The Shape of the External Human Ear: A Geometric Morphometric Study

İnsan Dış Kulağının Şekli: Geometrik Morfometrik Bir Çalışma

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ABSTRACT Objective: The aim of this study was to identify the shape variability of the external ear. Variability in the shape of the ear was investigated based on the type of ear, gender and facial side in terms of the shape of the helix and antihelix and the concha. **Material and Methods:** A landmark-based geometric morphometric technique was used to analyze the external shape of the ear. The study included 330 (177 females and 153 males) voluntary young adults aged between 18 and 24 years. All data were obtained from standardized digital photographic images taken from the right and left sides of the face. The data from the landmark coordinates were analyzed using statistical shape analysis. **Results:** Earlobes were classified according to the angle between the earlobe and the cheek. In accordance with this classification in our study, ear type was classified as type I (tapering-acute angle), type II (square-right angle) and type III (pendulous-obtuse angle) according to the appearance of the lobule. There were significant differences between the gender groups for right and left side separately regarding the shapes of the helix and the shape of the antihelix and the concha in type I ears. There were significant differences between type I and type II ears for right and left side separately regarding the shapes of the helix and the shape of the antihelix and the concha in females. **Conclusion:** The present study serves as a guide to future clinical studies by demonstrating localized variations in the components of the ear that constitute the overall shape of the ear.

Key Words: Ear; shape; morphometry; statistical shape analysis; geometric morphometrics

ÖZET Amaç: Bu çalışmanın amacı, dış kulağa ait şekil değişkenliğini tanımlamaktır. Kulağın şeklindeki değişkenlik kulak tipi, cinsiyet ve tarafa göre heliks ile antiheliks ve konkanın şekilleri açısından incelenmiştir. **Gereç ve Yöntemler:** Çalışmada, dış kulağın şeklini analiz etmek için nirengi noktası tabanlı geometrik morfometrik bir yöntem kullanılmıştır. Çalışmaya yaşları 18-24 arasında değişen 330 (177 kadın, 153 erkek) gönüllü genç erişkin dâhil edilmiştir. Tüm veriler yüzün sağ ve sol tarafından çekilen standartlaştırılmış dijital fotografik görüntülerden elde edilmiştir. Mirengi noktası koordinatlarından elde edilen veriler istatistiksel şekil analizi kullanılarak analiz edilmiştir. **Bulgular:** Kulak lobu, kulak lobu ile çene arasındaki açı dikkate alınarak sınıflanmıştır. Buna göre çalışmamızda kulak tipi, tip I (sivri-dar açılı), tip II (kare-dik açılı) ve tip III (pendülöz-geniş açılı) olarak sınıflanmıştır. Tip I kulak içinde yapılan karşılaştırmalarda, erkekler ve kadınlar arasında hem sağ kulağın, hem de sol kulağın heliks ile antiheliks ve konka şekillerine göre anlamlı farklılık bulunmuştur. Kadınlarda, tip I ve tip II kulak tipleri arasında hem sağ kulağın, hem de sol kulağın heliks ile antiheliks ve konka şekillerine göre anlamlı farklılık bulunmuştur. **Sonuç:** Bu çalışma, kulağın genel şeklini oluşturan bileşenlerindeki lokalize farklılıkları göstermesi açısından, gelecekte yapılacak olan klinik çalışmalara bir rehber olma niteliğindedir.

Anahtar Kelimeler: Kulak; şekil; morfometri; istatistiksel şekil analizi; geometrik morfometri

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The ear is a defining feature of the face. Its form (size and shape) is influenced by age, sex and ethnic origin. The appearance and symmetry of the ear contributes to facial aesthetics. Before performing reconstructive procedures involving the ear, plastic surgeons should have data available to them that define the limits of normal ear shape, size and orientation.[1,2] These data may also be important for treating congenital and acquired abnormalities of the ear. It is commonly believed that the shapes and characteristics of the human external ear are widely different and may be distinguishable such that it is possible to differentiate the ears of individuals.[3]

The overall shape of the ear tends to be dominated by the outer rim, or helix, and the shape of the lobe.[4] A common method of classifying the shape of the auricle is by defining it as oval, round, rectangular or triangular. The earlobes were classified according to the angle between the earlobe and the cheek.[5] The shape of the ear can also be referred to as type I (tapering-acute angle, where the lobe is free from the cheek), type II (square-right angle) and type III (pendulous-obtuse angle) according to the appearance of the lobule.[5,6] Shape deformations or variability in local shapes may also occur in other parts of the ear, including the helix, antihelix, concha, crus of the helix, intertragic notch and tragus. In addition to overall shape variability, statistical shape analysis can provide information about the variations in local shapes (deformations) that may be present.

