Aesth Plast Surg (2018) 42:766–773
https://doi.org/10.1007/s00266-017-1027-4

ORIGINAL ARTICLE FACIAL SURGERY

Three-Dimensional Analysis of the Ear Morphology

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Received: 20 August 2017 / Accepted: 2 November 2017 / Published online: 20 December 2017

Abstract

Background For surgical treatment of the face, detailed surgical planning is necessary to avoid later unaesthetic results. Most of the studies in the literature concentrate on the ears' anatomy during childhood and adolescence. Nearly no study evaluates the anatomy of ears of people aged 50 or older. It was our aim to measure and evaluate the ear's anatomy in Caucasians between the ages of 21 and 65.

Methods Three-dimensional scans of 240 volunteers were taken. The subjects were divided into groups of males and females and each of them into three groups by age (21–35, 36–50, 51–65). Landmarks were placed in these scans. Distances, relations and angles between them were recorded.

Results The distance between the subaurale and superaurale significantly increases ($p < 0.001$) during the aging process in males and females. Also, the width of the ear, measured between the preaurale and postaurale, significantly increased ($p = 0.007$) with advancing age. When the length of the ear is divided into four parts by anatomical landmarks, it extended the most in the lower quadrant with increasing subject age.

Conclusion The ear of Caucasians does not stop changing its shape during adulthood. Even after the body has stopped growing, the ear still does. With the measured values in this study, it should be possible for the surgeon to plan the operation in advance and achieve satisfactory aesthetic outcomes.

Level of Evidence V This journal requires that authors assign a level of evidence to each article. For a full description of these Evidence-Based Medicine ratings, please refer to the Table of Contents or the online Instructions to Authors www.springer.com/00266.

Keywords Ear morphology · Facial scanning · Three-dimensional

Introduction

Since antiquity, humans have assessed facial proportions as the basis for attractiveness [1]. These studies investigate facial morphology with regard to ethnic variations [2], age differences [3], gender differences [4] and characteristics of attractiveness. Some studies described attractiveness as: averageness [5, 6], sexual dimorphism [7], the appearance of childlikeness [8] and symmetry [9]. All studies in this field reported specific standard values of different ages and ethnic groups. Such data are useful for surgeons to reconstruct facial proportions and to achieve aesthetic results in regular clinical practice.

Surgeons rely on personal experience for aesthetic results. Whereas, nearby structures or symmetry may help in orientation during the operation, there are not always natural contours on which to rely. In that case, it is important to be aware of certain distances and angles of particular facial parts. Detailed therapy planning is required to determine what operation and transplantation methods and materials fit the best; for example, proper placement of the incision line without destroying the

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natural proportions, and the use of the incision line to conceal prospective scars to make it look natural [10]. Surgeons do not only need this knowledge for average patients, but also for patients of different ages and gender.

Because certain parts of the ear undergo various changes during a lifetime, the surgeon has to account for such variations to provide a suitable treatment for patients of varying ages [3]. Most existing publications concentrated on morphological changes during childhood and adolescence and extended to about 18 years [11]. Abundant measurements and norms have been reported for people aged 18–35 [2, 12]. However, the progress of morphological changes in adult ears is fragmentarily documented. To facilitate individual treatment planning for various ages, age-dependent standard values are strongly needed [3]. For example, following the norms of a mid-20s person, on which most of the available standard values are based, may look artificial in a 50-year-old.

Calculated standard values are essential for diverse surgical adult treatments. The ear undergoes surgical treatment for various reasons including: tumor therapy, trauma therapy, bite wounds and use of the cartilage for other reconstructions. Besides that, the ear is the subject of aesthetic-plastic interventions.

In view of these observations, the purpose of this study was to supply anthropometric data on the ears of Caucasian subjects using a modern measurement technique.

Materials and Methods

After institutional approval and informed consent, we divided 240 volunteers (120 female and 120 male Caucasians) into six groups of 40 subjects each. The groups consisted of three female subgroups: F1 (age 21–35), F2 (age 36–50), F3 (age 51–65) and three male subgroups: M1 (age 21–35), M2 (age 36–50), M3 (age 51–65). All volunteers were scanned with FaceScan3D (FaceScan3D; 3D-Shape GmbH, Erlangen, Germany). The acquired 3D data were imported into OnyxCeph version 3.2.45 (Image Instruments, Chemnitz, Germany). Facial landmarks were set to the volunteers' 3D scans and the software calculated distances, angles and proportions.

