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ARTICLE ORIGINAL

Ear identification: A multi-ethnic study sample

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KEYWORDS
Forensic science ;
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Population data

Abstract The external human ear is considered to be highly variable among individuals. Hence, forensic applications could be explored for human identification. This research compares the usefulness of Cameriere's ear identification method, in samples originating from six different countries (Brazil, India, Japan, Russia, South Africa and Turkey) in order to examine possible differences in their accuracy values. A sample of 2,225 photographs of the external human ear (1,134 left and 1,091 right ears) from 1,411 individuals (633 females and 778 males) was collected. The samples included healthy subjects with no systemic disorders and without any craniofacial trauma, maxillofacial abnormalities, auricular anomalies, ear diseases or previous auricular surgery. Cameriere's ear identification method was applied and measurements were performed on the images of each ear, considering four anatomic regions: helix, antihelix, concha, and lobe. The quantified measurement values were converted into a proposed coded number system. A search for identical codes was accomplished to find out the distinctiveness of the morphology of the human ear. The combined codes of left and right ears of each of the

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814 subjects were not repeated in this multi-ethnic study sample. Dirichlet's distribution and the inherent study equation showed that the probability of two different individuals having the same code (false-positive identification) was found to be < 0.0007. Because of the distinctive metrics of the ratios of external human ears, studies with Cameriere's ear identification method may be valuable for human identification. Studying the differences between the left and right ears of the same individual and across different ethnic groups could contribute to the development of supplementary tools for human identification.

Introduction

The external human ear is one of the most distinctive features of the face [1—3] and could be useful for human identification [4]. Other methods, such as fingerprints, dental records, and DNA analysis, are considered scientifically reliable and figure as primary means for the process of identification [5]. Additional anatomic structures, such as the ear, have been studied as adjuvant tools in this process. The distinctive shape and size of the ears are useful not only for the identification of the deceased, but also for the recognition of the living — such as crime suspects and victims [5—7]. The external human ear can be registered by means of crime scene photographs (static) and footage (dynamic), and these techniques do not require ionizing radiation [8]. In addition, the human ear is registered together with other body parts that contribute towards creating a profile of the suspect or victim. For instance, footage of the whole body may enable an estimation of the stature, while tattoos could point out cultural information [9]. Other scenarios include the imprints of the external human ear on surfaces such as doors and windows — situations in which the imprints could be taken like latent fingerprints. In this context, research [10] has demonstrated that specific facial landmarks might not be distinctive enough as sole parameters for human identification. The inclusion of a systematic assessment of the external human ear in facial anthropometric analysis, however, could be valuable. The external human ear may have not only distinct morphological features from genetic origin, but also distinctive features acquired through life, such as in sports' players (e.g. rugby and grappling) and individuals with syndromes (e.g. Goldenhar and DiGeorge syndromes).

Techniques to assess the external human ear date back to the 1940s [11,12]. More recently, studies have been developed to promote feature extraction approaches [13—17], and the validation of toolboxes within biometric databases [18—21]. Other studies have examined the effects of time and image compression on ear biometrics [22,23]. Current scientific literature has shown that each region of the external human ear is morphologically unique, and that variations may be population-specific [24—34]. The ear lobe, for instance, has been explored and used in comparative ear techniques, and is constantly implemented in new methods. In 2011, Cameriere et al. [35] proposed a technique for individual identification based on measurements of the ear considering a multivariate distribution of the helix, antihelix, concha, and lobe. According to the authors [35], a grid of four straight lines is drawn on the photograph of the ear to divide it and enable a systematic and sequential assessment. Then the helix, antihelix, concha, and lobe edges are determined. Measurements of these four regions are obtained to form anatomic ratios of the ear. Next, the quantified ratios are converted into a numeric 8-digit code by rounding the value of each ear region into a 2-digit number and placing them in a particular order (helix, antihelix, concha, and lobe). For example, helix = 15.4, antihelix = 52.7, concha = 15.6, and lobe = 16.3 forms the code number 15531616 [35].

Table 1 Age distribution for each individual sample.