Statistical shape analysis compares body forms using specific landmarks that are determined based on anatomical prominence.[7] Statistical shape analysis is a well-known approach studying diseases (patients versus normal controls) or variations in an anatomical structure in a particular population. The proper use of anatomical shape information can significantly improve our understanding of evolutionary processes and anatomical changes due to pathological disorders.[8] In the last two decades, a growing interest has been observed on the use of statistical shape analysis in the field of medicine. The main reasons for usage of statistical shape analysis widely in medicine are advances in imaging technology, and tendency to investigate the effects of diseases and environmental factors on the structure of an organ or organism.[9]

The aim of this study was to identify the shape variability of the external ear. Variability in the shape of the ear was evaluated based on the type of ear (type I and type II), gender and facial side in terms of the shape of the helix and antihelix and concha. These data may be useful for establishing a database for similar studies in the future and may have applications in plastic surgery and forensic science.

MATERIAL AND METHODS

SAMPLES

The study group consisted of 330 voluntary young adults (177 females and 153 males) aged 18-24 years. The participants were students from different parts of Turkey studying in the Uludağ University. After the approval of the Uludağ University Ethics Committee, written informed consent was obtained from the participants. There were no noticeable ear disfigurements and no history of previous ear surgeries in any of the subjects. The participants provided their informed consent. All data were obtained from standardized digital photographic images taken at a distance of 1 m of the right and left sides of the face using a 5.1 mega pixel digital camera. The same investigator took all the photographs. Extreme care was used to ensure that the best possible photograph was obtained. In the present study, the ear types were determined based on the appearance of the lobule. The earlobes were classified according to the angle between the earlobe and the cheek.[5] The ear was classified as type I (tapering-acute angle, where the lobe is free from the cheek), type II (square-right angle) or type III (pendulous-obtuse angle). This study was conducted in accordance with the requirements of the Helsinki Declaration.

COLLECTION OF TWO-DIMENSIONAL EAR LANDMARKS

External ear landmark data were collected from the two-dimensional digital images. Standard anthropometric landmarks were selected and were marked on each digital image using TPSDIG 2.04

software. To achieve a standard view, the images of the left ears were turned to the right side before marking. Twelve anatomic ear landmarks were marked on right and left sides. In accordance with the literature landmarks that could be marked homogenously on all images were preferred.[10]

While landmarks 1, 2, 3, 4, 5, and 12 were used to define the shape of the helix and the region belonging to the helix that shapes the external line of the ear, landmarks 7, 8, 9, 10, and 11 were chosen to define the shapes of the antihelix and the concha (Figure 1, Table 1). Landmark 6 (otobasion inferius) locates on the point that connects the earlobe to the cheek and landmark 6 was basically used to determine the ear types. To overcome shape variability that occurs from the ear type, landmark 6 was not included when comparing the shape variability of the helix, and antihelix and concha between ear types. Landmark 6 was included when evaluating gender and the side differences between the left and right ear for each ear type.

FIGURE 1: Landmarks of the external ear (X) indicates the shape of the helix, (●) indicates the shape of the antihelix concha). Landmarks 1 (preaurale), 2 (otobasion superius), 3 (superaurale), 4 (postaurale), 12 (lobule posterior), 5 (subaurale) and 6 (otobasion inferius) represent the helix. Landmarks 7 (incisura intertragica inferior), 8 (protragion), 9 (incisura anterior auris posterior), 10 (concha superior) and 11 (strongest antihelical curvature) represent the antihelix.

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TABLE 1: Landmarks used in the present study.

Number	Landmarks
1	Preaurale
2	Otobasion superius
3	Superaurale
4	Postaurale
5	Subaurale
6	Otobasion inferius
7	Incisura intertragica inferior
8	Protragion
9	Incisura anterior auris posterior
10	Concha superior
11	Strongest antihelical curvature
12	Lobule posterior

GEOMETRIC MORPHOMETRIC ANALYSIS

Statistical Analysis

A generalized Procrustes analysis was used to evaluate the shapes. The homogeneity of the variance–covariance matrices was examined using the Box-M test.[11] Because the variance–covariance matrices were homogeneous, the Hotelling T^2 test was used for comparisons with a large sample size. For small sample sizes, the Hotelling T^2 test was performed based on a resampling procedure, otherwise the James F_J test and the James F_J test based on a resampling procedure were performed for shape comparisons.[12]

Tangent shape space coordinates were computed for paired group comparisons, and a principal component analysis (PCA) was performed for these coordinates. After PCA, shape comparisons of the paired groups were done using the paired Hotelling T^2 test via principal component scores.

