External ear as a biometric identifier

Prosjektoppgave medisinstudiet UIO
Sintia Beliene-Molander og Charlotte Kristine Olsen

Veileder: Per Holck

Prosjektoppgave ved institutt/fakultet

UNIVERSITETET I OSLO

25.03.2018

Abstract

The human ear is a unique and universal part of the human body, that besides transmitting sound, may be a source of particular features that could help in identification of an individual. It was first used in the late 19 century by the French criminologist Alphonse Bertillon, as one of eleven anthropometric measurements for his manual system of identifying individuals (1). Later by Iannarelli in 1964 who studied thousands of ears along his career and created *The Iannarelli system of ear identification (2).* However, the ear as an established identification method is not yet widespread, and for many, an unknown resource due to several reasons. In this paper we aim to elucidate knowledge and provide tools supplementary to today's anthropometrics identification methods. The data for this study was based on analysis of ear photographs of 100 voluntarily individuals. By measuring specifics anatomic areas in the ear with a relatively simple but comprehensive method, we find that every single ear in this study was distinguishable from one another.

1.Introduction

Today's identification methods are based in documents, biometrics such as fingerprints, facial recognition, iris scanning, DNA profiling among others (3, 4). Fingerprints as identification is a well established and unquestionable resource. Nonetheless, in cases such as post-mortem degradation, fingerprints and face recognition could be a challenge (5). In other cases, uncooperative subjects, can delay the identification process.

Alphonse Bertillon was a French criminologist and biometrics researcher who developed an anthropometric system for identification. Before him, identification was only possible by name or photograph. He used a system of 11 measurements considered infallible, but later substituted by fingerprints. Alfred Victor Iannarelli was one of the first to classify about seven thousand ears using photographs. His system was based on a meticulous approach to ear photographs, enlarging and measuring a 12-point system scale, published “The Iannarelli system of ear identification” in 1964. One of the criticism to his method is due to difficulty and inaccuracy in finding the origo for the 12-points, factors compulsory for reliability and validity. His work is one of the most important contributions to this paper (6).

Other human characteristics are also being studied as possible biometric modalities. Utilization of biometric methods such as iris scanning has already been implemented in border controls (7). The external ear has its unique characteristics just as fingerprints have its arches, and despite cellular evolution the pattern of the ear is a lasting, immutable and individual as fingerprints. Apart from growing in size, its proportions remains constant throughout life until decomposition (8). The ear is mainly composed of skin and elastic cartilage with minimal amounts of water and fat (9), which may delay decomposition rate.

One particular study has showed that cartilage as a new parameter for estimation of time of death, may be useful for an objective determination of the postmortem interval in the late postmortem period (10). Having said that, it is important to take in consideration that the ears might undergo changes throughout life, such as mutilation, scars and surgery. Making it even more unique or in other cases making a valid comparison impossible. Compared to fingerprints, the recognition of the ear, can be performed without the subject's cooperation or consent as long a proper photography is obtained. Furthermore, technology and social media, gives easy access to a great deal of personal information facilitating the process of recognition or identification (11). However, in order to identify someone, the comparison with an existing database is necessary. Together with a well-established protocol for every step in the identification system. This study does not seek to elaborate a comprehensive anthropometric measurement system, but rather provide knowledge about the ears uniqueness and verify its validation in biometrics.

2. MATERIALS AND METHODS

Subjects

Ear photographs of Norwegian subjects 57 women, 43 men. Age varying between 18 to 45 years old in the male population and 19 to 62 years old in the female population. Both groups with mean age corresponding 23,7 years. Subjects with earlier ear-operations or malformations were excluded. Subjects wearing earrings and piercings were included to imitate a normal situation. All subjects who joined the study were asked to consent and sign a consent form. Only the ears were photographed and the subjects were linked to their photograph by a number, to guarantee anonymity.

Photographs and measurements

The photographs were taken with a Nikon D3100, digital reflex camera (pixels: 4608 x 3072(L), 2304 x 1536 (S), 3456 x 2304(M)). Shutter speed: 1/4000-30s in steps of ⅓ EV. No flash was used, only natural reflected light.

The volunteers were photographed at a distance of about 1 meter, in normal lateral profile. Only left ears were used. The photos were taken in the same room with the same background and saved as jpg files with no picture processing applied.