	Age distribution	
Country	Mean age	Standard deviation
Brazil	23.73	6.68
India	39.69	15.46
Japan	55.63	20.38
Russia	33.06	10.08
South Africa	20.25	4.46
Turkey	39.45	15.73
Total sample	37.35603	18.80498

Since the proposed method assumes that there are no people with the same code number, a study that tests its validity is necessary and, for that, a larger sample from different populations is required. Thus, this study aimed to test and evaluate Cameriere's ear identification method [35] for individual identification using samples from six countries, namely Brazil, India, Japan, Turkey, Russia, and South Africa.

Materials and methods

Sample

The dataset had 1,411 images of ears from 1,411 individuals (633 females and 778 males). An additional subset of left and right human ears of 814 individuals (370 females and 444 males) was established. The total sample was 2,225 images of external human ears (1,134 left and 1,091 right). The sample's age distribution by country and the standard deviation are illustrated in Table 1.

The countries of origin of the individuals were Brazil, India, Japan, Russia, South Africa and Turkey. The sample distribution according to sex and country of origin is displayed in Table 2. This study was conducted after an approval from the Ethics Committee of Iwate Medical University, School of Dentistry (approval no.: 01354/2021), the Ethics Committee of Sechenov First Moscow State Medical University, Moscow, Russia (approval no. 13-22 of 22/06/2022) and the Ethics Committee of Ankara University (approval no.: 16/257 of 24/09/2019).

Table 2 Sample distribution according to sex and country of origin.

Sex	Brazil	India	Japan	Russia	South Africa	Turkey	Total
F	72	49	129	4	136	243	633
M	43	51	161	96	136	291	778
Total sample	115	100	290	100	272	534	1411

No identification data were collected. The photographs were collected retrospectively from different sources. Each institution and researcher collected the sample prospectively once the study started. Hence, the photographs were not taken from a private collection, but they built a new collection by the end of the study. Professional cameras were used by each research and a distance about 100 cm between lens and ear was established. The participants were photographed while standing sideways and facing forward with the inferior margin of the mandible parallel to the floor. The photographs were stored as high-resolution (> 600 dpi) .jpeg files and were automatically anonymized prior to the selection process. All data were recorded in an Excel® file and the columns were indicated as follows: country, subject's identification number and sex. Subjects with a previous history of craniofacial trauma, maxillofacial abnormalities, auricular anomalies (congenital and traumatic) ear diseases or previous auricular surgery, were not included in the sample. Images in which individuals were wearing various accessories such as earrings and piercings were not considered in our study. Ear images occluded with hair were excluded from the study. Part of the total sample, and more specifically, 115 subjects (43 males and 72 females) aged between 18 and 60 years old from the Brazilian sample, was published as separate literature [36] and figured as a pilot study.

Measurements

To conduct the analysis, the software ImageJ (https://imagej.nih.gov/ij/index.html) was used and the photographs were analyzed by eight observers with varying levels of experience in ear identification. The examiner-trainees were provided with video training describing the study protocol, selection criteria, and guidance regarding the evaluation and ear measurements of two ear images. The examiner-trainees reviewed the training material independently and then successfully proceeded to the sample measurements. This process consisted of a self-taught calibration exercise, which was video-based and distance supervision was provided by the original developer of the method. According to the method [35], each ear was divided into four regions (helix, antihelix, concha, and lobe) based on the arrangement of two parallel lines in the horizontal direction and two parallel lines in the vertical direction (Fig. 1). Then, the areas corresponding to each of these regions were delimited and their values were obtained in pixels.

Intra- and inter-observer reproducibility

Intra- and inter-examiner reproducibility tests were performed by means of Intraclass Correlation Coefficient (ICC).

