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A study of ear biometrics in autopsied cases at the Universiti Kebangsaan Malaysia Medical Centre

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Abstract

Background The ears have increasingly been recognized as one of the supportive tools in forensics, based on the identification of landmark variations of ear biometrics in living persons. However, no studies on the reliability of such comparisons have been done on the deceased.

Methods The study aimed to investigate the correlation between ear biometrics and the age, sex, and stature of the deceased. The study was conducted on 181 deceased persons, aged between 18 and 70 years old on cases received by the Forensic Unit of Universiti Kebangsaan Malaysia Medical Centre. Documentation of age, sex, race, and height was recorded, and photographs of bilateral ears were taken. Measurements of twelve ear biometrics based on the Iannarelli method and ear length and ear width were taken from the photographs.

Results Results showed that there was a significant difference between males and females in six ear biometrics. There was also a significant correlation between ear biometrics, that is, ear length and ear width with the age and height of an individual.

Conclusions In brief, there exists a significant difference between males and females in ear biometrics with good correlations between ear biometrics and the height and age of an individual. Hence, the ear can be used for personal identification in the forensic field.

Keywords Identification, Ear biometrics, Age, Sex, Forensic

Background

One of the goals of medicolegal investigation is to establish personal identification of human remains. The identity of an unknown deceased is important in legal proceedings, as well as in social matters. The means of primary identification listed by INTERPOL are fingerprints, DNA analysis, and forensic dentistry (Caplova et al. 2018). Physiognomic features of a human body are also used for identification purposes such as (i) visual recognition, (ii) specific facial/body areas, (iii) biometrics, and (iv) dental superimposition (Caplova et al. 2018).

The use of ear morphology and biometric properties of its distinguished anatomical landmarks has emerged since 1890 when French criminologist Alphonse Bertillon wrote (Hurley et al. 2007):

> *"The ear, thanks to these multiple small valleys and hills which furrow across it, is the most significant factor for identification. Immutable in its form since birth, resistant to the influences of environment and*

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> *education, this organ remains, during the entire life, like the intangible legacy of heredity and the intrauterine life."*

He pioneered the use of physical measurements of various parts of the body, both quantitatively and qualitatively, which was called anthropometry (Ross and Abaza 2011). The biometrics of the ear caught the interest of Alfred Iannarelli, who gathered a sample of 10000 ears (Hurley et al. 2007), examined them, and later came out with a conclusion that they were all different. He developed the Iannarelli System of Ear Identification, which comprises taking several measurements around the ear by placing a transparent compass with eight strokes at equal intervals of 45° over an ear photograph (Hurley et al. 2007; Ross and Abaza 2011).

Over time, work has concentrated on developing automated computer programs using various complicated mathematical equations (Abaza et al. 2013). Taking measurements from different parts of the ear and individualizing them to a person is an attractive alternative for identification purposes. The ear protrudes from the head in varying degrees, with some set close and flat to the head, while others recede deep and recess into the head. The shapes of the outer ear rim are also different, with some individuals having oval, round, triangular, or rectangular shapes, which are the most defining features of the external ear. The concha area can be deep, wide, shallow, or narrow. Ears may be positioned at different levels on the head, with some having low-set ears, whereby the upper rim of the helix is situated below the level of the eyebrow (Kapil et al. 2014).

The ear is relatively a stable organ and is a defining feature of the face. It is situated on both sides of the head and is not affected by facial expressions and speech (Hurley et al. 2007). Studies have demonstrated that the imprints made by the human ear are unique to each person (Krishan and Kanchan 2016; Meijerman 2006). The ear growth between four months to 8 years old is linear, after which it becomes constant throughout adult life until about 70 years old when it spikes again (Masaoud et al. 2013).

The ear starts to appear between the fifth and seventh weeks of pregnancy (Abaza et al. 2013). At this stage, the embryo's face takes on more definition as mouth perforation, nostrils, and ear indentations become visible. The embryo develops initial clusters of embryonic cells that serve as the foundation, from which a body part or organ develops. Two of these clusters termed the first and second pharyngeal arches will form six tissue elevations called auricular hillocks during the fifth week of development. In the seventh week, the auricular hillocks begin to enlarge, differentiate, and fuse, producing the final shape of the ear, which is gradually translocated from the side of the neck to a more cranial and lateral site. By the ninth week, the morphology of the hillocks is recognizable as a human ear. Hillocks 1–3 form the first arch of the ear (tragus, helix, and cymba concha), while hillocks 4–6 form the second arch of the ear (antitragus, antihelix, and concha).