Manually measurements

The ears and head length of the volunteers were also measured manually. First we obtained the longest part of the ear by measuring the height of the ear. To do this we used an anthropological calliper/sliding calliper and measured the ear from the outer edge of the superior part to the inferior part of the lobe. Than the cranium length was measured with anthropological callipers, from Protuberantia Occipitalis Externa to the longest achieved measurement of the frontal bone.

Analysing the photographs

To obtain the ear measurements, we needed to agree on a standardized measuring system, so that the origo for our measurements did not vary from subject to subject. It became clear to us that we needed a standardized guideline, that we could base all the other measurements upon. The guideline A (figure 1) was obtained by deciding the deepest part of the intertragic notch (point 10, figure 1) and then draw a line to the meeting point of the inferior crus and the rim of the helix (point 1, figure 1), then we draw a line between this two points and extended the line to the outer edge of the ear (point 3, figure 1). This way we managed to obtain guideline for the measuring system that was possible to replicate with high accuracy among the other subjects. In search for an easy, nevertheless comprehensive and accurate method, the measurement of ear length was soon discarded due to reliability issue. Reproducing the same numbers for ear length in a photograph, became a challenge. Since the ear length was measured in vivo, one can use it as part of the total analysis of the ear together with anatomical variables. Such as ear shape, ear lobe attachment, Darwin's tubercle, etc. The ear lobe was not included among the quantitative variable because it undergo changes throughout life, leading to an invalid parameter.

Manually measurements of the photograph

Ear orientation and determination of helix, antihelix, concha, and lobe edges were obtained by the technique described in the text below and by figure 1. The ear photographs were analysed and measured manually with the assistance of a pre-molded frame containing the same measurements as figure 1.

- **Line A** (Figure 1) extends from the deepest part of the intertragic notch (point 10 Figure 1) to the meeting point of the inferior crus and the rim of the helix (point 1 figure 1). After point 1 and 10 is determined, line A can be expanded to the outer edge of the helix, passing through point 10 and 1.
  - Line A consists of 4 subdivisions*:*
  A,point 3-2: the line between the outer edge and the inner edge of Helix Rim.

A,point 2-1: the line from inner edge of the Helix Rim to point 1.
A,point 1-Origo: the line from Origo to point 1.
A,Origo-point 10: the line from Origo to point 10.

- **Origo**, obtained by dividing the line between point 10 and 1 in two equal lines.
- **Line B** (figure 1) is a line in a 45° angle between line A and C.
  Line B consists of 3 subdivisions:
  B,point 6-5: the line from the outer to the inner edge of the Helix Rim.
  B,point 5-4: the line from the inner edge of Helix Rim to Anti Helix´s edge.
  B,point 4-Origo: the line from Anti Helix´s edge to origo.
- **Line C** (figure 1) is perpendicular to line A, with Origo as base.
  Line C consists of 2 subdivisions:
  C, Origo-point 7: a horizontal line from Origo to the inner edge of the Anti Helix.
  C,point 7-8: a horizontal line from the inner edge of the Anti Helix to the outer edge of Helix.
- **Line D** (Figure 1) is a 45° angle between line A and C, and ends at the edge of the antitragus. (figure 1).