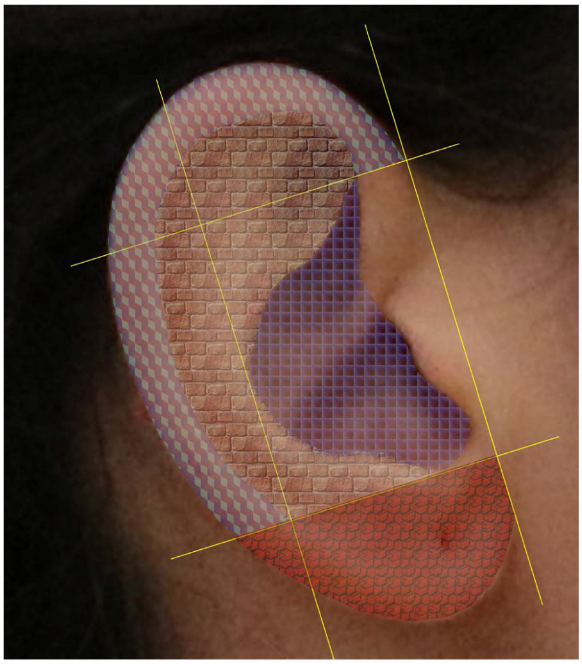


Figure 1 Photograph of the right ear of a female divided into the following regions: lobe (red leather texture), anti-helix (bricks texture), helix (blue legacy texture): helix, and concha (blue grid texture).

The intra-examiner reproducibility test consisted of the reassessment of 80 photographs from the main sample 30 days after the initial analysis, while the inter-examiner reproducibility test required the comparative assessment of photographs between observers. The ICC for the intra-examiner reproducibility was 0.92 for helix (95% CI: 0.88 to 0.95), 0.96 for antihelix (95% CI: 0.95 to 0.97), 0.914 for concha (95% CI: 0.86 to 0.94) and 0.92 for lobe (95% CI: 0.89 to 0.95) (Table 3). For the inter-examiner reproducibility, the ICC results were 0.83 for the helix (95% CI: 0.74 to 0.90), 0.94 for the antihelix (95% CI: 0.90 to 0.94), 0.80 for the concha (95% CI: 0.69 to 0.88), and 0.70 for the lobe (95% CI: 0.56 to 0.82). It must be noted that this is a metric method and is susceptible to human error during operator-depending steps. In some of the assessed areas, helix, concha and lobe for instance, the metric analysis did not reach high reproducibility rates as the remains ones. The rationale behind this phenomenon relies on the anatomic structures themselves, which have more pronounced curvatures - hampering the metric outline. Additionally, we recruited multiple observers for image annotations and metric analyses. Hence, lack of uniform measuring could be expected. The positive aspect is

Table 3 Intra- and inter-examiner repeatability.

Ear parts	Intra-examiner repeatability		
	ICC	95%CI	
Helix	0.926	0.887	0.952
Antihelix	0.968	0.95	0.979
Concha	0.914	0.869	0.944
Lobe	0.928	0.89	0.953
Turkey	ICC	95%CI	
Helix	0.983	0.957	0.993
Antihelix	0.981	0.953	0.992
Concha	0.991	0.977	0.996
Lobe	0.973	0.935	0.989
Japan	ICC	95%CI	
Helix	0.963	0.91	0.985
Antihelix	0.962	0.908	0.985
Concha	0.96	0.904	0.984
Lobe	0.963	0.91	0.985
Brazil	ICC	95%CI	
Helix	0.854	0.742	0.92
Antihelix	0.959	0.924	0.978
Concha	0.84	0.72	0.912
Lobe	0.832	0.706	0.907
Ear parts	Inter-examiner repeatability		
	ICC	95%CI	
Helix	0.830	0.740	0.900
Antihelix	0.940	0.900	0.970
Concha	0.800	0.690	0.880
Lobe	0.700	0.560	0.820

CI: confidence interval.

that all of our outcomes were above moderate and represent acceptable reproducibility for the study.

Statistical analysis

To test the possible relationship between the 8-digit code and the countries sampled in this study, we used the Pearson X^2 test. The density functions of the multivariate distribution of helix, antihelix, concha, and lobe (expressed as proportions of the ear) were estimated according to the Dirichlet distribution family, the density of which may be written as follows:

$$f(y_1, y_2, y_3) = \frac{\Gamma(p_1, p_2, p_3, p_4)}{\Gamma(p_1)\Gamma(p_2)\Gamma(p_3)\Gamma(p_4)} y_1^{p_1-1} y_2^{p_2-1} y_3^{p_3-1} (1 - y_1 - y_2 - y_3)^{p_4-1}$$

where $\Gamma(x)$ is the gamma function, y_1 the helix fraction of the ear, y_2 the concha fraction, and y_3 the lobe fraction, respectively, with $y_i \geq 0$ i = 1,2,3; and $\sum_{i=1}^{3} y_i \leq 1$. Clearly, the antihelix fraction may be obtained as $y_4 = 1 - y_1 - y_2 - y_3$.