Methods

The study was conducted on 181 subjects comprised of 148 males and 33 females of the age range between 18 and 70 years old. All subjects were selected based on the inclusion and exclusion criteria. Age, sex, race, height, and anatomical landmarks from bilateral ears were recorded. This study was approved by the Institutional Ethics Committee (Research Ethics No: FF-2021-068).

The subject was placed on the autopsy table with the head of the deceased placed in such a way that its longitudinal axis is parallel to the long axis of the autopsy table. A living staff would place the deceased's ear lightly against a glass panel with a fixed scale of 150 mm. Two photographs of the right ear and left ear were captured by a Pentax K-r 12.4MP digital single-lens camera, which was placed perpendicular to the subject under sufficient lighting conditions, i.e., within a 15-cm distance. All photos were printed out after normalizing accordingly with the Iannarelli method.

Measurements of twelve ear biometrics were taken based on the Iannarelli method, which was labeled as R1 until R12 for the right ear and L1 until L12 for the left ear (Fig. 1). In addition, the ear length and ear width were also measured (Fig. 2). The ear length was the maximum distance of a vertical line between the top end of the superior helix rim and the bottom end of the inferior lobule of the ear. The ear width was the maximum distance between the most anterior end of the helix rim and the most posterior end of the helix rim, where a horizontal line was formed, that crosses perpendicularly with the ear length. Measurements were taken twice with the Insize Digital Caliper 150 mm, and the average of the measurements was taken. Quality assurance was practiced to ensure compliance with the procedure adopted by using the same instruments and protocols throughout the measuring process.

The data were analyzed statistically by IBM SPSS Statistics 28.0. The Shapiro-Wilk test was used to examine the fit of the quantitative values to a normal distribution. An independent *t*-test was used to determine whether there was any difference in the biometrics. The *p*-value is the level of marginal significance within a statistical hypothesis test in representing the probability of the occurrence

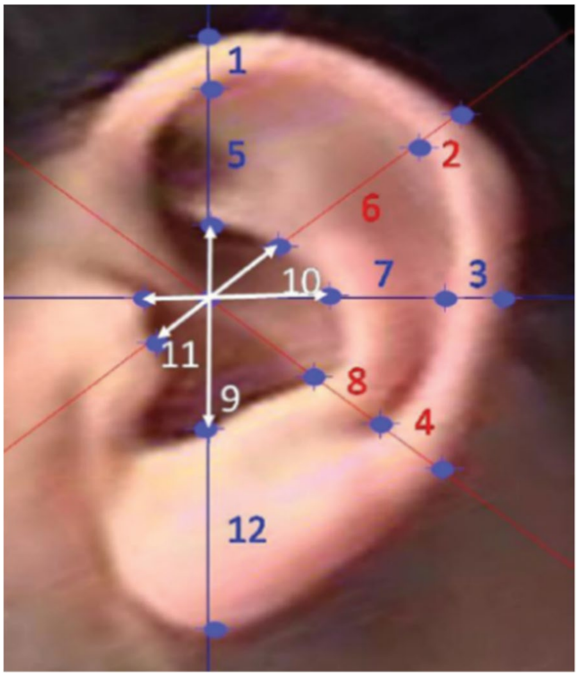

Fig. 1 The diagrammatic representation of the ear biometrics

of a given event. The significance level taken in all of the tests was $p<0.05$. Pearson correlation was used to determine the correlation between ear biometrics with height and age of an individual.

Results

A total of 181 cadavers were sampled in this study, comprising 148 males (81.8%) and 33 females (18.2%) in the age range between 18 and 70 years old. About 21% of the subjects were Malays, 43.1% Chinese, 12.2% Indians, and the remaining 23.8% were non-Malaysians.