Exclusion criteria for the study were: prior injuries or operative treatments of the ears, wearing earrings, and non-Caucasian subjects.

FaceScan3D

FaceScan3D is an optical 3D scanner for acquiring a digital surface scan of the human face. The structured light technique is used to acquire 3D surface information. No physical contact or ionizing radiation is employed. To acquire this information, the scanner utilizes two black and white cameras, a commercial digital SLR camera and an LCD projector, as well as two professional flashes. A mirror configuration surrounds a volunteer's face permitting a 180° panoramic record to be taken in one single shot. One recording takes 800 ms. As stated in the technical data provided by 3D-Shape, FaceScan3D has a precision of 0.1 mm. A commercial personal computer controls the scanner. This computer uses Slim3D software (3D-Shape GmbH, Erlangen, Germany) for post-processing raw data acquired by the cameras. Finally, a 3D model consisting of triangles with texture information is exported as a Wavefront Object (.obj) file with its texture information stored in a Joint Photographic Experts Group File Interchange Format (.jpg) and a Material Template Library file (.mtl) file. The mean error in measuring distances using this method is 1.17 mm [13]. Each volunteer was scanned similarly: seated inside the mirror construction and aligned with the crosshairs projected by FaceScan3D. Subjects were instructed to relax their face and look towards the scanning unit.

Scan Analysis

The facial datasets were imported into commercially available orthognathic planning software (OnyxCeph version 3.2.45). Using this software, distances, angles and proportions were measured. Ultimately, for adequate orthognathic therapy, measurement parameters can be set by the user. Points necessary for planned facial analysis were patched into this software. All distances, angles and proportions between these landmarks were calculated automatically.

The landmarks to optimally show extensions and proportionality of the ear were selected. A clearly definable position of the landmark, typically a point of strong convexity or concavity, was required. The definitions of the landmarks (Table 1) were described previously by Swennen et al. and Sforza et al. [14, 15].

The angle between SupAu–SubAu and PreAu–PostAu could not be measured in the three-dimensional view because the points did not have an intersection in common. Thus, reference planes were constructed. These were the Camper projection plane, defined by the two Tragion points and Subnasale, as well as the sagittal plane, vertically positioned on the Camper projection plane meeting Subnasale, and the midpoint between the two Tragion points. SupAu–SubAu and PreAu–PostAu were projected perpendicularly on the sagittal plane and the measurement of the angle between them taken within that plane.

Chosen measuring points for the lateral ear are shown in Fig. 1. Figure 2 shows the measured relation.

Table 1 Definitions and abbreviations of chosen landmarks

Abbreviation	Landmark	Definition
Tra	Tragion	Point at the upper margin of the tragus
SupAu	Superaurale	Most cranial point of the ear
SubAu	Subaurale	Most caudal point of the ear
PreAu	Preaurale	Most ventral point of the ear
PostAu	Postaurale	Most dorsal point of the ear
Osup	Otobasion superius	Cranial point of the attachment of the ear to the cheek
Oinf	Otobasion inferius	Caudal point of the attachment of the ear to the cheek
Ia	Incisura anterior	Point of highest concavity at the anterior notch between the cranial origin of the helix and the tragion
ITra	Incisura intertragica	Point of highest concavity on the inner helix between tragion and antitragion