The image of a given ear is allocated an 8-digit code number, which is obtained by rounding off the four proportions y_i, i = 1,4; to the integer numbers of two digits. In order that a second ear image of a different individual produces the same code number, it is necessary that its proportions of helix, concha and lobe differ from y_1, y_2 and y_3 by less than 0.005. Consequently, the probability that two ear images of different individuals are identified as belonging to the same individual (i.e., false positive identification) may be estimated as:

$$\int_R f(x_1, x_2, x_3) dx_1 dx_2 x_3 (2)$$

where f(x1, x2, x3) is the density function (1) and

$$R = \{(x_1, x_2, x_3) \in [0, 1]^3 | x_i - y_{i|}| < 0.005\}$$

The empirical test described in [37] was used to evaluate the goodness-of-fit and accuracy of model predictions. Statistical analysis of data and related graphs was carried out with the R statistical program (R foundation, Vienna, Austria) and the Microsoft Excel® program (Microsoft Corp., Redmond, WA, USA). The significance level was set at 5%.

Table 4 Distribution of code repetitions for the left, right and both ear (repetition = 0 means uniqueness of the code).

Ear	0	1	2	3	Total
Left	895	93	15	2	1134
Right	917	80	6	0	1095
Both	814	0	0	0	814

Results

For left and right ears, the number of 8-digit code repetitions is reported in Table 4. In the presence of the encodings of both ears, none of the 814 individuals had the same code as another individual, meaning that the obtained code was unique in the sample. This is to say that the double code (left and right combined) uniquely identifies the subjects. Considering the left and right ears separately, we detected 895 and 917 unique codes, respectively. Since the code number of an ear is obtained by rounding off the proportions to the integer numbers of 2 digits, the images of 2 different ears produce the same code number if the proportions differ by less than 0.005.

With respect to the countries sampled in this study, the distribution of frequencies is reported in Table 5. The reported frequencies show the non-homogeneous distribution between left and right ears when the country is considered. Countries such as India and Russia showed unique codes for the left ear, for instance, but the uniqueness was not uniform between opposite ears and across countries. The Pearson χ^2 test did not show any statistically significant association between unique code proportions and countries for both left and right ear ($p = 0.408$ and 0.314, respectively).

The empirical goodness-of-fit test for the Dirichlet distribution showed that the hypothesized distribution function and its corresponding empirical distribution did not differ significantly ($P > 0.09$), indicating that the assumed distribution matched observations well (Figs. 2 and 3) for both right and left ear. When the Dirichlet distribution is used

Table 5 Total and unique codes of the left and right ears in relation to the country of origin of the sample and in relation to all the country in the sample.

Ear	Country						
	Brazil	India	Japan	Russia	South Africa	Turkey	Total
Left	115	100	290	95		534	1134
Unique codes	111	100	268	95		460	1034
Unique codes vs. all country	93	77	232	81		412	895
Right	115	100	290	96	276	218	1095
Unique codes	109	96	268	94	258	210	1035
Unique codes vs. all country	89	84	241	85	237	181	917