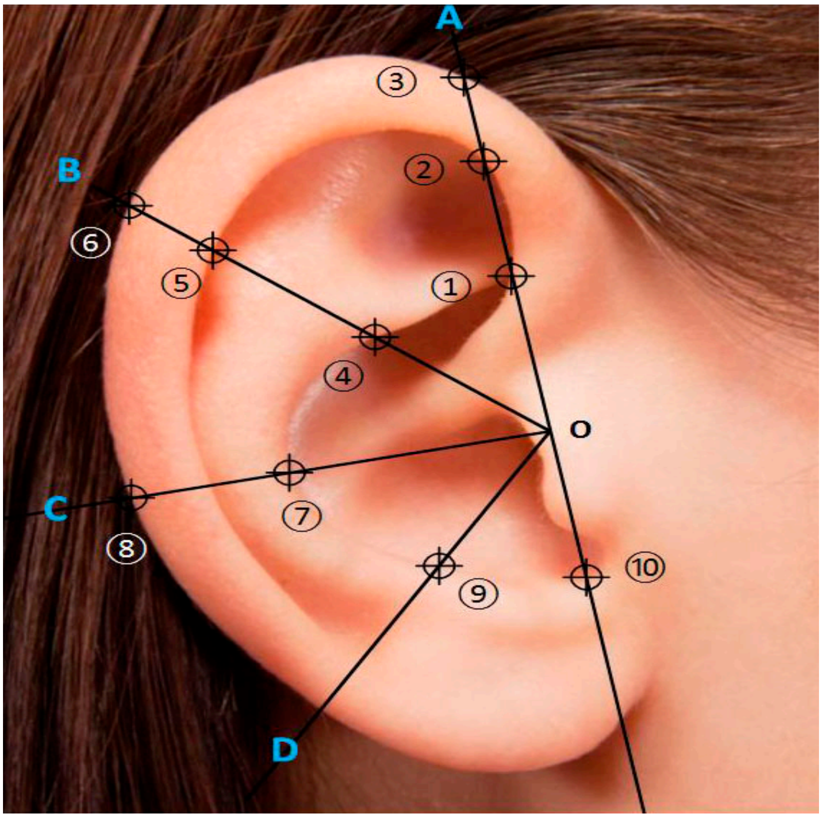

Fig.1: Measuring system, details in the text above.

Fig.2: External ear anatomy

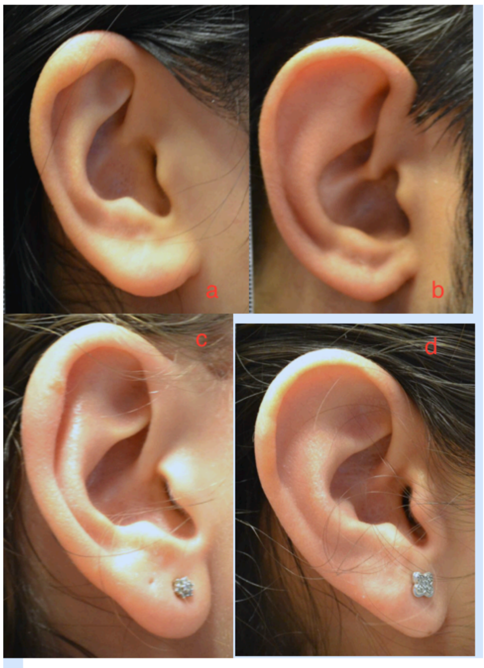

Fig.3: Morphological shapes of ear.
a. Rectangular; b. Round; c. Oval; d. Triangular

Mathematical formula

In total there are 4 principal lines A, B, C, D and 9 intersections. Resulting in 13 different variables for each ear. These variables will be implemented in a simple mathematical formula, which will provide each ear with a individual constant. The ear grows rapidly the first year of life, but later there is relatively no change considering the proportion to the over-all-growth besides the ear lobe. By dividing the proportions by the Line A, we expect to compensate for natural ear growth especially in ear-length. Another argument for dividing the variables by Line A is the level of standard deviation. Among the all the four lines, Line A shown the greatest standard deviation. In all manually measurements there are sources of error. However we anticipate that the use of manually measurements will be exchanged with digitally scanning methods in the nearest future, and the margin of error will decrease accordingly.

$$\frac{\left(\left(\frac{Ai}{A}\right)\times\left(\frac{Aii}{A}\right)\times\left(\frac{Aiii}{A}\right)+\left(\frac{Ax}{A}\right)\times\left(\frac{Biv}{B}\right)\times\left(\frac{Bv}{B}\right)\times\left(\frac{Bvi}{B}\right)+\left(\frac{Cvii}{C}\right)\times\left(\frac{Cviii}{C}\right)+D\right)=k}{A}$$

$$\frac{\left(\left(\frac{7}{48}\right)\times\left(\frac{15}{48}\right)\times\left(\frac{13}{48}\right)\times\left(\frac{13}{48}\right)+\left(\frac{9}{32}\right)\times\left(\frac{10}{32}\right)\times\left(\frac{13}{32}\right)+\left(\frac{17}{25}\right)\times\left(\frac{13}{25}\right)+13\right)=0{,}27678}{48}$$

Figure 4: The formula

3. RESULTS

The collected data was statistically analysed using Excel Version 15.33 (Microsoft Excel for Mac). Results shows that 41% had an oval ear shape and less common was the round shape with 9 %. The majority (71%) of the subjects had a free ear lobe. Our data showed no direct association of ear length with body height.

