ARTIFICIAL INTELLIGENCE AIDED FORENSIC FACIAL IDENTIFICATION VIA CRANIOFACIAL ANTHROPOMETRIC MEASUREMENTS OF EGYPTIAN ADULT POPULATION IN SHARKIA GOVERNORATE

***Dalia Ahmed Selim Ali Abdou*[1], *Essam M. Youssef*[2], *Mohamed Ibrahim Amin*[3], *Nahla M. Ibrahim*[1]**

[1]*Forensic Medicine and Clinical Toxicology Department, Faculty of Medicine, Zagazig University, Egypt,*

[2]*Neurosergury Department, Faculty of Medicine, Zagazig University, Egypt,*

[3]*Diagnostic Radiology Department, Faculty of Medicine, Zagazig University, Egypt.*

ABSTRACT

Introduction: In forensic research studies, facial reconstruction has been presented as a human identification tool, the accuracy of which has been assessed via different subjective and objective assessment methods. These methods have been widely and empirically used in literature, but not statistically correlated. **Aim of the work:** was to assess the role of craniofacial anthropometry as an objective method for judging the accurateness of facial reconstructions through reconstructing three dimensional faces from unknown skulls in a group of Egyptian population, then evaluating the accuracy of the results by comparing them with other subjective and objective methods. **Subjects and Methods:** 30 head CT scans were reconstructed via fitting facial templates onto scanned skulls. The facial reconstructions were assessed by the subjective face resemblance scores and the differences of objective surface distances. Craniofacial anthropometry is presented as an objective method for assessing the accuracy of facial reconstructions by comparing linear ratios and angles with the other methods. **Results:** Comparison of the ranks for each case according to the different subjective and objective tests showed no significant difference. The subjective resemblance and the objective SD tests showed the highest strongest significant correlations, and the anthropometric angles correlated with both the subjective resemblance and the objective SD tests. The anthropometric linear ratios correlated only with the subjective resemblance test. The significant correlation was stronger between the skulls-to-real faces angles differences and the skulls-to-reconstructed faces angles differences. Among the individual linear ratios, there was no specific ratio correlated with any of the other tests. The 3 angles involving points A, C and E were significantly correlated with the objective surface distance (SD) test. **Conclusion:** The current study provides an application of the craniofacial anthropometry as a facial identification objective method, with the craniofacial angles showed more significant correlations with the previously published subjective and objective methods. The results also showed variations among different facial parts in their predictive facial identifications values. In particular, the orbital and chin areas and their anatomical and mathematical relation to the facial width and length were significant.

Keywords: *Facial reconstruction, human identification, craniofacial anthropometry.*

Corresponding author: *Dr. Dalia Ahmed Selim*

Email: dr.d.selim@gmail.com

ORCID:0009-0003-4201-3774

INTRODUCTION

Forensic human identification is a necessity for both legal, such as; in criminal cases and post-mortem identification, and civil purposes, such as; inheritance, marriage and refugees ***(De Boer et al., 2019)***. Human identification entails a comparison between current and previously available data, or post mortem and ante mortem data in case the unknown is deceased. Forensic identification methods carry various weights in their reliability to prove or exclude the identity subject to the circumstances of the different cases. Identification methods, such as DNA, dental records, or fingerprints are usually more accurate, provided that ante mortem data is available. This does not always happen in real forensic cases ***(Stephan and Henneberg, 2006)***.

Studies have emerged following the continuing rise in unlawful migration from the African and Middle-eastern countries to the European ones. With the dangers included in crossing of the Central Mediterranean Sea, the deaths of thousands of these migrants occur. While the exact numbers are unknown and likely underestimated, the International Organization for Migration (IOM) estimates that between 62.3% in 2014 and 75.7% in 2016 out of the worldwide migration related fatalities happen in the Mediterranean Sea ***(Olivieri et al., 2018)***.

Challenges rise due to the lack of ante mortem data to identify the victims, and herein lays the importance of less conclusive but more screening identification methods e.g. forensic anthropology. Forensic anthropology has been of paramount importance in disaster victim identification whether natural or human induced ***(De Boer et al., 2019)***.

The additional value of forensic anthropological expertise at the scene has been demonstrated by numerous examples over the recent years, such as; after the 2001 terrorist attack in USA, the 2009 bushfires in Australia, and the 2014 MH17 airplane event in Ukraine ***(De Boer et al., 2019)***.

Forensic facial reconstruction is considered a screening tool for aiding human identification when no other data is available and when facial identification is not possible (e.g. the remains are in advanced decomposition, disfigured, burnt or skeletonized). It aims to create a facial replica that resembles the unknown during life to a degree that attracts potential attention from the public, or the law authorities, to suggest a possible identity that can then be confirmed or excluded by the primary identification methods ***(Vanezis et al., 2000; Vanezis, 2008; Gupta et al., 2015)***.

Re-establishing the physical appearance of the people of ancient civilizations has been of great interest to more modern populations. That entailed restoring the shape and the identity of ancient mummies, for example; the facial reconstruction of the Belgrade mummy in 1991 and the Egyptian mummy Crisalis in 1983 ***(Cesarani et al., 2004)***.

Various research studies have presented several approaches of facial reconstructions starting with manual and developing to more digital methods. Three main facial reconstruction schools have been published. The "American" school follows a facial reconstruction approach in which the face is built from the skull together with the facial soft tissue as one unit. In contrast, the "Russian or Gerasimov" school adopts an anatomical pattern building the individual facial muscles, fat and skin onto the skull ***(Wilkinson, 2005; Vanezis, 2008; Verzé, 2009; Gupta et al., 2015)***.

On the other hand, in the "Manchester or Combination" school, the muscles of the face are reconstructed with the guide of anatomical landmarks at which the soft tissue thicknesses are taken into account ***(Wilkinson, 2005)***. The approach followed in the latter two schools is referred to in the present study as "facial muscles dependent" approach.

