a deeper assessment of ear symmetry is necessary to obtain more insight into its significance [38]. Its worthwhile to mention that ear asymmetry help to differentiate between normal persons and cases with trisomy 21 [11].

The number of subjects examined in the present investigation is comparable to that analyzed in several cross-sectional [1,5,9,12,27,28] and longitudinal [7] anthropometric investigations, even if some studies analyzed one or two thousands of individuals [2,8,17,26,29]. It has to be mentioned that in some of those investigations only selected linear distances were measured [2,8,17], two-dimensional measurements were used [2], and only some age groups were analyzed [2,17,26,29]. In the current study, the number of subjects was reduced in the first and last age groups, and these should be implemented with new healthy children and adults. Data collected in the present investigation could represent a useful data base for the quantitative description of ear morphology and position in normal Italian Caucasian subjects.

5. Conclusion

In the current study, a detailed information about the normal sex- and age-related linear and angular ear dimensions in healthy Italian Caucasians were provided. The analyzed age interval covered eight decades of life, being the largest three-dimensional study for Caucasians reported in literature. Overall, when compared to literature data, some differences were found, pointing out the necessity of data collected on each ethnic group. The age-related trends for linear dimensions were similar to those found in most previous studies, showing progressive increments of ear dimensions with advancing age; ear length increased more than ear width. Data about symmetry and angular position of the auricles were provided, allowing a more complete description of facial morphology.

Data collected in the present investigation could serve as a data base for the quantitative description of human auricular morphology during normal growth, development and aging, also considering sex- and ethnic-related variations. Soft-tissue facial characteristics are among the most used for personal identification, and knowledge of their age-related modifications is necessary to build data banks informative for forensic investigations. Among the others, the detection of facial dimensions that remain stable over time (or that have reduced age-related variations) may help in personal identification even years after the actual crime. A further application (using those characteristics that show the largest age-related variations) may be the estimation of the age of both living and dead persons, using direct measurements as well as photographic records. The same data may enter into simulations of facial growth and aging, helping in personal identification.

Conflict of interest

The authors have no conflict of interest related to the current investigation.

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