	Calculated Range	**Mean +-SD**
Total ear length	5,8-6,8	6,0 SD (0,36)
Height	155-184	168,8 SD (6,2)
A	38-50	43,4 SD (2,8)
B	27-36	34,4 SD (2,1)
C	19-32	24,7 SD (2,2)
D	06-12	8,7 SD (1,4)

Table 1. Biometric measurements in female population, ear length and body length

	Calculated Range	**Mean +-SD**
Total ear length	5,3-7,3 cm	6,4 SD (0,38)
Height	158-198 cm	180,9 SD (6,5)
A	42-51	46,5 SD (2,5)
B	20-40	33,9 SD (3,4)
C	14-30	25,1 SD (2,7)
D	05-14	9,8 SD (1,8)

Table 2. Biometric measurements in male population, ear length and body length.

	Calculated Range	Mean +-SD
A	38-51	45 SD (3,02)
B	20-40	33 SD (2,85)
C	14-32	34 SD (2,48)
D	01--14	9 SD (1,73)

Table 4. Biometrics measurements in both female and male population, ear length and body length.

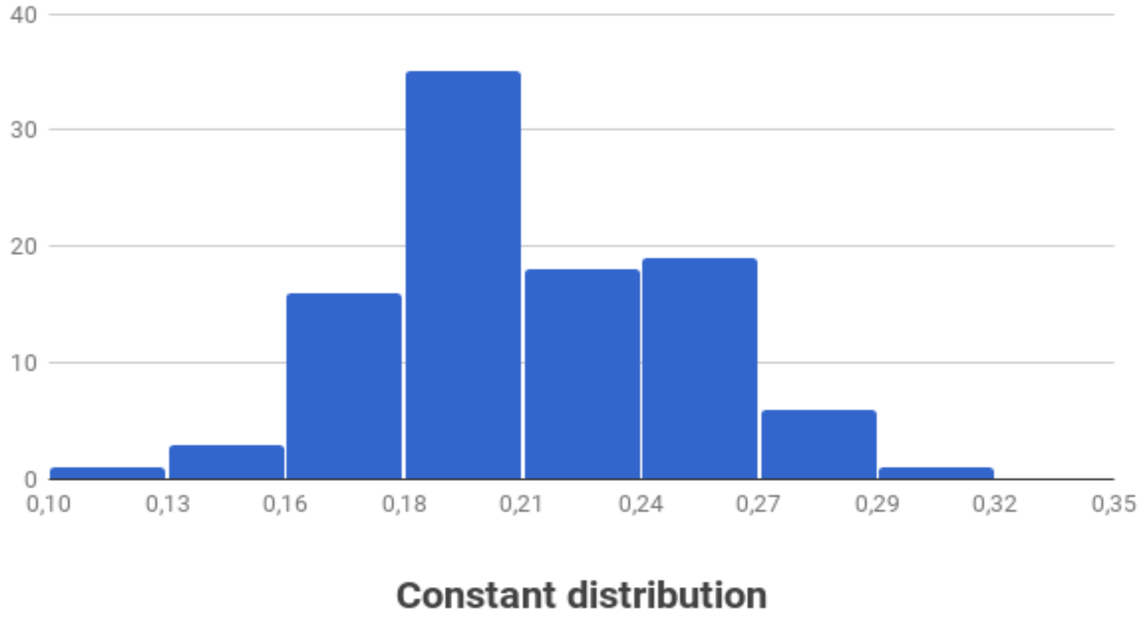

Figure 5: The distribution curve of the constants from our study. The constant is based on the formula (figure 4), and the measurements obtained from the subjects in the study. The results indicate that each subject has its own constant and none of them are equal. Figure 6: Most the subjects in the distribution curve lies between 0,18 and 0,21.