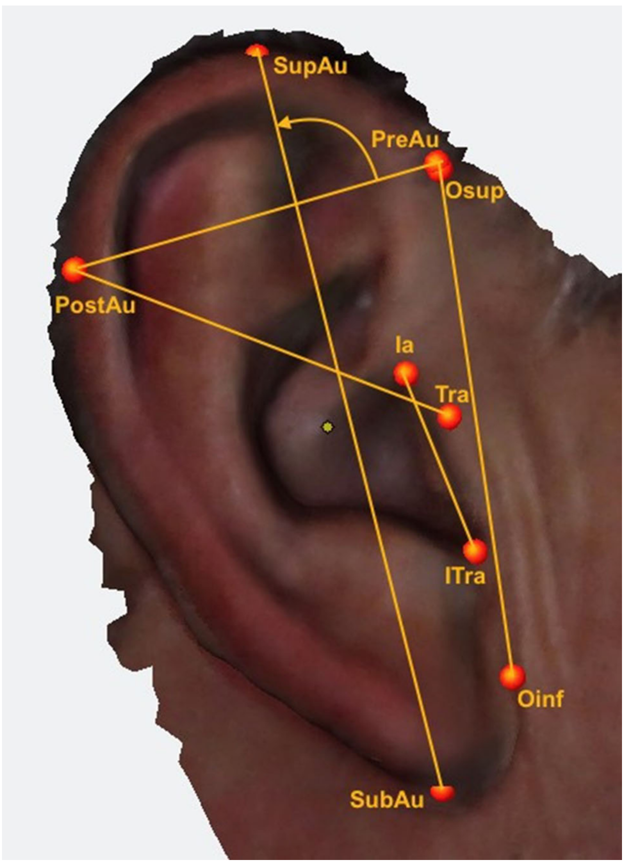

Fig. 1 Measuring points ear lateral

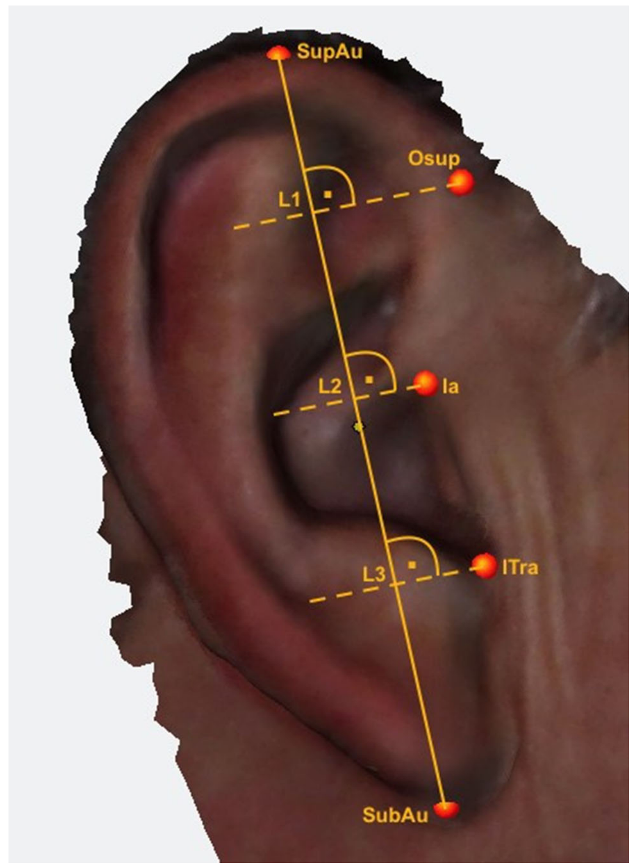

Fig. 2 Four quadrants of the ear

Statistical Analysis

First, we averaged the values of a total of 480 ears for each volunteer and the resulting 240 datasets were statistically analyzed with Prism GraphPad Version 6 (GraphPad Software, Inc. La Jolla USA). The data were checked for normality using the D'Agostino-Pearson normality test in omnibus K2 variant. The data were normally distributed. For statistical analysis between the male and female groups, a *t* test was used. For analysis between groups of different ages, a one-way ANOVA analysis of variance was performed. The level of significance was set to $p \leq 0.05$. All data were expressed as mean values ± standard deviation.

Results

Ear Lateral

Table 2 shows measured values for SubAu–SupAu and associated p values. With increasing age, the distance between superaurale and subaurale increased significantly in males and females ($p < 0.001$) with increasing age. Figure 3 demonstrates the increase of the distance between superaurale and subaurale.

Table 3 illustrates the results of the other measured distances. Also, the distances increase with advancing age—in particular, the distance between preaurale and postaurale is age-dependent. All values are significantly higher for men than for woman. The angle between the distances SubAu–SupAu and PreAu–PostAu does not show a correlation with the aging process, but shows a significant dependence on gender. The difference between men and women in the relation Ia–Itra: Osup–Oinf is statistically significant also.