Traditionally, in the manual methods, the face is built using a modelling material such as clay or plasticine which is placed onto the defleshed skull or its model ***(Vanezis et al., 1989)***. Facial reconstruction was first digitized by ***Vanezis et al. (1989)*** by fitting a 3D image of a facial template onto the skull employing computer software. The aim of this process is to transform/model the facial template to take the shape of the skull producing a reconstructed face that is similar in shape to the original face. This is close to the American school but with consideration given to the facial soft tissue thickness at certain craniofacial anatomical landmarks ***(Vanezis et al., 1989; Vanezis, 2008)***.

This approach is referred to in the present study as "facial template dependent" approach. The facial template can be obtained via a scanner e.g. laser scanner, Computed Tomography.

In applied forensic research, the resulting facial reconstructions have been evaluated via different methods that assess whether they show resemblance to the studied individual. This, however, does not always guarantee identification in real forensic cases ***(Hayes, 2016)***. Generally speaking, these methods are either subjective (i.e. reliant on the subjects' evaluation), or objective (e.g. by computer software) ***(Richard et al., 2014)***.

Due to the inevitable subjectivity in the subjective tests, the objective methods have been considered more accurate. Despite this limitation, the subjective assessment tests are designed to resemble real life scenarios as much as possible, therefore, they are still used in research studies. The subjective tests for assessing facial reconstructions comprise two types; face pool and face resemblance tests. In the police eyewitness line-ups, the suspect is placed among a group of similar looking individuals as "foils" or "fillers", either live or as photographs, then the eyewitnesses are asked to choose the “target” ***(Ashcroft et al., 2003)***. In forensic studies, this concept has been adopted to form the “face pool” tests that are used to assess the accuracy of facial reconstructions, where volunteers try to identify certain face from a group of similar faces. Then the percentage or rate of the correct identification of the target face is calculated ***(Stephan and Henneberg; 2006, Wilkinson et al., 2006; Moyers, 2007)***.

In contrast, in the face resemblance test, a volunteer is asked to directly compare and give a score of the similarity between the studied target and their reconstructed face ***(Snow et al., 1970; Stephan and Arthur, 2006; Moyers, 2007; Stephan and Cicolini, 2008; Vanezis, 2008)***. This resembles real forensic cases when a reconstructed face of an unknown is presented to the public and as the acquaintances of missing individuals see a “satisfactory” resemblance, further investigations are then initiated.

Similarly, the objective methods have been widely used in research. Various methods were based on comparing the mathematical Euclidean (i.e. the shortest) distance at certain landmarks defined on the aligned 3D reconstructed and real facial surfaces as an objective measure of their degree of closeness ***(Claes et al., 2006; Vandermeulen et al., 2006; Wilkinson et al., 2006; Lee et al., 2012; Decker et al., 2013; Short et al., 2014)***. In this objective landmark-based technique, the surface distance differences can be presented as; Surface Deviation ***(Wilkinson et al., 2006; Lee et al., 2012; Short et al., 2014; Decker et al., 2013)***, Root Mean Square (RMS) ***(Jayaratne et al., 2012)***, Sum of Square Differences (SSD) ***(Vandermeulen et al., 2006)***, and Euclidean Distance Matrix (EDM) descriptors ***(Claes et al., 2006; Vandermeulen et al., 2006)***.

Geometric morphometrics is another example of objective measure used in forensic research. It is described as a statistical shape analytical technique of an object via coordinate points (landmarks) that define the object shape, and compare various shape patterns. ***Jedrzejowska (2001)*** applied this method for defining the viscero-cranium (i.e. the facial skeleton) profile by studying the relations between different skull parts and the angles between them.

This helped identifying the correlations between facial soft tissue and skeletal parts, which is useful for human identification. Craniofacial anthropometry has been presented in forensic human identification research studies as a landmark-based geometrical morphometric analysis ***(Kleinberg et al., 2007; Starbuck and Ward, 2007; Vanezis, 2008; Short et al., 2014; Hayes, 2016)***.

Kleinberg et al. (2007) compared 2D facial images from surveillance camera footages for the purpose of facial identification. The study analyzed, proportion indices, mathematically calculated from linear measurements between certain facial landmarks, as well as the angles between the landmarks. The authors concluded that facial anthropometry was neither successful for identification of the face as a whole nor among the studied individual landmarks, even with high quality images.

Short et al. (2014) applied craniofacial anthropometry in assessing the facial reconstruction accuracy, by comparing linear and angular measurements between the real and reconstructed faces. The results showed no statistical differences between the reconstruction and the target faces. However, variations were observed among anatomical facial regions, where the nose and the mouth, for example, were significantly larger than other areas.

Furthermore, class II and III skulls ***(Pithon et al., 2014; Utsuno et al., 2014)*** showed variations in the angular and linear measurements, especially at the naso-labial angle.

The face of a young woman was previously reconstructed by ***Hayes (2014)***. After the identity was confirmed by other methods, ***Hayes (2016)*** used geometric anthropometry to assess the accuracy of the reconstructed face, compared to ante mortem photographs of the victim and a database of images of similar population, age, sex, and posture. This objective method was applied after external factors (e.g. head pose variances) were removed. The objective method highlighted that the originally used facial reconstruction method needed further development as the subjective differences between the real and reconstructed face were obvious after the identity was confirmed. This showed the potential value of geometric anthropometry in forensic facial reconstruction research.

A study by ***Simmons-Ehrhardt et al. (2020)*** performed geometric morphometric analysis of facial reconstructions of known individuals compared with CT reference database.

The results showed high rates of matching the reconstructed faces with the known faces by means of inter-landmark distance calculation.

CT scanners have been used to generate 3D digital skull images for facial reconstruction research ***(Quatrehomme et al., 1997; Cavalcanti and Vannier, 1998; Attardi et al., 1999; Cesarani et al., 2004; Wilkinson et al., 2006; Jayaratne et al., 2012; Lee et al., 2012)***.

Sakuma et al. (2010) and ***Jayaratne et al. (2012)*** compared 3D reconstructed faces reconstructed from skulls obtained via CT scans by superimposing these faces to ante mortem photographs of the targets. The images were successfully superimposed with minimal errors.

Rational of the Study Design

The facial reconstruction approach adopted in the present study was the "facial template dependent" approach which was previously evaluated ***(Vanezis et al., 1989; Vanezis, 2008; Abdou et al., 2018)***.