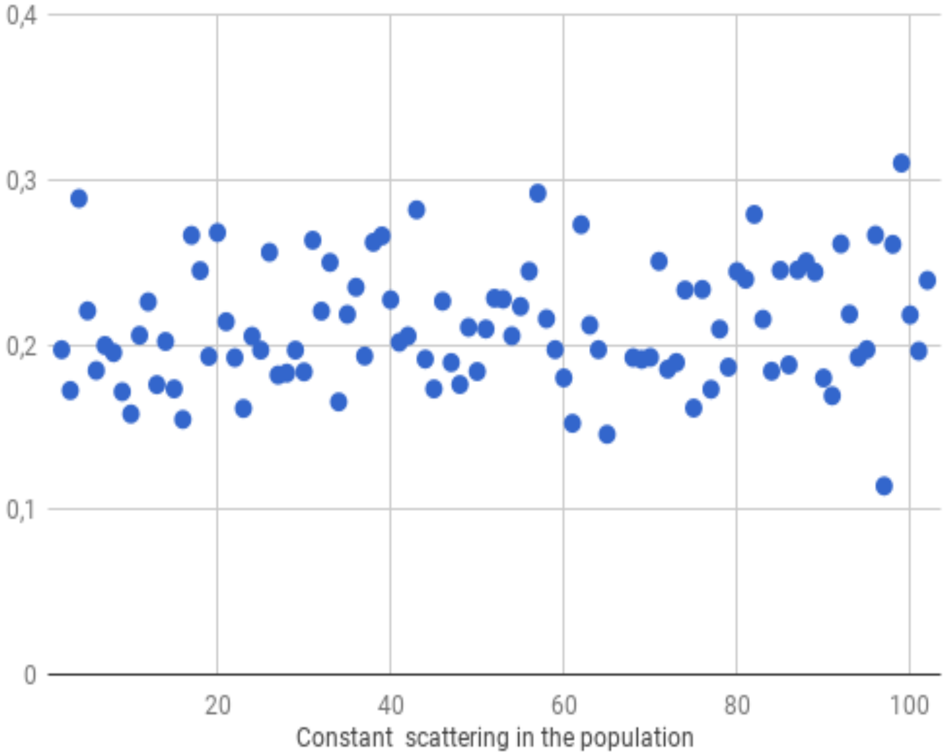

Figure 6: Distribution of the subjects in our study and their constant.

Constant	
Calculated range	Mean +-SD
0,114-0,310	0,212 SD (0,037)

Table 5: Constant range for both female and male population.

4. DISCUSSION

From forensics to national security, the application of ear biometrics might be an additional resource to today's existing identifying techniques. Biometrics is the technical term for body measurements and calculation where one can use it as an identification-form. The idea is to prevent fraud, enhance security and identify individuals. The West Virginia High Technology Foundation performs research and development within data analysis and signal processing. The implementation of the external ear to a profile face picture has already been considered and it is an ongoing project, with the purpose of optimizing recognition (12). The use of the external ear as a possible identification method is yet unknown to many in the field of forensics and in law enforcement today, mainly due to lack of research and difficulty in gathering enough material to prove that ears are as unique as fingerprints.

The external ear´s anatomical changes occur from birth to the ninth month and by then it will be completely developed. After this period it is only growing in size (13). In a four to five year old child, the auricle is about 80 percent of an adult size reaching full adult size by approximately nine years of age (14). In other hand, human face is prone to changes that can affect its consistency in the identification process to a greater extent. Aging, change of expression, cosmetic procedures, among other examples, making a potential recognition difficult or sometimes inconclusive. The ear is not exposed to the same amount of variability. Apart from individuals with deformed or protruded ears, the great majority have no expectation to theirs ears form; or either give it any thought in a daily basis. Thus diminishing any probability of an attempt to modify it.

In passive biometrics where the subject is not aware of a potential surveillance, there might be challenges in obtaining a proper ear image. Objects such as earrings, headsets, hair or any other occluding material might interfere in a crowd surveillance. Electro optical cameras, are used around the world today, in surveillance systems on airports, subways, universities and public places. Some with the purpose of just recording activity for evidence, others are actively being monitored by autonomous tracking system (15). Many of these cameras are amplified with high definition infrared (thermal) devices to counter the lack of light. Thermal cameras are able to produce high quality pictures under low light conditions with high detection accuracy (16).

In forensics, the process of identification of corpse is completely dependent on a collaboration of a multidisciplinary team. The group is usually constituted by police, geneticists, dentists, and coroner where the police stands with the main responsibility. One method used is the comparison of ante- and postmortem information; for instance, hair colour, tattoos, dental records, birthmark etc. Minimum two identification criteria must correspond in order to confirm a positive match, together with no significant discrepancies(17). It is important to remember that visual recognition of the deceased is not always an option, depending to cause of death many of these personal characteristics may be vanished or inconclusive. In such conditions, DNA samples of the deceased and reference DNA from closest relatives, are taken for analysis.