The shape deformations were evaluated using Thin Plate Spline (TPS) analysis. Procrustes mean shapes were computed for TPS analysis. Based on the results of the TPS analysis, the areas exhibiting the greatest enlargements or reductions were marked in color to indicate deformations. R and PAST software were used for statistical shape analysis.

LANDMARK RELIABILITY

We calculated the intra-rater reliability coefficient for a two-facet crossed design ('landmark pairs-by-rater-by-subject', l x r x s) based on the generalizability theory (GT).[13] In the GT, the reliability for relative (norm-referenced) interpretations is referred to as the generalizability (G) coefficient.[14] In this study, all landmarks were marked by the same investigator. After one month, the same investigator marked landmarks on 20 individuals (10 males and 10 females) randomly selected from the study population. An analysis was performed to obtain a G reliability coefficient. The rating indicated a strong repeatability for both the female and the male subjects (G=0.9969).

RESULTS

In this study, type I (84.45%) ear was the most common ear type in the Turkish population. Type II and type III ears occurred in 11.21% and 3.94% of the study population, respectively. There was no statistical significance between the ear types and gender (Table 2).

The shape differences and ear types were examined using statistical shape analysis. The shape of the ear was evaluated based on the shape of the helix and the shape of the antihelix and concha. Due to the low frequency of the type III ear, it was excluded from the analysis.

There were no significant differences between the right and left sides of the type I and type II ears for each gender group separately regarding the shape of the helix and the shape of the antihelix and concha.

There were significant differences between the gender groups for right and left side separately regarding the shapes of the helix and the shape of the antihelix and concha in type I ears (Figure 2). However, there were no significant differences in type II ears. When evaluating the differences in the shapes of the helix and antihelix and concha based on gender in the type I ear, all landmarks included in the study and the regions of the ear where the landmarks were taken influenced the shape variability of the left and right ears (Figure 3).

There were significant differences between type I and type II ears for right and left side separately regarding the shapes of the helix and the shape of the antihelix and concha in females. However, there were no significant differences in males (Figure 4). When evaluating the differences in the shapes of the helix and antihelix and concha based on ear types in females, all landmarks included in the study and the regions of the ear where the

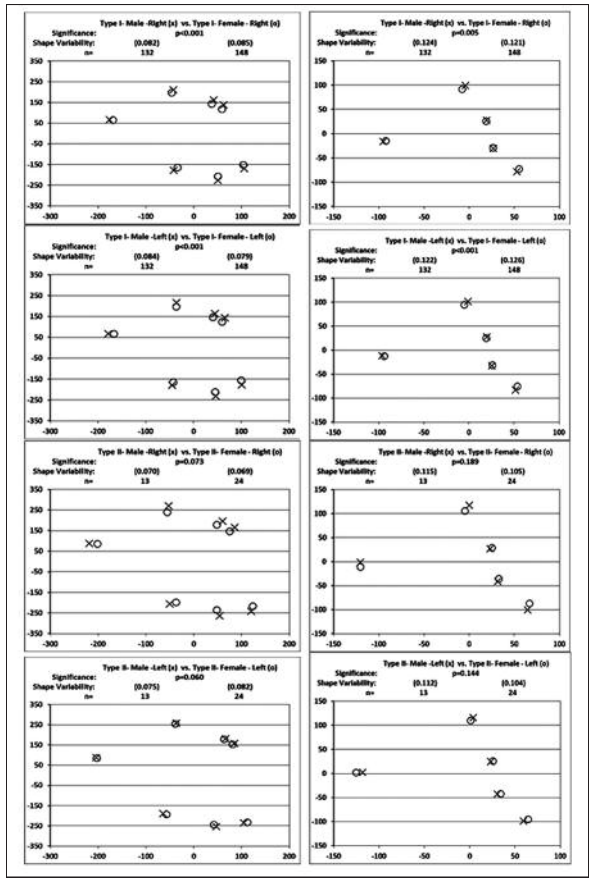

FIGURE 2: Within ear type comparisons between gender according to the shape of the helix (left column), antihelix and concha (right column) for left and right ear separately.

TABLE 2: The distribution of ear types.