Comparative statistics for the ear biometrics between different sexes with mean values, standard deviations, and "*p*" values were tabulated (Table 1). By using an independent *t*-test, there was a significant difference between different sexes in six biometrics, i.e., biometrics 3, 6, 7, 9, ear length, and ear width ($p < 0.05$) as shown in the Table 1. However, the other biometrics showed no difference between the different sexes. Stepwise and multivariate discriminant analyses of the ear biometrics (3, 6, 7, 9, ear length, and ear width) were tabulated (Table 2).

Function 2 was used to develop the discriminant function as the classification rate is the highest (85.5%) (Table 2). The analysis was significant, based on six discriminant functions ($p < 0.001$; Wilk's $\lambda = 0.772$; $\chi^2 = 45.125$; $df = 6$) (Table 3), allowing a canonical discriminant function (D) to be employed (Table 4):

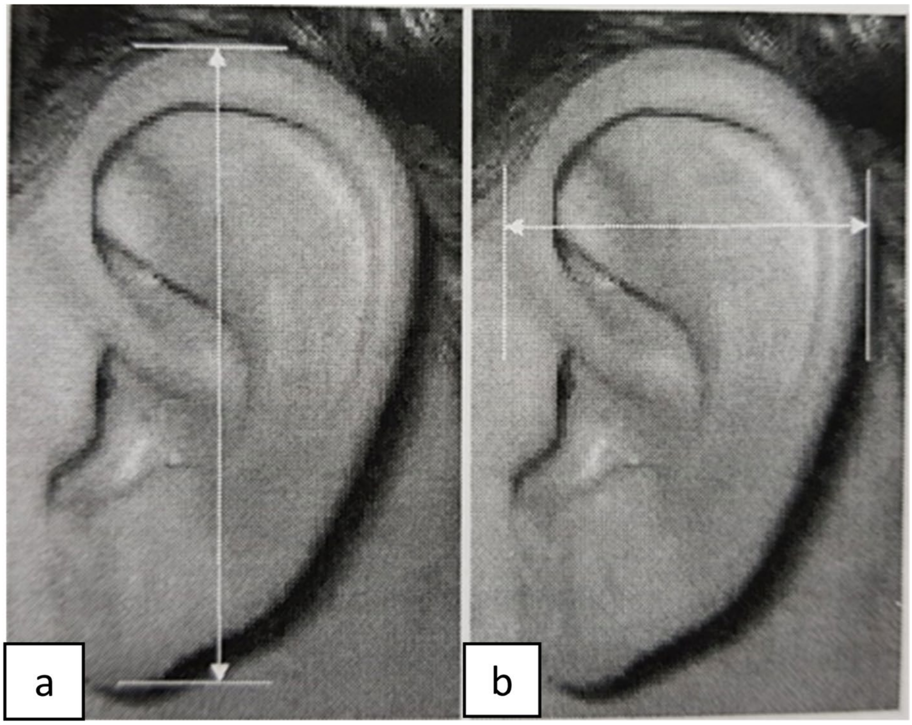

Fig. 2 The diagrammatic representation of the ear length (**a**) and ear width (**b**)