The studied cases were obtained in 3D format from CT scans of a group of Egyptians' patients, already indicated for medical or clinical purposes.

The resulting facial reconstructions were then assessed subjectively and objectively. It was previously concluded that the face resemblance test format is more reliable in subjectively assessing facial reconstruction than the face pool test format ***(Abdou et al., 2018)***. Therefore, the subjective assessment method chosen in the present study was the face resemblance test. The objective assessment was done via facial surface Distance Standard Deviation (SD) test, a method that was repeatedly used for the same purpose ***(Wilkinson et al., 2006; Lee et al., 2012; Short et al., 2014)***. The newly introduced craniofacial anthropometric indices were adopted from ***Kleinberg et al. (2007)***.

It was developed further by using 3D images as opposed to 2D photographs in ***Kleinberg et al. (2007)***'s study, which could have led to limitations of the previous studies as will be discussed later.

THE AIM OF THE WORK

The purpose of our study was to evaluate the role of craniofacial anthropometry as an objective method for judging the accurateness of facial reconstructions through reconstructing three dimensional faces from unknown skulls in a group of Egyptian population then evaluating the accuracy of the results by comparing with other subjective and objective methods. The Null hypothesis was that craniofacial anthropometry does not correlate significantly with previously published subjective and objective methods. In order to achieve this aim and test this hypothesis, the following objectives were attempted:

- Evaluating the faces reconstructed from the studied CT scanned skulls according to their similarity to the real faces using; (1) the subjective face resemblance test, (2) the objective facial surface distance Standard Deviation (SD) test, and (3) the objective method (craniofacial anthropometry) described in this study.
- Ranking the reconstructed faces according to each of the tests, and then performing a statistical correlation between these ranks.

SUBJECTS AND METHODS

This study was approved by the Institutional Research Review Board (IRB) of Zagazig University. Informed consents were obtained from all participants. The present study followed the "facial template dependent" approach described above.

Inclusion Criteria

- Age: 16 years and over.
- Population: Egyptian.
- Can understand and agree to sign the patient consent form.

- CT scans already indicated for medical or clinical purposes.
- A complete head CT scan.
- Scans associated with information about the age and sex of the patient.

Exclusion Criteria

- Age: less than 16 years old.
- Population: Non-Egyptian.
- Cannot understand or does not agree to sign the patient consent form.
- Incomplete head scans, or scans of traumatized, damaged or deformed bones or facial tissue, or scans including any implantable devices.
- Cases with bone disease and blood disorders.

The Study Sample

A total of 85 head CT scans were obtained and anonymised using open source (DICOManonymizer®) software. Of them, 61 scans met the inclusion criteria mentioned above. They were divided into males (n = 34), and females (n = 27), and into age groups (16-20y, 21-30y, 31-40y, 41-50y and >50y) **(Table 1)**.

They were further divided into two sources of data; the “skulls” group (the faces of which were to be reconstructed) and the “facial templates” group (to be fitted onto the anthropologically similar skulls). The former group consisted of 30 skulls (17 males, and 13 females) **(Table 2)**, and the latter group consisted of the remaining 31 scans.

It was aimed to cover all age groups of both sexes. However, due to limited availabilities, some age groups are less presented than others.

From the group of “facial templates”, at least three anthropologically similar (i.e. same sex and age group) faces were merged via the commercial software (Geomagic Wrap®). This has generated one or two “average” facial templates representing each anthropological group. The aim of this step was to overcome the subjectivity implied when using certain faces as templates with specific facial features which was criticised as affecting the reconstructed face appearance ***(Andersson and Valfridsson; 2005, Wilkinson et al., 2006)***.

The Facial Reconstruction Process

The present study comprises using custom made Facial Reconstruction (FR) software that was first presented by ***Vanezis (2008)*** for the purpose of facial reconstruction research, and was then upgraded in 2009. The software performs automatic digital reconstruction of a face from a skull. This incorporates certain 3D objects; a 3D mesh for the selected skull, a 3D mesh for the selected face template, and 2 sets of corresponding landmarks for the skull and the face template.

These digital landmarks are located at pre-defined craniofacial anatomical points. Each landmark is located by placing a digital peg that has an orientation and a length. The latter is defined at each landmark by the used facial soft tissue thickness at that anatomical site.

The base of the peg is located at the skull anatomical point and the end of the peg points to the corresponding facial anatomical point.

For each case, the images of the studied skull and the average facial template were improted into the software, and aligned/registered at the corresponding craniofacial landmarks with a pre-prepared set of facial soft tissue depths.

For the present study, ***El-Mehallawi and Soliman (2001)*** facial depths of the Egyptian population were combined with facial depths from ***Rhine and Moore (1982)*** and ***Helmer (1984)*** depths of Caucasian population ***(Vanezis, 2008)*** as the former study was missing midline landmarks.

Assessing the Accuracy of Facial Reconstructions

The similarity between the faces reconstructed from the studied skulls and their corresponding real faces was assessed subjectively and objectively as described below.

1- **Subjective Face Resemblance Test**

Participants were asked to rate the similarity between the real and reconstructed faces using a (0 - 10) numerical rating scale, starting from to the lowest resemblance to the highest resemblance.

The test was designed so that the observers could view the reconstructed faces remotely and in a 3D interactive format to allow the assessing of the faces from all angles **(Figure 1)**.

Tests were arranged in a number of successive online surveys containing the 3D faces displayed via an online website (Sketchfab).

The total number of participants ranged between 65-76/case, with a mean age of 35.2 years old. They were divided into experts and non-experts groups. The experts group (n=26), with ages between 27 – 68 years old (mean=38.6 y), were classified as females (68%) and males (32%), and as Egyptians (27%) and non-Egyptians (73%). The experts had different expertise; forensic pathology, forensic psychology, forensic anthropology and forensic facial reconstruction. The non-experts group (n=51), with ages between 20–65 years old (mean=33.8 y), were classified as females (67%) and males (33%), and as Egyptians (16%) and non-Egyptians (84%). All assessors were asked to base their assessments on the hard structures of the head (e.g. forehead, eye bones, cheek bones, temple bone, and chin), rather than the soft tissues.