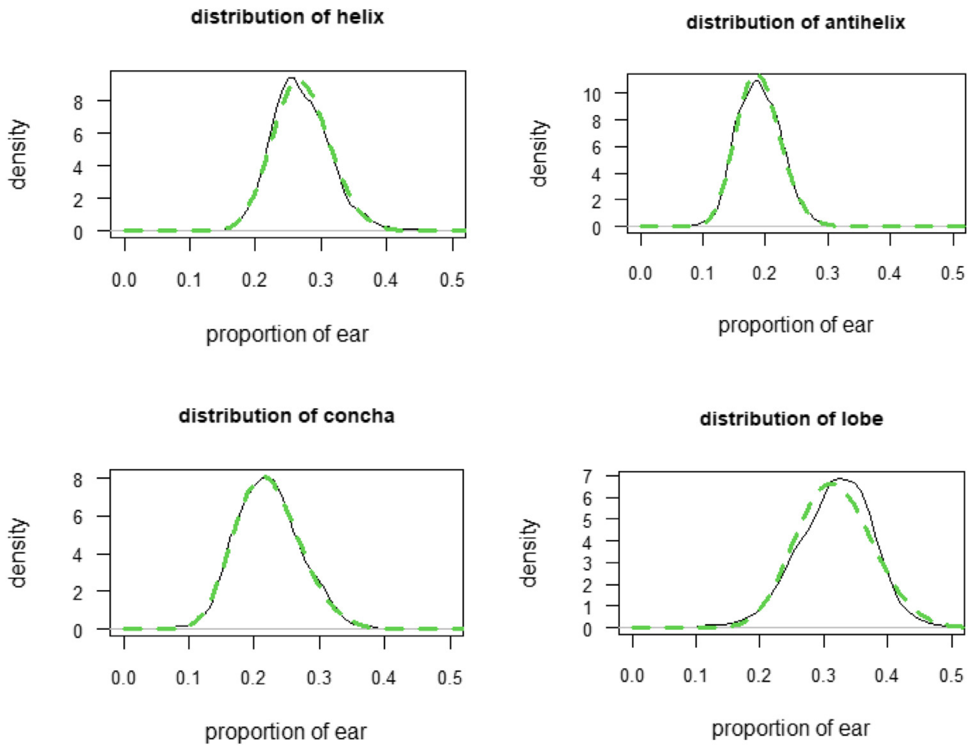


Figure 2 Observed distributions of helix, antihelix, concha, and lobe of the right ear (continuous lines) and corresponding univariate beta distributions (dotted lines).

with the estimated parameters (Fig. 4) to evaluate the probability that two different individuals had the same code number (false-positive identification), it showed a probability of < 0.0007.

Discussion

Due to the increasing number of crimes being recorded on videos and images, personal identification of the living is becoming an increasingly important issue. In cases of crimes or unauthorized use of a person's image, expert witnesses are asked to confirm that a person seen on a certain video or image is the same person as the suspect. These investigations demand accurate and verified methods to evaluate individualizing features that can be observed in images and videos. The face and facial features are central to the majority of techniques using image analysis for individual identification. The use of a metric method, specifically the calculation of facial indices on 2D images for comparison of the represented subject and the suspect, has been suggested in research studies [38,39]. However, the final estimation regarding whether the reference and questioned evidence match may be influenced by the subjective judgment of the observer. Nevertheless, methods used to identify individuals in images are typically based on scientific investigation. Biometrics have emerged as a potential solution during forensic investigations as a means to quantify evidence and improve the reliability of techniques based on image analysis.

Linear metric analyses can be useful to quantify anatomic distances on the face, for instance, but they do not provide a comprehensive assessment of the morphological features of anatomical structures. In other words, many people may have the exact same facial measurement (distances), but the anatomical features within the measurements may change (e.g. the same facial width, but with anteroposterior