Table 1 The ear biometrics in males and females

Ear biometrics	Sex	*N*	Mean (mm)	Standard deviation	Independent *T* test ("t" value)	Independent *T* test ("*p*" value)
R1	Female	33	6.19	1.81	−1.79	0.07
	Male	148	6.85	1.92		
R2	Female	33	4.36	1.12	−1.77	0.07
	Male	148	4.78	1.25		
R3	Female	33	4.27	0.68	−2.49	0.01**
	Male	148	4.69	0.92		
R4	Female	33	6.84	1.56	−1.82	0.07
	Male	148	7.39	1.57		
R5	Female	33	14.37	2.49	0.87	0.38
	Male	148	13.91	3.69		
R6	Female	33	14.81	2.49	−5.17	<0.01**
	Male	148	17.61	2.87		
R7	Female	33	7.28	1.95	−4.60	<0.01**
	Male	148	9.28	2.31		
R8	Female	33	8.10	1.81	−1.32	0.18
	Male	148	8.66	2.26		
R9	Female	33	21.45	2.40	−3.48	0.01**
	Male	148	23.10	2.77		
R10	Female	33	17.56	2.56	−0.68	0.49
	Male	148	17.90	2.42		
R11	Female	33	15.99	2.37	1.45	0.15
	Male	148	15.35	1.91		
R12	Female	33	20.44	3.82	−0.36	0.71
	Male	148	20.73	4.16		
Right ear length	Female	33	63.90	5.73	−2.22	0.02*
	Male	148	66.73	6.77		
Right ear width	Female	33	31.64	3.06	−4.15	<0.01**
	Male	148	34.54	3.74		
L1	Female	33	5.57	1.77	−1.64	0.10
	Male	148	6.13	1.77		
L2	Female	33	4.57	1.02	−0.51	0.61
	Male	148	7.32	30.95		
L3	Female	33	4.54	0.90	−2.24	0.02*
	Male	148	4.97	1.01		
L4	Female	33	7.68	1.74	−0.22	0.82
	Male	148	7.75	1.41		
L5	Female	33	16.01	2.71	−0.10	0.91
	Male	148	16.08	3.43		
L6	Female	33	14.00	2.27	−4.26	<0.01**
	Male	148	16.48	3.15		
L7	Female	33	6.84	1.52	−3.69	<0.01**
	Male	148	8.38	2.28		
L8	Female	33	8.77	2.05	−1.19	0.23
	Male	148	9.27	2.20		
L9	Female	33	20.80	2.26	−3.30	0.01**
	Male	148	22.43	2.63		
L10	Female	33	17.83	2.52	−1.22	0.22
	Male	148	18.41	2.27		

Table 1 (continued)

Ear biometrics	Sex	*N*	Mean (mm)	Standard deviation	Independent *T* test ("t" value)	Independent *T* test ("*p*" value)
L11	Female	33	16.07	1.73	0.44	0.65
	Male	148	15.90	2.04		
L12	Female	33	20.96	3.37	0.52	0.59
	Male	148	20.57	3.93		
Left ear length	Female	33	64.28	4.55	−2.94	0.01**
	Male	148	66.92	5.12		
Left ear width	Female	33	31.92	2.63	−6.34	<0.01**
	Male	148	35.44	2.93		

** $p<0.01$, *$p<0.05$

Table 2 Stepwise and multivariate discriminant analysis of the ear biometrics in males and females

Functions	Ear biometrics	Wilks' Lambda	"*p*" value	Classification (%)	Cross-validated (%)
Function 1 (stepwise)	3, 6, ear width	0.796	<0.01**	84.4%	83.8%
Function 2 (multivariate)	3, 6, 7, 9, ear length, ear width	0.772	<0.01**	85.5%	83.2%
Function 3	Ear length, ear width	0.854	<0.01**	83.8%	83.2%

** $p<0.01$

Table 3 Summary of canonical discriminant functions

Test of function(s)	Wilk's Lambda	Chi-square	df	Sig.
1	0.772	45.125	6	<0.001

Table 4 Unstandardised canonical discriminant function coefficients

	Function 1
R3	0.468
R6	0.159
R7	0.083
R9	0.130
Ear length	−0.032
Ear width	0.152
Constant	−11.663

Table 5 Unstandardised canonical discriminant functions evaluated at group means

	Function 1
Female	−1.138
Male	0.257

Table 6 Classification results for female and male ears

		Sex	Predicted group membership		
			Female	Male	Total
Original	Count	Female	12	21	33
		Male	5	141	146
	%	Female	36.4	63.6	100.0
		Male	3.4	96.6	100.0
Cross-validated	Count	Female	8	25	33
		Male	5	141	146
	%	Female	24.2	75.8	100.0
		Male	3.4	96.6	100.0

$$\begin{aligned}\mathrm{Discriminantscore(DS)} = {} & 0.468(\mathrm{R3}) + 0.159(\mathrm{R6}) \\ & + 0.083(\mathrm{R7}) + 0.130(\mathrm{R9}) \\ & + (-0.032)(\mathrm{earlength}) \\ & + 0.152(\mathrm{earwidth}) + (-11.663)\end{aligned}$$

The sectioning point is −0.44. If the score >−0.44, it is classified as male, and if the score <−0.44, it is classified as female. The unstandardized canonical discriminant functions were evaluated at group means (Table 5). The classification functions gave correct classification rates for 85.5% of cases. The accuracy of identification was 96.6% for males and 36.4% for females (Table 6). The classification functions also gave cross-validated correct classification rates for 83.2% of cases. The accuracy of identification was 96.6% for males and 24.2% for females (Table 6).