Four Quadrants of the Ear

As shown in Fig. 2, the ear was divided into four distances by anatomical tissue points. Distances between them are shown in Table 4 for the different groups. Because the distances between superaurale, L1, L2 and L3 show a slight dependence on age, the largest increase during adulthood takes place in the distance L3–Subaurale. This increase is significant. Figure 4 demonstrates the increase of the distance between L3 and SubAu.

Using the anatomical tissue landmarks to divide the ear into four parts, the percentage distribution for both genders is as shown in Fig. 5. The lengths between the selected tissue landmarks in Fig. 5 are expressed as part of the total length.

Discussion

The techniques of anthropometry include: classical measurements using a spreading caliper, two-dimensional photographs, laser-scanning, cephalometry, computed tomography, magnetic resonance tomography and three-dimensional surface imaging based on passive or active triangulation [12, 16–20]. Regarding anthropometrical surface measurements, the triangulation systems are advantageous. This is because performing the investigation that way only needs a few minutes—mainly for positioning the volunteer. Moreover, taking the three-dimensional photograph requires less than 1 s. Additionally, the volunteer is not exposed to ionizing radiation throughout the

Table 2 Measured values for the distance between SubAu–SupAu and associated p values

Ear lateral	*M1*	*M2*	*M3*	*F1*	*F2*	*F3*	*M*	*F*	All
SubAu–SupAu (mm)	62.72 ± 3.66	66.15 ± 3.60	68.19 ± 4.04	58.85 ± 3.02	61.65 ± 4.40	63.08 ± 4.36	65.68 ± 3.77	61.19 ± 3.93	63.44 ± 3.85
p value			< 0.001			< 0.001		< 0.001	

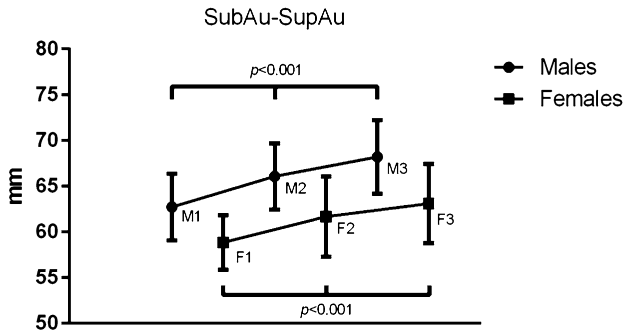

Fig. 3 Increase of distance between SubAu and SupAu in different groups depending on gender

investigation [13, 19, 21]. Optical three-dimensional face scans are used in craniofacial surgery for diagnostics and therapy planning—customarily in addition to common techniques such as radiographs. Furthermore, they can be applied as a control tool during operations and postoperatively in the context of follow-ups of surgical interventions [22–24]. The accuracy of modern optical 3D scanners is sufficient for this medical purpose [13, 21, 25]. In contrast, many of the existing measurements—and especially those with a larger number of Caucasian test persons and landmarks—were performed with outdated techniques, e.g. measuring with a spreading caliper [2, 3, 12]. Nowadays, superior techniques like the above-mentioned triangulation systems are available [13, 19].

Another shortcoming in the existing literature is that the overwhelming majority of existing studies concentrate on measurements over the entire face [2, 12, 26, 27], whereas only few focus on specific parts of the face, e.g. the ear [28, 29]. So far, the benefit to surgical interventions that usually take place in limited facial areas, e.g. the upper lip or nose is small. Concerning the selection of volunteers, prior investigations used mainly younger adult volunteers, mostly between 18 and 35 years [2, 12, 17]. In contrast, the morbidity and thus the necessity of reconstructive interventions, grow with increasing age. Hence, the surgeon should perform an aesthetic facial reconstruction considering the actual age of the patient. However, gathering information for natural proportions of older adults is difficult.

The shape of the ear of each human being is asymmetric, but there is no accordance in the literature of how the asymmetry exactly occurs, e.g. that the right ear would always be 3% bigger than the left ear [12, 15]. In the present study the mean values of right and left ear were used due this knowledge and to give a database of average ears for different ages and gender.