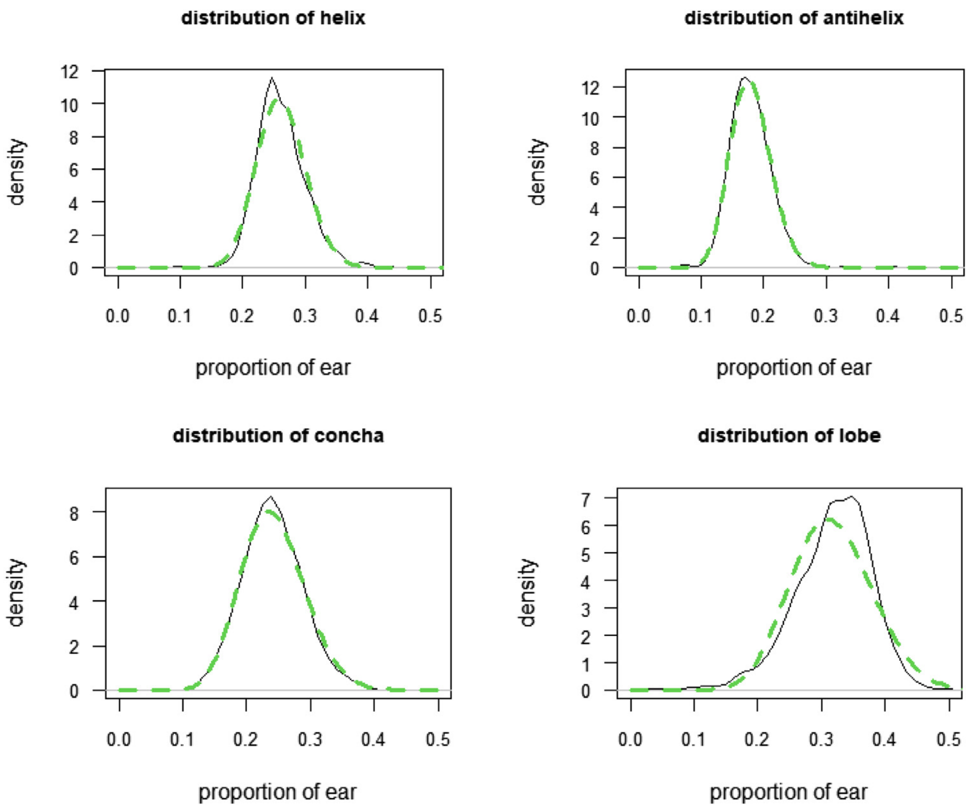
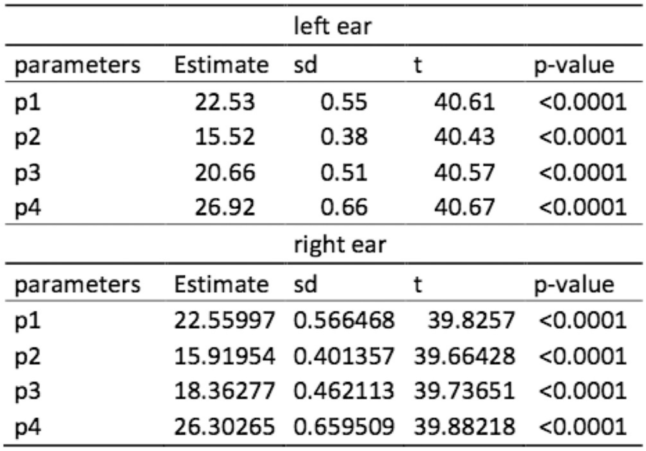


Figure 3 Observed distributions of helix, antihelix, concha, and lobe of the left ear (continuous lines) and corresponding univariate beta distributions (dotted lines).



		left ear		
parameters	Estimate	sd	t	p-value
p1	22.53	0.55	40.61	<0.0001
p2	15.52	0.38	40.43	<0.0001
p3	20.66	0.51	40.57	<0.0001
p4	26.92	0.66	40.67	<0.0001
		right ear		
parameters	Estimate	sd	t	p-value
p1	22.55997	0.566468	39.8257	<0.0001
p2	15.91954	0.401357	39.66428	<0.0001
p3	18.36277	0.462113	39.73651	<0.0001
p4	26.30265	0.659509	39.88218	<0.0001

Figure 4 Maximum likelihood estimates of the parameters of Dirichlet distributions for the left and right ears. SD: standard deviation; *P*: statistical significance set at 5%.

differences in the position of the maxillae and zygomatic bones). Image superimposition figures in this context as an alternative, but limitations exist [40]. Currently, one of the main challenges is to determine how closely two facial images must match one another in order to be identified as belonging to the same person. The method proposed by Cameriere et al. [35] takes into account four different anatomic regions of the external human ear and enables metric analyses that are not simply based on linear measurements. The analyses aim to calculate ratios of the human ear that can be converted into distinctive numeric codes. Hence, the method is both morphological (qualitative) for the division of the ear regions, and metric (quantitative) when it comes to the quantification of pixels in the specific ear region.

An important aspect to be considered is that the proposed method relies on bidimensional image analysis, while tridimensional methods already exist [41]. One of the reasons behind the choice of planar bidimensional images is the reproducibility in forensic practice. CCTV cameras and images from crime scenes or even cybernetic environments (such as child pornography) may have suboptimal image quality [42]. Despite the considerable contribution of tridimensional imaging to forensic science, such as surface scanning and photogrammetry, the implementation of these tools in practice is challenging because of the high cost of the equipment and advanced knowledge necessary to operate them. These limitations could play a significant part in developing countries. Forensic experts must be able to visualize and benefit from the advantages of tridimensional imaging, but they must also consider simple resources with more palpable translation to practice.