The influence of the individual differences between the assessors on the subjective tests results was explored and will be published separately. However, for the purpose of the present study, the overall subjective resemblance scores given by all the participants was collectively calculated to be included in the comparison with the other assessment methods.

2- Objective Test (1): Overall Facial Surface Distance Standard Deviation (SD)

Geomagic Control® Software, previously named Geomagic Qualify©, was previously used to assess the accuracy of facial reconstruction ***(Lee et al., 2012)***.

Via this software, the resulting reconstructed face for each case was aligned onto the real face of the same case distributed on the facial surfaces. The software automatically registers the aligned surfaces together and calculates absolute quantitative differences between the two facial surfaces at the selected points. It also generates histograms (color map) to visually show the surface differences **(Figure 2)**.

The surface differences are presented in the form of; maximum and minimum ranges, an average surface distance, root mean square (RMS) of surface deviations, and Standard Deviation (SD) of the errors between the overlapped surfaces.

These absolute quantitative differences were noticed to change with adjusting the maximum deviation settings of the software for the surface comparison, with the least changes noticed in the Standard Deviation (SD) ***(De Greef et al., 2005)***. In addition, this was used in previous studies as an objective measure of the similarity between the compared faces ***(Wilkinson et al., 2006; Lee et al., 2012; Short et al., 2014)***.

3-Objective Test (2): Craniofacial Anthropometry

This method was adopted from ***Kleinberg et al. (2007)*** and developed so that five craniofacial anatomical landmarks (Right and Left Ectocanthion, Nasion, Midline Dental Point, Gnathion) **(Table 3)** were defined on the 3D images of the skulls and faces (both real and reconstructed). This employed Geomagic Wrap® software, which has several tools to manually locate points, edit 3D images, and then automatically perform registration of the images at the allocated corresponding points. It can also calculate the mathematical distances as absolute differences between points on the same surface.

The inter-landmarks distance between each two anatomical points was identified as a straight line on the skull, real and reconstructed faces **(Figure 3)**.

Figure (4) shows the anatomical craniofacial points, from which these distances (i.e. linear measurements) (n=9) were taken. This was followed by calculating ratios (n=13) and angles (n=11) between individual linear measurements **(Table 4)**.

These ratios and angles are absolute values (i.e. no specific distance units were generated). For each case, comparisons included; the differences in the skulls-to-real faces linear ratios and angles were compared with the differences in the skulls-to-reconstructed faces linear ratios and angles. Moreover, the absolute differences between the real and the reconstructed faces' linear ratios and angles were calculated, and then averaged.

Table (1): The total number and classification of the obtained head CT scans.

Age Group (y)	Total Male scans		Total female scans	
	Group I (skulls)	Group II (facial templates)	Group I (skulls)	Group II (facial templates)
16 - 20	1	3	2	2
21 – 30	5	4	3	4
31 – 40	6	3	2	3
41 – 50	1	2	4	4
>50	4	4	2	1
Total	17	17	13	14

Table (2): The total number and classification of the studied skulls group.

Age Group (y)	Males	Females	Total
16 - 20	1	2	3
21 – 30	5	3	8
31 – 40	6	2	8
41 – 50	1	4	5
> 50	4	2	6
Total	17	13	30

Table (3): The definitions of the anatomical points used for linear measurements.

Anatomical Point	Skull Definition	Face Definition
(A) Right Ectocanthion	Bony projection of the ectocranial surface of the frontal bone, vertically centered on the orbit, next to the lateral orbital border	A point lateral to the outer canthus (angle) of the eye, vertically centered on the orbit, next to the lateral orbital border.
(B) Nasion	The midline of the Naso-frontal suture. A point at the top of the nasal bone, at the horizontal level of a line dividing the orbit into upper and lower halves.	
(C) Left Ectocanthion	Bony projection of the ectocranial surface of the frontal bone, vertically centered on the orbit, next to the lateral orbital border	A point lateral to the outer canthus (angle) of the eye, vertically centered on the orbit, next to the lateral orbital border.
(D) Midline Dental Point	A point where the upper and lower teeth meet in the midline in line with the Supradentale (The jaw Centre, between the upper incisive teeth) and the Infradentale (The jaw Centre, between the lower incisive teeth).	A point in the midline halfway between the Labiale Superius (The midline point of the upper lip) and the Labiale Inferius (The midline point of the lower lip).
(E) Gnathion	Lowest point of the front of the chin in the midline	Lowest point of the front of the chin in the midline

Table (4): The used linear measurements, linear ratios, and angles.

MEASUREMENT	RATIO	ANGLE
AC	AB/AD	AEC
AB	AB/BD	CAE
BC	BC/CD	CAD
AD	BC/BD	ACE
CD	AD/BD	ACD
BD	CD/BD	ABE
AE	AB/AE	CBE
BE	AB/BE	CDB
CE	BC/CE	ADB
	BC/BE	CEB
	AE/BE	AEB
	CE/BE	
	AC/BE	

Figure (1): An example of a face resemblance test demonstrating the corresponding real and reconstructed faces