	Female n(%)	Male n(%)	Total
Type I	148(83.60)	132(86.30)	280(84.85)
Type II	24(13.60)	13(8.50)	37(11.21)
Type III	5(2.80)	8(5.20)	13(3.94)
Total	177(53.60)	153(46.37)	330
Significance	0.207		

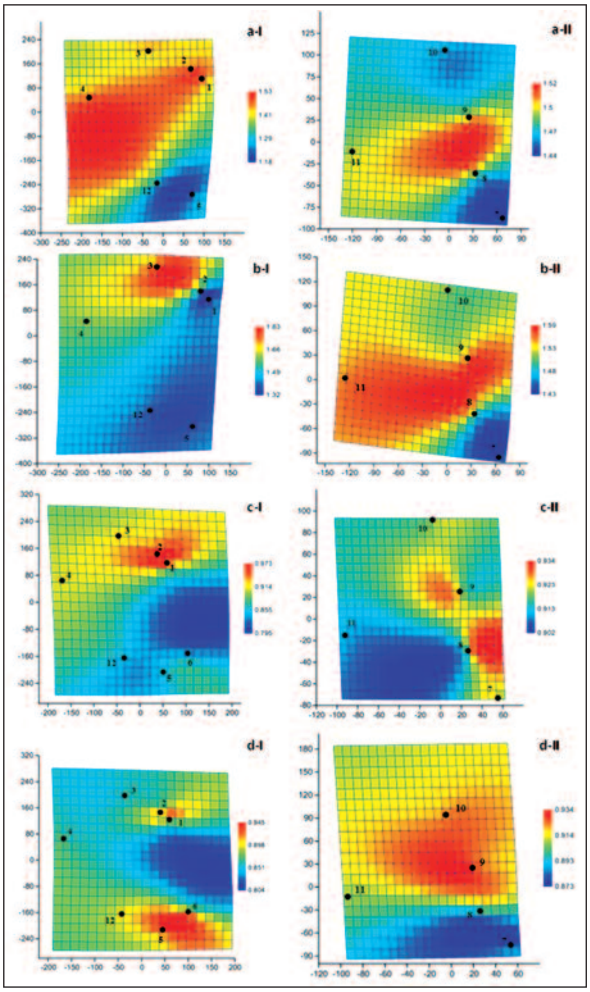

FIGURE 3: Thin plate spline (TPS) graphics demonstrating the shape deformation of **a-I** (from a type I female right ear to a type II female right ear according to the shape of the helix), **a-II** (from a type I female right ear to a type II female right ear according to the shape of the anti-helix and concha), **b-I** (from a type I female left ear to a type II female left ear according to the shape of the helix), **b-II** (from a type I female left ear to a type II female left ear according to the shape of the anti-helix and concha), **c-I** (from a type I male right ear to a type I female right ear according to the shape of the helix), **c-II** (from a type I male right ear to a type I female right ear according to the shape of the anti-helix and concha), **d-I** (from a type I male left ear to a type I female left ear according to the shape of the helix), and **d-II** (from a type I male left ear to a type I female left ear according to the shape of the anti-helix and concha).

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landmarks were taken influenced the shape variability of the left and the right ears (Figure 3).

DISCUSSION

The external ear is composed of three primary components: the helix-antihelical complex, the conchal complex, and the lobule. The structural traits of these components are aesthetically important. The earlobe in these parts provides a significant contribution to aesthetics. Based on the type of earlobe, the distribution of the ear types in this study were as follows: 84.85% type I, 11.21% type II and 3.94% type III. Our results were both similar and contrary to several other studies in the literature.[5] For example, Sharma et al. reported that the square lobule was the most common ear type lobule in a northwest Indian population.[6] Although the earlobe is a key element that constitutes the overall differences in the shape of the ear, differences in the shapes of the other parts (e.g., helix, antihelix, and concha) of the ear are also important. In our study, there was no difference in the distribution of ear types and gender.

Somatoscopy of the external ear provides a general view of the shape of an ear, the form of the