Pearson correlation analysis showed significant correlations between R4, R6, R7, R9, R10, right ear length, right ear width, L6, L7, L9, L10, L11, left ear length, and left ear width and height ($p < 0.05$) (Table 7).

The right ear showed positive correlations between R3, R5, R7, R8, R12, ear length, ear width, and age, while R10 and R11 exhibited inverse correlations with age (Table 8). For the left ear, only L9, ear length, and ear width showed positive correlations with age. As age advances, the size of the ear also tends to increase. However, L10 and L11 showed inverse correlations with age (Table 8).

Table 7 Pearson correlation between ear biometrics and height

Ear biometrics	Pearson correlation	"p" value
R1	0.11	0.14
R2	0.04	0.59
R3	0.05	0.52
R4	0.16	0.03*
R5	−0.06	0.39
R6	0.29	<0.01**
R7	0.17	0.02*
R8	0.01	0.92
R9	0.32	<0.01**
R10	0.21	0.01**
R11	0.07	0.33
R12	0.12	0.10
Right ear length	0.21	0.01*
Right ear width	0.17	0.02*
L1	−0.02	0.76
L2	0.01	0.94
L3	0.13	0.09
L4	0.06	0.46
L5	0.11	0.13
L6	0.24	<0.01**
L7	0.18	0.01*
L8	−0.001	0.99
L9	0.38	<0.01**
L10	0.20	0.01**
L11	0.15	0.03*
L12	0.07	0.32
Left ear length	0.33	<0.01**
Left ear width	0.38	<0.01**

** $p<0.01$, *$p<0.05$

Table 8 The Pearson correlation between ear biometrics and age

Ear biometrics	Pearson correlation	"p" value
R1	0.03	0.70
R2	0.13	0.09
R3	0.17	0.02*
R4	−0.03	0.69
R5	0.18	0.02*
R6	0.13	0.08
R7	0.24	0.01*
R8	0.24	0.01*
R9	0.13	0.07
R10	−0.29	<0.01**
R11	−0.15	0.04*
R12	0.16	0.03*
Right ear length	0.28	<0.01**
Right ear width	0.21	0.01**
L1	0.07	0.37
L2	0.10	0.16
L3	0.13	0.07
L4	0.06	0.46
L5	0.13	0.08
L6	0.07	0.32
L7	0.11	0.16
L8	0.12	0.11
L9	0.15	0.05*
L10	−0.20	0.01**
L11	−0.19	0.012*
L12	0.08	0.29
Left ear length	0.24	0.01**
Left ear width	0.14	0.05*

** $p<0.01$, *$p<0.05$

Discussion

Numerous global studies have been carried out to illustrate the morphological and morphometric differences in human ears. Some recent studies (Hurley et al. 2007; Cameriere et al. 2011; Purkait 2016; Verma et al. 2016) have shown that possesses its own distinct morphology, exhibiting reasonable variations among individuals and different population groups. These research endeavors have delineated diverse type categories and configurations of the ear, various forms of the helix and tragus, types of Darwin's tubercles, shape size, and forms of the earlobes. The presence and prevalence of these traits have been computed, and characteristics based on population data have been gathered to establish connections between these attributes and a specific community. In previous years, several studies were conducted on ear biometrics for identification, but a majority of them were done only on living persons. Some argued that it may also be used to identify the deceased, but no such study has been done (Caplova et al. 2018). Hence, this study aimed to collect such data on the deceased for identification purposes.

Significant differences between sexes were obtained in six biometrics, which were found to be larger in males than females ($p<0.05$) (Cheng et al. 2019; Murgod et al. 2013). One of the reasons may be attributed to differences in the puberty period in different sexes. The age in puberty for a boy is 1 year later than that of a girl indicating a different time frame for a boy to grow in comparison to a girl. The difference in ear biometrics may also be due to different genetic predisposition, which begins early postnatally and leads to different ear growth in males and females (Hurley et al. 2007).