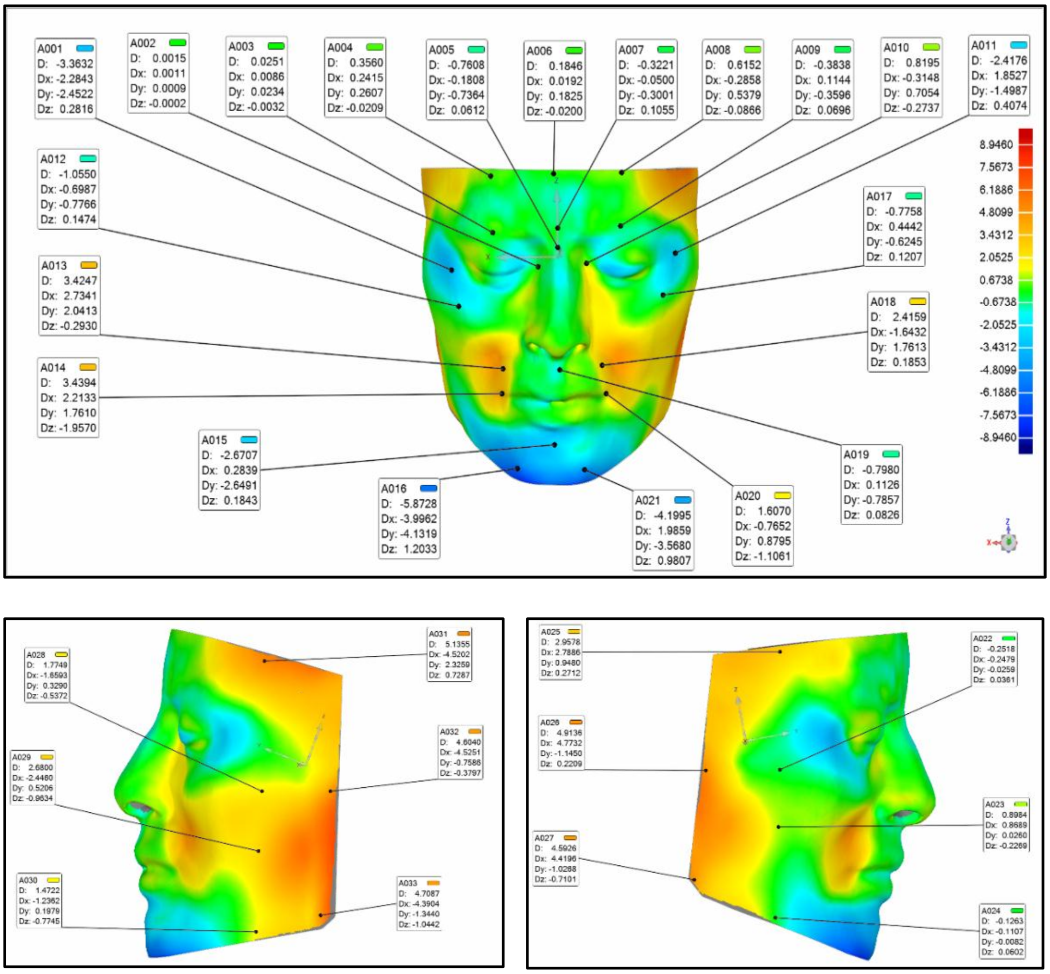
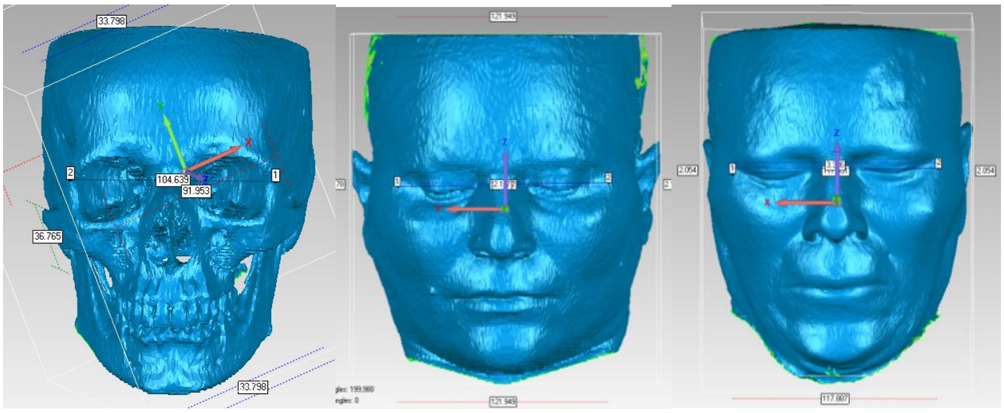


Figure (2): Histogram (colour map), showing the surface differences between aligned real and reconstructed faces at frontal and side views.



a b c

Figure (3): Identifying the inter-landmarks distances on 3D image of the (a: Skull, b: real face and c: reconstructed face).

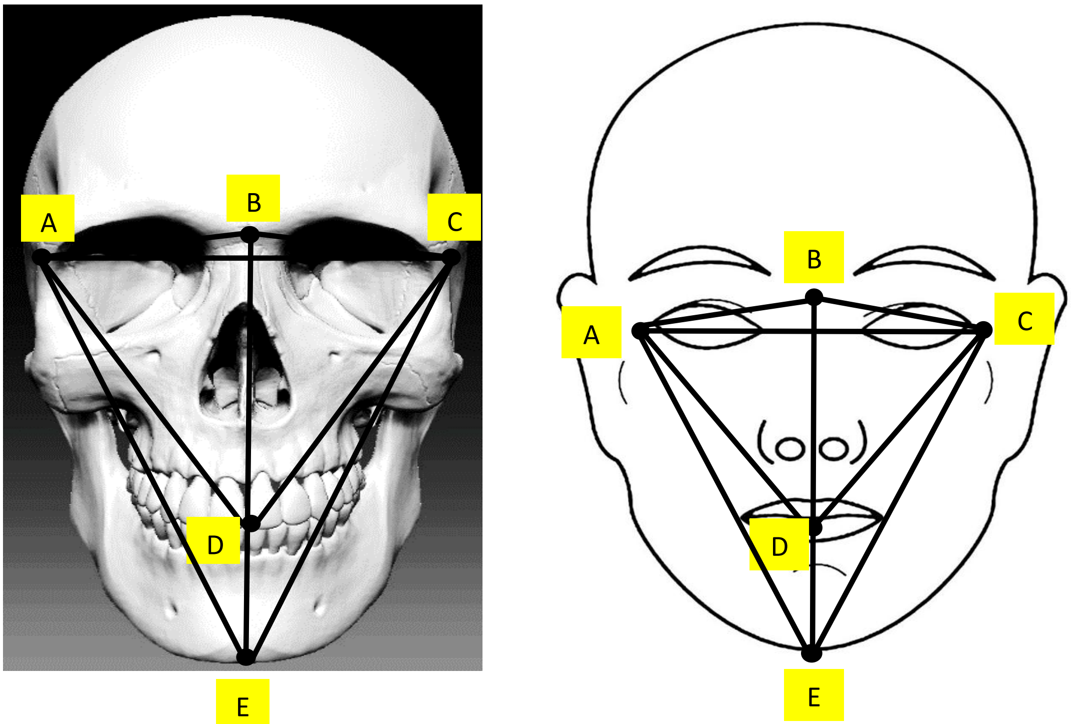


Figure (4): A diagram showing the used anatomical points and linear measurements.