DNA profiling as we know today was first discovered in 1985 by professor Alec Jeffreys and his team at the University of Leicester and has revolutionized forensic techniques and criminal investigation

(18). In cases of natural disaster as the Tsunami in 2004, the number of offers reached beyond five thousand; making the corpse identification a challenging task. The large scale of victims from different nations, combined with a dysfunctional National Mass Fatality Plan and the lack of antemortem information, made the postmortem identification significantly complex (19). According to a report made by the WHO, one important lesson learned was that the "Identification of victims should not only rely in DNA analysis, but also in external evidences, dental records and fingerprints".
There are today few studies about postmortem changes in the human ear. However due to its location and composition of scant fat and water, the ears are decomposing slowly and one can expect to have workable material longer compared to other soft tissue. An effective and valid implementation of ear analysis, could in some cases, ease the burden on professionals during victim identification.

The limitations of using ear biometrics as an identifying tool is as many as the reasons why to use it. Both Bertillion and Iannarelli were aware of the difficulties to take any exact measure once it was the performed manually by different operators. The first biometric identification systems where to impractical to use and were soon replaced by fingerprint technique, which showed great potential. Fingerprint is widely used today as an established identification method. It is socially and legally acceptable as evidence despite the relative small number of studies or evidence showing that fingerprints in fact are unique enough to separate among individuals(20). The same arguments used by critics when discussing the validity of ear identification methods. Iannarelli though, suggested to have proven that the ears physical growth and lifetime changes does not disrupt the symmetry and therefore can still be used throughout a lifetime.

In our study, we present the external ear also as an exclusion material just as much as an identification method. When we decided which anatomical structures and marks to use as origo for our biometric measurements, it became very clear that we needed a system that enabled us to measure as precise as possible. Most importantly, an identification system being able to replicate among individuals. If the base of the measurements tends to vary, all the other measurements would also be imprecise. This is one of the problems that arises in the earlier studies and in many of the manually biometrical identification methods. To erase this problem completely, there will be a need to use digital scan and software programming in contrast to manual techniques. Structures such as the Darwinian notch among others, were not considered due to its variable prevalence among ethnic groups. One study showed that the Darwinian notch was present in approximately 10.4% of the Spanish adult population, 40% of Indian adults, and 58% of Swedish school children (21, 22). It is also important to have a subjective perspective when looking at the ears as a hole in addition to the anthropometric measurements, such as ear shape in general. We have in this study grouped and analysed the ears in four categories, round, rectangular, triangular and oval(23). At the same time, it will be expedient to look at the ear position in relation to the skull and neck. Protruding ears, low or high set ears is a trait that easily can distinguish between ear donors. But as mentioned earlier this is an imprecise method and can not alone include or exclude a person when it comes to identification. Because the ear protrudes from the skull it is easily exposed to changes and alterations. Damage and scarring can change the ear´s structure vastly and if someone would like to change its appearance, it can quite easily be done; either by plastic surgery or visually coverage.

Ear print identification have even more limitations than ear-biometric-identification, because the ear print have many more variables. Once the ear print is left behind by someone its is difficult to calculate the exact anatomical appearance based on the print. In forensic field a considerable number of research has been made to investigate the strength of earmarks and prints as evidence. Recently studies have shown that the use of ear prints in the same way we use fingerprints have some weaknesses, mainly due to intra-individual variation. A single external ear can give rise to different ear prints just by changing the amount of pressure applied by it (24). Therefore, the approach to the external ear as an identification method has moved away from ear prints rather towards a biometric point of view, accompanied by automated and more applicable methods.

As mentioned earlier, studies of ear-individuality was in the beginning based on manually obtained measurements and a theory that every ear could be proven unique if only the manual technique suggested was used correctly. Alphonse Bertillion, Sir Francis Galton, Alfred Iannarelli and Van der Lugt were scientists that contributed to this basis of forensic thinking. Today scientists apply many of the original theoretical thoughts to their work, combined with modern computer engineering. However, they are equally applicable in forensic identification today as for nearly 100 years ago. Alfred Iannarelli and Alphonse Bertillon suggested different systems of taking anthropometric measurements of the human anatomy that also included recording the size, shape and position of the ear on the head for identification. In addition to this, it became clear that the ear anatomy as an identification method requires a modern digital approach. 3D scan configuration and implementation of the measurements into an algorithm independent of angle or distance. Our idea formed working on this study is to use the contrast made by the ears anatomy in pictures and surveillance cameras using a 3D scanning program. This will make identification based on ears easier, faster and more accurate.