In this study, we sampled individuals from five continents in order to have a worldwide perspective of ear ratios. The scientific literature has already reported studies from several countries, such as the United States, Italy, India and Turkey [43—49]. Most of these studies reported that ear sizes varied metrically across populations. For example, in a study conducted on Turkish and African individuals [50], left and right tragus-helix and tragus-antihelix distances of Turkish men were found to be significantly lower than African men. Furthermore, right and left lobular width and lobular height were found to be significantly higher in Turkish men than African men. Left and right ear length, lobular width and left lobular width of Turkish women were significantly higher than African women ($P < 0.05$) [50]. When comparisons are performed side-wise, a lack of statistically significant differences in the size of ear is reported in the literature [51]. Differences in the size of the ear across populations could be explained by genetic factors or even nutritional/environmental conditions [52]. In our study, the differences between countries seemed less evident, since the quantity of unique codes did not reach statistical significance ($P < 0.05$). It means that, in practice, the distinction of ear shapes based on country-related (geographic provenance) phenotypical features will be challenging. On the other hand, the presence of unique codes pooling countries together showed highly distinctive patterns of ear shapes that could be useful for human identification.

This study showed that there is a low probability (< 0.0007) of finding two individuals with the exact same numeric code proposed by Cameriere et al. [33]. According to the literature, this is the first study in which Cameriere's ear identification method [35] is explored for human identification utilizing a vast sample with origins in six different populations (Brazil, India, Japan, Turkey, Russia and South Africa). To statistically handle the sample with over two thousand ear images, Dirichlet distribution was considered and indicated that the assumed distribution matches the observations for both ears quite well. Only after developing a model of the ear and estimating the probability of uniqueness occurring in the population can the uniqueness of the ears be estimated [35]. A particular situation in forensic practice, however, would require more knowledge of the alleged uniqueness of the external human ear, which is the investigation of twins. Authors have demonstrated that the human ear may be a powerful tool to distinguish not only people in a random population, but also monozygotic twins [53]. Interestingly, the analysis of human ears has been suggested as an alternative to facial recognition systems [53]. The theory of an existing uniqueness of the external human ear is supported by authors that investigate deep and by means of experimental analyses the shape of the human ear between twins [54]. The authors found out that their ears might be similar, but not identical [54].

Future studies in the field can be guided by current and existing forensic evidence. Pinto et al. [36], for example, compared left and right ears of the same individual and detected statistically significant differences in the size of the helix ratios. The authors also highlighted the possibility of predicting the size of the opposite ear when only the image of one ear is available. The specific characteristics of the ear observed in the study were justified based on the high miscegenation rates in the original country (Brazil) of the sample [36]. These outcomes suggest additional fields of interest worthy of further research in the forensic field.

Conclusion

Cameriere's ear identification method led to a highly distinctive pattern of numeric codes when left and right sides were combined in a single individual. The probability of two matching individuals was $< 0.0007\%$ in the collected sample. Differences in numeric codes considering the six countries sampled in this study were not statistically significant.

The present tool could be an alternative to be combined with existing techniques for human identification based on anatomic features. Potential scenarios include cases that involve photographs and video footage of perpetrators or victims, such as in digital forensics related to child pornography, and urban surveillance.

Disclosure of interest

The authors declare that they have no competing interest.

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Compliance with ethical standards, ethical approval and research involving human participants, their data or biological material

This research study was conducted retrospectively from photos obtained for orthodontic clinical purposes. The study was performed in accordance with the ethical standards as laid down in the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards. This study was conducted after an approval from the Ethics Committee of Iwate Medical University, School of Dentistry (approval no.: 01354/2021), the Ethics Committee of Sechenov First Moscow State Medical University, Moscow, Russia (approval no. 13-22 of 22/06/2022) and the Ethics Committee of Ankara University (approval no.: 16/257 of 24/09/2019).

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