STATISTICAL ANALYSIS

Most data in forensic anthropology and facial reconstruction studies are presented as non-parametric data (i.e. do not follow normal distribution), such as facial identification percentages in face pool tests, resemblance scores in survey-like tests, and rankings. Therefore, it is important to select the correct statistical tests to analyze these non-parametric data.

In the present study, the 30 studied cases were ranked according to each of the methods described above (subjective face resemblance test scores, objective surface standard deviations, objective craniofacial linear ratios, and objective craniofacial angles).

As these ranks represent ordinal variables in non-parametric data, the most appropriate statistical correlation test was Spearman's correlation coefficient ρ (rs), as opposed to Pearson’s correlation coefficient, which is applied on parametric data. In addition, the ranks of each case in all the methods were summed, and the non-parametric Freidman’s test was then used to detect the differences between the individual cases according the summed ranks given by all the tests.

RESULTS

According to all previous methods, the ranks for each case according to the different subjective and objective tests did not differ significantly when compared via Freidman's test (P-Values=0.19).

Table (5) shows the correlations between the different subjective and objective tests presented as Spearman rank correlation coefficients ρ (rs) and P-values.

The subjective resemblance and the objective SD tests showed the highest strongest significant correlations (ρ=-0.681). Moreover, the anthropometric angles correlated with both the subjective resemblance and the objective SD tests.

Whereas, the anthropometric linear ratios correlated only with the subjective resemblance test, but not with the objective SD test. It is to be noted that in the subjective method, cases received lower ranks means they have received the higher resemblance score.

In contrast, in the objective methods, cases that received lower ranks means they have showed the least difference (i.e. the better the fit) between the faces. This explains the negative correlation between the subjective and objective tests.

Within the craniofacial anthropometry method, the skulls-to-real faces linear ratios' differences had a strong (P=0.781) and significant (P-Value=0.000) correlation with the skulls-to-reconstructed faces linear ratios' differences.

The significant (P-Value=0.000) correlation was even stronger (ρ=0.937) between the skulls-to-real faces' angles differences and the skulls-to-reconstructed faces' angles differences.

Among the individual linear ratios, no specific linear ratio consistently correlated with any of the other tests. On the other hand, the 3 angles involving points A, C and E (i.e. the angles AEC, CAE and ACE) significantly correlated with the objective surface distance (SD) test.

These points represent; the right orbital angle (point A), the left orbital angle (point C), and the lowest midline point of the chin (point E). In particular, it was noted that the AEC angle (angle of the mid chin point) showed significant correlation with both subjective and objective tests.

Table (6) summarizes only the significant correlations between the individual anthropometric linear ratios and angles and the subjective resemblance scores and objective surface difference.

Table (5): The correlations between the different subjective and objective tests presented as Spearman rank correlation coefficients ρ (rs) and P-values.

	Subjective Resemblance Scores		Objective surface (SD)	
	ρ (rs)	P-value	ρ (rs)	P-value
Objective surface (SD)	- 0.681	0.000	N/A	N/A
Average linear ratios differences	- 0.378	0.039	0.328	**0.077**
Average angle differences	- 0.472	0.008	0.475	0.008

Table (6): The significant correlations between the anthropometric linear ratios and angles and the subjective resemblance scores and objective surface difference.

Anthropometric methods	Subjective Resemblance Scores		Objective surface (SD)	
	ρ (rs)	P-value	ρ (rs)	P-value
Linear ratio (AB/AD)	-0.568	0.009		
Linear ratio (BC/BD)			0.398	0.029
Linear ratio (BC/CE)			0.443	0.014
Angle (AEC)	- 0.480	0.032	0.437	0.016
Angle (ADB)	- 0.556	0.011		
Angle (CAE)			0.380	0.038
Angle (ACE)			0.546	0.002
Angle (CDB)			0.378	0.039
Angle (CEB)			0.430	0.018

(A) Left Ectocanthion, (B) Nasion, (C) Right Ectocanthion, (D) Midline Dental Point, (E) Gnathion.

DISCUSSION

Starbuck and Ward (2007) compared the objective anthropometric craniofacial variability index with subjective assessment of resemblance score of three variants of the reconstructed faces, and the results were insignificant. Target's photographs were used for the comparison. Similarly**, *Kleinberg et al. (2007)*** compared 2D facial images from surveillance camera footages for the purpose of facial identification. The study analyzed proportion indices, mathematically calculated from linear measurements between certain facial landmarks, as well as the angles between the landmarks. The authors concluded that facial anthropometry was neither successful for identification of the face as a whole nor among the studied individual landmarks.

With 2D images, matching the exact viewpoints and landmarks can be limited, which is a possible explanation of failure of anthropometry in the above studies. Therefore, in the present study, the concept presented by ***Kleinberg et al. (2007)*** was developed and applied on 3D images rather than 2D photographs. The results of the present study showed more significant findings, especially the significant correlation between the anthropometric angles and the other methods.

Vanezis (2008) performed an objective assessment of facial templates (to be used for facial reconstructions) using mathematical Procrustes Shape Analysis of the facial surfaces at certain landmarks. The author correlated these findings with the subjective resemblance ranks of the corresponding cases, which was statistically insignificant. The author concluded that their objective methods was based on a more holistic (overall) matching, whereas the subjective resemblance rating assessment was likely dependent on individual facial features. In a similar vein, ***Short et al. (2014)*** applied craniofacial anthropometry in assessing the facial reconstruction accuracy by comparing linear and angular measurements between the real and reconstructed faces. The results showed no statistical differences between the reconstruction and the target faces, but showed statistical significant in certain facial areas.

This is consistent with the findings of the present study which point towards the potential value of certain facial features over others in facial comparative identifications, as shown by the correlation between the angles at the outer orbital and mid chin points. These points can be seen to be mathematically connected in the form of a triangle which represents the anatomical correlation between the facial breadth at the orbital level and the facial length. A similar conclusion was presented by ***Sarkodie et al. (2022)*** where they have recorded significant variations in the facial height and breadth between two Ghanaian tribes, which showed the value of facial parameters in human identification and racial morphological classification even within the same population.