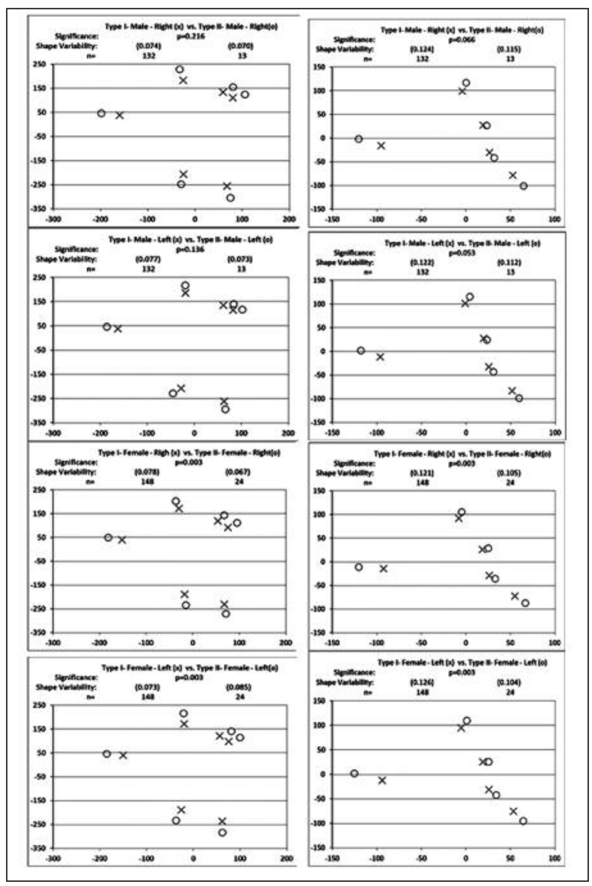

FIGURE 4: Within gender comparisons between type I and type II ear according to the shape of the helix (left column), antihelix and concha (right column) for left and right ear separately.

helix, the presence (or absence) of Darwin's tubercle and the attachment of the ear lobe to the cheek.[15] A detailed analysis of the soft tissue of the ear regarding the size and shape is of great importance for physicians performing reconstructive surgery and physical anthropologists and forensic scientists for identification purposes. Prior to an operation, a detailed analysis of the ear size and shape is one of the most important factors influencing the diagnosis of irregularity and the eventual outcome of surgery. In addition to fingerprint analysis, the shape of the ear has been widely used in recent years for personal identification in the field of forensic medicine. Jain et al. indicated that the somatoscopic features of the ear could act as soft biometric traits in personal identification.[16] The authors also indicated that although those traits could provide information about an individual, they might lack the distinctiveness and permanence to sufficiently differentiate between individuals.[16] In addition to the overall external ear shape, localized variations of the ear are useful in pre-operative evaluations and for identifying individual characteristics and differences.

It is important to know the details of the anatomical features of the ear hence the details of the shape of the ear for manufacturing hearing aids. In accordance with the results of our study, the differences in the shape of the antihelix and the concha in terms of gender and ear type also highlight the importance of this issue. Baloch et al. proposed that a shape descriptor for 3D ear impressions, derived from a comprehensive set of anatomical features.[17] Motivated by hearing aid (HA) manufacturing, the selection of the anatomical features is carried out according to their uniqueness and importance in HA design.

In this study, we investigated localized shape variations in the external shape of the ear using a statistical shape analysis method. The variations between ear types (type I, type II) and within each ear type based on gender and facial side were evaluated. Differences that are known to distinguish the shape of the ear lobule were excluded when analyzing differences between ear types. In the type I and type II ears of both genders separately, there were no differences in the shape of the helix and the shape of the antihelix and the concha between the right and left ears. This result supports the finding that there is generally symmetry between the right and left ears. Although it has been reported that the left ear is significantly wider than the right ear and the lengths of the right and left ears can vary up to 4 mm, we did not determine any differences between the right and left ears in this study based on statistical shape analysis.[18,19] There were significant differences between the gender groups for right and left side separately regarding the shapes of the helix and the shape of the antihelix and the concha in type I ears. There were no significant differences in type II ears. When evaluating the differences in the shapes of the helix and the antihelix and the concha based on gender in the type I ear, all landmarks included in the study and the regions of the ear where the landmarks were taken seemed to influence the shape variability of the left and right ears.

Recently, the development of reconstructive procedures in ear surgery, which are required upon the congenital absence of an ear or severe deformities and the development of computerized personal identification systems, which could detect minimal personal differences using external ear landmarks, urged us to question the quality and efficiency of current analyzing methods. In this aspect, the statistical shape analysis provides a novel approach for the evaluations on the human body.

Cosmetic surgery requires consideration of gender and ear type. This study should be a step to clarify these important points.

CONCLUSION

This study suggests that there are differences in the soft tissue parameters of the ear depending on the gender of the individual. Previous studies that focused on the morphology of the ear used measurements obtained by traditional morphometric methods and primarily evaluated the shape or morphology of the ear lobule. The present study serves as a guide to future clinical studies by demonstrating localized variations in the components of the ear that constitute the overall shape of the ear.

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