As a result of these observations, the aim of the present study was to create a database of measurements of the ear as a part of the face, which can impact various surgical

Table 3 Measured values for the distance between landmarks on the lateral ear and associated *p* values

Ear lateral	*M1*	*M2*	*M3*	*F1*	*F2*	*F3*	*M*	*F*	All
PreAu–PostAu (mm)	32.66 ± 3.27	34.06 ± 2.82	36.34 ± 2.83	31.61 ± 2.57	33.08 ± 2.78	33.82 ± 2.27	34.35 ± 2.97	32.84 ± 2.54	33.60 ± 2.76
p value			0.007			0.002		0.007	
Tra–PostAu (mm)	37.94 ± 2.69	38.19 ± 2.82	38.93 ± 2.97	34.20 ± 2.59	34.78 ± 3.02	36.01 ± 2.95	38.35 ± 2.83	34.99 ± 2.85	36.67 ± 2.84
p value			0.186			0.025		< 0.001	
Osup–Oinf (mm)	46.27 ± 4.11	49.51 ± 5.26	48.50 ± 3.70	3.71 ± 3.33	44.14 ± 3.80	45.58 ± 4.86	48.10 ± 4.36	44.48 ± 4.00	46.29 ± 4.18
p value			0.009			0.094		< 0.001	
Ia–ITra (mm)	17.86 ± 1.24	17.77 ± 1.18	18.75 ± 1.58	16.05 ± 1.15	16.29 ± 1.59	16.54 ± 1.35	18.13 ± 1.33	16.29 ± 1.36	17.21 ± 1.35
p value			0.002			0.293		< 0.001	
(SubAu-SupAu)−(PreAu-PostAu) (°)	79.98 ± 6.76	80.67 ± 6.88	78.63 ± 6.29	76.56 ± 7.67	77.89 ± 7.01	78.70 ± 6.81	79.76 ± 6.76	77.72 ± 7.17	78.74 ± 6.90
p value			0.344			0.384		0.025	
Ia–ITra: Osup–Oinf (%)	38.60	35.89	38.66	36.71	36.90	36.29	37.69	36.63	37.16
p value			0.004			0.789		0.016	

Table 4 Measured values for the ear divided in quarters and associated *p* values

Quadrants of ear	*M1*	*M2*	*M3*	*F1*	*F2*	*F3*	*M*	*F*	All
SupAu–L1 (mm)	12.88 ± 2.58	12.56 ± 2.01	12.90 ± 2.24	11.70 ± 1.83	12.66 ± 2.39	12.81 ± 2.51	12.78 ± 2.27	12.39 ± 2.24	12.58 ± 2.26
p value			0.742			0.051		0.217	
L1–L2 (mm)	18.27 ± 2.58	19.91 ± 2.48	20.04 ± 2.29	17.46 ± 1.76	17.38 ± 2.42	17.22 ± 2.53	19.41 ± 2.45	17.35 ± 2.24	18.38 ± 2.35
p value			0.022			0.888		< 0.001	
L2–L3 (mm)	16.94 ± 1.32	16.95 ± 1.28	17.76 ± 1.48	15.11 ± 1.20	15.31 ± 1.65	15.58 ± 1.49	17.22 ± 1.36	15.33 ± 1.45	16.28 ± 1.40
p value			0.007			0.404		< 0.001	
L3–SubAu (mm)	14.63 ± 2.49	16.63 ± 2.74	17.49 ± 2.68	14.58 ± 1.72	16.29 ± 2.48	17.47 ± 2.58	16.25 ± 2.64	16.11 ± 2.26	16.18 ± 2.45
p value			< 0.001			< 0.001		0.592	