The face appearance is influenced by the skull as well as the facial soft tissue depths, which differ between different craniofacial anatomical parts. These depths are determined by the amount of the subcutaneous fat, being thickest at the cheeks, followed by the chin, and almost absent in the forehead and lip zones ***(De Greef et al., 2009)***. The less the subcutaneous fat, the easier to predict the morphology of that facial area from the skull shape. This can, therefore, partially explain the findings in the present study as the significant results were observed in the orbital and chin landmarks where there is almost no subcutaneous fat.

Limitations of the study

With limited similar studies, it was difficult to ascertain the "appropriate" study sample size. As well, in the present study, certain age groups are better represented than others, and male and female are not balanced which might have led to sex difference errors.

Furthermore, as in similar research, there are external inevitable factors that can influence the accuracy of facial reconstructions, such as the practitioner's expertise, the quality of the original CT scans, and the variation in facial soft tissue thickness.

To attempt to overcome this, all the facial reconstructions were performed by the same practitioner, and the source of the CT scans was limited to only 2 sites, with a standard preparation process of all scans. However, the facial soft tissue thickness variations are a recognized influential factor that creates several variations in the resulting facial reconstructions. Facial soft tissue thickness variations among populations are acknowledged. Only one study representing the Egyptian population facial soft tissue depths ***(El-Mehallawi and Soliman, 2001)***. However, this data lacked midline depths so, we have used a combined set of facial depths of that study together with the midline facial depths from Rhine and ***Moore (1982)*** and ***Helmer (1984)*** depths of Caucasian population ***(Vanezis, 2008)***. As neither of these depths have not been tested for facial reconstructions before, further development would be needed and more population specific data would make the resulting facial reconstructions more accurate. However, the purpose of this study was to correlate the facial reconstruction assessment tests rather than assessing the facial reconstruction technique.

Similarly, in the assessment process, external factors need to be considered that make the subjective and objective assessment methods difficult to be standardized and calibrated. For example, in the subjective method the inter-participant characteristics (e.g. their age, gender, training and professional experience) would generally affect the resemblance scores. As mentioned in the methodology section, this has been explored and will be published separately.

However, the results showed strong correlation with the other objective method, thus, could be reliably taken into account when interpreting the study results. Although such subjectivity is much less observed in the objective methods, there is a degree of inevitable subjectivity related to the practitioner performing the anatomical point location and measurements in these objective methods.

However, the process is often guided as these anatomical points have been anatomically defined and published to help minimize biases in measurements and assessments.

CONCLUSION

The craniofacial anthropometry as an objective assessment method of facial reconstructions entails the use of point-based mathematical calculations of linear ratios and angles. It can be applied easily with the adequate definitions of the anatomical landmarks. The current study provided an application of the craniofacial anthropometry with validation against other subjective and objective methods. The presented approach included linear ratios and angles between the anthropometric measurements. The craniofacial angles showed more significant correlations with the previously published subjective and objective methods.

The results also showed variations among different facial parts in their predictive facial identifications values. In particular, the orbital and chin areas and their anatomical and mathematical relation to the facial width and length were significant.

RECOMMENDATIONS

It is to be acknowledged that the study focuses on a specific population (Egyptian), with their population-specific facial soft tissue thickness and possible unique facial feature. While this may not be easily generalized to other populations, this study can be a representative of the Egyptian population. We would recommend continuing research in a larger study sample, with a well-balanced gender distribution, which would provide more power to the correlations. This study can also be a guide for similar research in other populations as a base of similar applications for human facial identification, and more craniofacial parameters can be explored with continuing research in this field.

REFRENCES

1. **Abdou, D.; Johnston, A. and Vanezis, P. (2018):** Three Dimensional (3D) Forensic Facial Reconstruction in an Egyptian Population using Computed Tomography Scanned Skulls and Average Facial Templates. *Queen Mary Uni. London.*
2. **Ashcroft, J.; Daniel, D. and Hart, S. (2003):** Eyewitness Evidence: A Trainer's Manual for Law Enforcement. *Office of Justice Programs, National Institute of Justice, 25-62. Available at: http://nij.ojp.gov/library/*

publications/eyewitness-evidence-trainers-manual-law-enforcement.