5. CONCLUSION

Our study shows that none of the ears compared in our material is identical. (figure 6). To conclude upon the use of this method in identification work, it will be necessary to view a larger set of subjects. However, we can conclude that the method can be used as supportive evidence or to exclude individuals in forensic identification work, based on the variability and the vast possible outcomes using our measuring system.

1. McClaughry ABRW. Signalectic intructions including the theory and practice of anthropometric identification. Chicago: New York Werner Co., 1896.; 1896.
2. Iannarelli AV. The Iannareli system of ear identification 1. ed. Brooklyn: Foundation Press,; 1964.
3. Caplan RM. How fingerprints came into use for personal identification. J Am Acad Dermatol. 1990;23(1):109-14.
4. Choi CJ, Lefebvre DR, Yoon MK. Validation of the facial assessment by computer evaluation (FACE) program for software-aided eyelid measurements. Orbit (Amsterdam, Netherlands). 2016;35(3):117-20.
5. Sauerwein K, Saul TB, Steadman DW, Boehnen CB. The Effect of Decomposition on the Efficacy of Biometrics for Positive Identification. Journal of forensic sciences. 2017;62(6):1599-602.
6. Cameriere R, DeAngelis D, Ferrante L. Ear identification: a pilot study. Journal of forensic sciences. 2011;56(4):1010-4.
7. Daugman J. New methods in iris recognition. IEEE Trans Syst Man Cybern B Cybern. 2007;37(5):1167-75.
8. Iannarelli AV. The external ear. The Iannarelli system of ear identification. Brooklyn: Foundation Press; 1964. p. 3.
9. Schumaker MSESU. Thieme atlas of anatomy. Head, neck, and neuroanatomy. 2. ed. New York: Thieme; 2016.
10. Alibegovic A. Cartilage: a new parameter for the determination of the postmortem interval? J Forensic Leg Med. 2014;27:39-45.
11. Lin FY, Huang CC, Chang PY. A cloud-based forensics tracking scheme for online social network clients. Forensic science international. 2015;255:64-71.

12. Data Analysis and Signal Processing [Web Page]. Fairmont: West Virginia High Technology Foundation; 2018 [Available from: http://wvhtf.org/data-analysis-and-signal-processing/.

13. Iannarelli AV. The external ear. The Iannarelli system og ear identification. Brooklyn: Foundation Press; 1964. p. 4
.

14. Wright CG. Development of the human external ear. J Am Acad Audiol. 1997;8(6):379-82.

15. Surveillance camera code of practice.

16. Bourlai AAT, Foundation WVHT. Human Ear Detection in the Thermal Infrared Spectrum. Thermosense: Thermal Infrared Applications XXXIV [Internet]. 2012 18 May 2012; Vol. 8354.

17. Rodge S. Identifisering av de døde.
Michael. 2005;4:349-56.

18. Jeffreys AJ. The man behind the DNA fingerprints: an interview with Professor Sir Alec Jeffreys. Investig Genet. 2013;4(1):21.

19. Tun K, Butcher B, Sribanditmongkol P, Brondolo T, Caragine T, Perera C, et al. Panel 2.16: forensic aspects of disaster fatality management. Prehosp Disaster Med. 2005;20(6):455-8.

20. Evett CCIW. Probabilistic Approach to Fingerprint Evidence. Journal of Forensic Identification 2001;Volume:51(Issue:2):101 to 22.

21. Ruiz A. An anthropometric study of the ear in an adult population. International Journal of Anthropology. 1986;1(2):133-44.

22. Singh P, Purkait R. Observations of external ear--an Indian study. Homo : internationale Zeitschrift fur die vergleichende Forschung am Menschen. 2009;60(5):461-72.

23. Iannarelli AV. The external ear. The Iannarelli system of ear identification. Brooklyn: Foundation Press; 1964. p. 13.

24. Meijerman L, Nagelkerke NJ, Van Basten R, Van Der Lugt C, De Conti F, Drusini AG, et al. Inter- and intra-individual variation in applied force when listening at a surface, and resulting variation in earprints. Medicine, science, and the law. 2006;46(2):141-51.