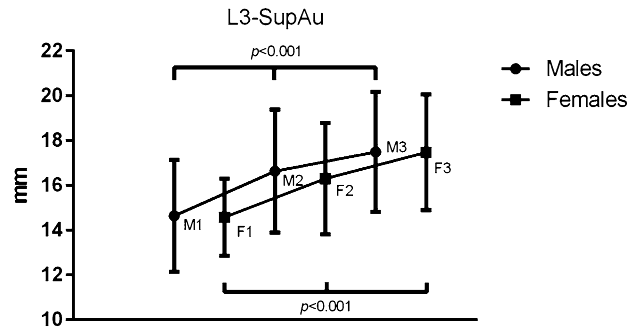

Fig. 4 Increase of distance between L3 and SubAu in different groups depending on gender

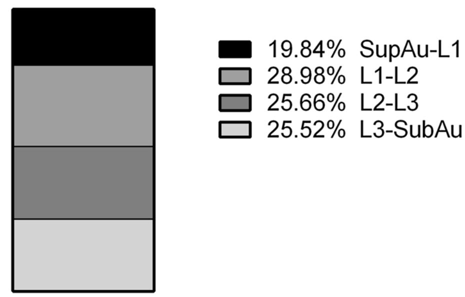

Fig. 5 Distribution of length in the four quadrants of the ear in both genders

treatments. Therefore, one of the main goals was to acquire a homogenous collection of volunteers from the age of 21–65 to simplify individual therapy planning for people of varying ages.

Another consideration involves the lateral part of the ear during photography—mainly using the mirror construction of FaceScan3D. A difficulty for three-dimensional photography for longhaired volunteers, was to get a clear view of each part of the ear. If it was not possible to place the hair behind the ear, then a surgical cap was used. There was the possibility that hair or the surgical cap affected the cranial part of the ear by slight pressure. However, the potential effect on the final results was negligible because the calculated height and width of the ear correlated with the results in other studies [15, 28].

Because the selected landmarks are used for orientation during surgical interventions, they must therefore be clearly definable in the three-dimensional photography as well as in real life. The landmarks Tra, SupAu, SubAu, PreAu and PostAu were frequently used in previous studies [15, 28] and thus are readily compared with the current study. Thus, the age-dependent increasing distances and gender-dependent variations for certain parts of the ear can be confirmed. Conversely, the landmarks, Ia, ITra, Osup and Oinf, have not been commonly used in the literature. Therefore, they provide new findings to the anthropometry of the external ear.

Some difficulties occurred while positioning the outer landmarks of the ear, e.g. Osup and PreAu sometimes appear to lie almost at the same position. This is caused by the convexity of the ventral area of the ear and varies between subjects. Also, for SupAu and PostAu, it was difficult to clearly define the point of highest convexity. Therefore, correct positioning of the subject during the scan was important.

All lateral ear measurements (Fig. 1), showed a significant dependence on gender. All measured values were higher in men than in women. Remarkably, the relation between Ia–Itra and Osup–Oinf in every age and gender was slightly lower than the golden section with a significant difference between men and women. Some distances—especially SupAu–SubAu and PreAu–PostAu—showed a significant relation to the volunteer's age. The measured values not only showed an increase of the vertical height of the ear with greater age, but also the main reason for this increase was noted in the lowest quadrant of the ear, which grows the most. The dependence of this part on age demonstrated significance for both sexes. A reason for this may be that the earlobe only consists of skin, fat and connective tissue and—in contrast to other parts of the ear—does not contain any cartilage. Therefore, the higher elasticity of the tissue together with gravity could be the reason for the growth change during adulthood.

Symmetry of the ears is important for facial aesthetics. From a surgical standpoint, a defect of one-fourth of the ear permits direct closure without a creating an aesthetic catastrophe. For this investigation, we divided the ear into four parts of equal height [30]. It is unclear whether a division of the ear by distance or by landmarks into four parts is more practical in surgery. The present study forms the basis for such considerations. To get four parts of almost the same height, the following anatomical landmarks were used in the investigation: superaurale, incisura anterior, tragion, incisura intertragica, subaurale. When the distances between these landmarks were compared to the total length of the ear, rounded values from cranial to caudal of 20, 30, 25 and 25% were detectable. Only the cranial half of the ear differed from the classical metrical division.

In total, the measured values for males and females in an expansive age range should be helpful for planning resections of the ear and the subsequent reconstruction.

Compliance with Ethical Standards

Conflict of interest The authors declare that they have no conflict of interest to disclose.

Ethical Approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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