3. **Cesarani, E.; Martina, M.; Grilletto, R. et al. (2004):** Facial Reconstruction of a Wrapped Egyptian Mummy Using MDCT. *Am. Roent. Ray. Soc., 183:755–758.*
4. **Claes, P.; Vandermeulen, D.; De Greef, S. et al. (2006):** Craniofacial reconstruction using a combined statistical model of face shape and soft tissue depths: methodology and validation. *Forensic Sci. Int., 159: S147-S58.*
5. **De Boer, H.; Blau, S.; Delabarde, T. et al. (2019):** The role of forensic anthropology in disaster victim identification (DVI): recent developments and future prospects. *Forensic Sci. Res., 4 (4)*: Special Issue on Modern Advances in the Technological Approach to Disaster Victim Identification (DVI).
6. **Decker, S.; Ford, J.; Davy-Jow, S. et al. (2013):** Who is this person? A comparison study of current three-dimensional facial approximation methods. *Forensic Sci. Int., 229(1-3):161.e1-8.*
7. **De Greef, S.; Claes, P.; Mollemans, W. et al. (2005):** Semi-automated ultrasound facial soft tissue depth registration: method and validation. *J. Forensic Sci., 50(6):2004547-7.*
8. **De Greef, S.; Vandermeulen, D. and Claes, P. (2009):** The influence of sex, age and body mass index on facial soft tissue depths. *Forensic Sci. Med. Pathol.,5(2):60-65.*
9. **DICOMANONYMIZER®.** *Available at: http://bit.ly/2AnMkKb.*
10. **El-Mehallawi, I. H. and Soliman, E. M. (2001):** Ultrasonic assessment of facial soft tissue thicknesses in adult Egyptians. *Forensic Sci. Int., 117: 99-107.*
11. **GeomagicControl®.** Geomagic Control Software. [Cited 2023 August]. *Available from:https://support.3dsystems.com/s/article/Geomagic-Control-X?language =en_US.*
12. **GeomagicWrap®.** Geomagic Wrap Software. [Cited 2023 August]. Available from: https://support.3dsystems.com/s/article/Geomagic-Wrap?language=en_US.
13. **Gupta, S.; Gupta, V.; Vij, H.; et al. (2015):** Forensic Facial Reconstruction: The Final Frontier. *J. Clin. Diag. Res., JCDR, 9, ZE26.*
14. **Hayes, S. (2014):** Facial approximation of 'Angel': Case specific methodological review. *Forensic Sci. Int., 237:e30-e41.*
15. **Hayes, S. (2016):** A geometric morphometric evaluation of the Belanglo 'Angel' facial approximation. *Forensic Sci. Int.,268:e1-e12.*
16. **Jayaratne, Y. S.; McGrath, C. P. and Zwahlen, R. A. (2012):** How accurate are the fusion of cone-beam CT and 3-D stereophotographic images? *PloS One., 7(11):e49585.*
17. **Jedrzejowska, Z. K. (2001):** Craniometry and mathematical calculations as a method for viscero-cranium profile determination. *Forensic Sci. Int.,117(1):145-151.*
18. **Kleinberg, K. F.; Vanezis, P. and Burton, A. M. (2007):** Failure of anthropometry as a facial identification technique using high-quality photographs. *J. Forensic Sci., 52(4):779-783.*
19. **Lee, W. J.; Wilkinson, C. M. and Hwang, H. S. (2012):** An Accuracy Assessment of Forensic Computerized Facial Reconstruction Employing Cone-Beam Computed Tomography from Live Subjects. *J. Forensic Sci., 57(2):318-327.*
20. **Moyers, D. K. (2007):** Validation Study of ReFace (Reality Enhanced Facial Approximation by Computational Estimation).
21. **Olivieri L.; Mazzarelli D. and Bertoglio B. D. (2018):** Challenges in the identification of dead migrants in the Mediterranean: The case study of the Lampedusa shipwreck. *Forensic Sci. Int., 285: 121-128.*
22. **Pithon, M. M.; Ribeiro, D. L. R. and Dos Santos, R. L. (2014):** Soft tissue thickness in young north eastern Brazilian individuals with different skeletal classes. *J. Forensic Legal Med., 22: 115-120.*
23. **Richard, A. H.; Parks, C. L. and Monson, K. L. (2014):** Assessment of presentation methods for ReFace computerized facial approximations. *Forensic Sci. Int., 242:283-292.*
24. **Sakuma, A.; Ishii, M.; Yamamoto, S., Shimofusa, R., (2010):** Application of Postmortem 3D-CT Facial Reconstruction for Personal Identification. *J. Forensic Sci., 55: 1624-1629.*
25. **Sarkodie, F. K.; Abaidoo, C. S.; Diby, T. K. et al. (2022):** A cross-sectional study of the anthropometry of the face among Bonos and Ewes in the Bono region of Ghana. *Egy. Forensic Sci 12: 33.*
26. **Simmons-Ehrhardt, T. L.; Monson K. L.; Flint, T. et al. (2020):** Quantitative accuracy and 3D biometric matching of 388 statistically estimated facial approximations of live subjects. *Forensic Imag., 21: 00377.*
27. **Short, L. J.; Khambay, B.; Ayoub, A. et al. (2014):** Validation of a computer modelled forensic facial reconstruction technique using CT data from live subjects: a pilot study. *Forensic Sci. Int., 237:147. e1- e8.*

28. **Sketchfab. 3D models sharing website: [Cited 2023 August].** *Available from: https://sketchfab.com.*
29. **Snow, C. C.; Gatliff, B. P. and McWilliams, K. R. (1970):** Reconstruction of facial features from the skull: an evaluation of its usefulness in forensic anthropology. *Am. J. Phys. Anthropol., 33(2):221-227.*
30. **Starbuck, J. M. and Ward, R. E. (2007):** The effect of tissue depth variation on craniofacial reconstructions. *Forensic Sci. Int., 172(2):130-136.*
31. **Stephan, C. and Arthur, R. (2006):** Assessing facial approximation accuracy: how do resemblance ratings of disparate faces compare to recognition tests? *Forensic Sci. Int., 159:S159-S63.*
32. **Stephan, C. and Cicolini, J. (2008):** Measuring the accuracy of facial approximations: a comparative study of resemblance rating and face array methods. *J. Forensic Sci., 53(1):58-64.*
33. **Stephan, C. and Henneberg, M. (2006):** Recognition by forensic facial approximation: case specific examples and empirical tests. *Forensic Sci. Int., 156(2):182-191.*
34. **Utsuno, H.; Kageyama, T.; Uchida, K. et al. (2014):** Facial soft tissue thickness differences among three skeletal classes in Japanese population. *Forensic Sci. Int., 236: 175-180.*
35. **Vandermeulen, D.; Claes, P. and Loeckx, D. (2006):** Computerized craniofacial reconstruction using CT-derived implicit surface representations. *Forensic Sci. Int., 159:S164-S74.*
36. **Vanezis, P.; Blowes, R. W.; Linney, A. D. (1989):** Application of 3-D computer graphics for facial reconstruction and comparison with sculpting techniques. *Forensic Sci. Int., 42: 69-84.*
37. **Vanezis, M. (2008):** Forensic facial reconstruction using 3-D computer graphics: evaluation and improvement of its reliability in identification*: Univ. Glasgow.*
38. **Verzé, L. (2009):** History of facial reconstruction. *Acta. Biomed., 80: 5-12.*
39. **Wilkinson, C. (2005):** Computerized forensic facial reconstruction. *Forensic Sci. Med. Pathol., 1: 173-177.*
40. **Wilkinson, C.; Rynn, C.; Peters, H. et al. (2006):** Blind accuracy assessment of computer-modeled forensic facial reconstruction using computed tomography data from live subjects. *Forensic Sci. Med. and Pathol.,2(3):179-187.*