Females achieved full ear length and width at different rates than males. Males have at least an extra 1-year or 2-year time interval for vertical ear growth to occur. Besides, a 4-year time interval is needed for horizontal ear growth to occur in males compared to that in females (Niamtu 2018). Males and females react differently towards environmental factors. For instance, females with two chromosomes XX will react more slowly with lower intensity towards environmental stress during growth. Also, ear expansion will have a slower starting point in females compared to males. For example, ear expansion in the age range of 12 to 15 years old and 19 to 30 years old could cause an increase in ear length and ear width, respectively. The ear length and ear width showed an increase of about 4.1 mm and 1.8 mm in males compared to about 0.9 mm and 0.8 mm in females, respectively. These findings showed that an increase in ear length may occur much higher than that in-ear width, which may occur at different rates in both males and females (Meijerman et al. 2007).

This study yielded positive correlations of the ear biometrics (R4, R6, R7, R9, R10, L6, L7, L9, L10, L11, right and left ear lengths, right and left ear widths) with height ($p<0.05$). It was supported by several studies, which exhibited good correlations between craniofacial parameters and height, with some parameters found to increase with body height (Cheng et al. 2019; Wang et al. 2011).

This study involved a wide range of ages from 18 until 70 years old. Analysis showed strong correlations between ear biometrics and age. This can be demonstrated during post-maturity growth, whereby the ear may expand in size within the age of 50 years old until 70 to 80 years old when there will be a loss of elastin and the ear becomes less resilience with diminutive tensile strength of connective tissues and other changes in the intracellular tissues (Meijerman et al. 2007). The gravitational force and reduction in the amount of cartilage cells per unit area will lead to a lengthening of ear lobule resulting in increased ear length of about 11 mm in males and 13 mm in females by the age of 80 years old (Kapil et al. 2014).

However, there were several limitations in this study. It has to be cautioned that these results were optimized only for this sample, as the samples in this study were collected mostly from the Universiti Kebangsaan Malaysia Medical Centre. Hence, they may not be representative of the Malaysian population. Additionally, there is a lack of established protocol standards in ear biometrics for identification. Ear measurements may be subject to error due to the inherent flexibility of the ear, glass panel pressure variation, and subjective experience of the practitioner.

Conclusions

The study concludes that in brief, there were significant differences between males and females in ear biometrics, whereby males showed increased measurements compared to females. There were positive correlations between the height and age of individuals with ear biometrics leading to the generation of equations for the identification of individuals. Regarding the distinctiveness of the ear, the research affirms that each human ear is one-of-a-kind. This uniqueness is attributed to the considerable variability observed in the external structure of the ear. The study contributes fresh insights into the diversity and attributes of the ear in a North Indian population, enhancing anthropological understanding and morphological variability of ear structure. This knowledge can be further applied in forensic examinations, particularly in processes involving the identification of individuals through ear images. Hopefully, more research will be done in this field on an extended sample to improve the identification process for deceased persons.

Abbreviations

INTERPOL	International Criminal Police Organization
DNA	Deoxyribonucleic acid

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Authors' contributions

All authors contributed significantly to the work, whether in the conception, design, utilization, collection, analysis, and interpretation of data or all these areas. NAA was a major contributor in writing the manuscript. NKA, NUMN, and NO performed the statistical analysis. NAA, FMN, MSS, and NAR interpreted the data and participated in the article's drafting, revision, or critical review, giving their final approval for the version. NAR decided on the journal to which the article would be submitted and made the responsible decision to be held accountable for all aspects of the work. All authors read and approved the final manuscript.

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Availability of data and materials

All data and materials are available.

Declarations

Ethics approval and consent to participate

This study was approved by the Institutional Ethics Committee (Research Ethics No: FF-2021-068).

Consent for publication

The anonymity of the subject and confidentiality were well preserved.

Competing interests

No benefits have been received from a commercial party related directly or indirectly to the study.

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