Personal identification through digital photo superimposition of dental profile: a pilot study

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ABSTRACT

The usefulness of teeth for personal identification lies mainly in their vast individual variability, making them virtually unique for every subject. Odontological identification represents a reliable and important complement to forensic inquiries, in particular in the event of unidentifiable human remains. However, this technique is based on the availability of ante-mortem records containing significant evidence. In the absence of dental records, the only available ante-mortem elements are often photographs. In the present study, dental profile photographs of selected smiling subjects were compared to the relevant plaster study models through digital image analysis. In order to ascertain the reliability of the technique, the comparison was carried out both in a homologous and heterologous manner with the Facecomp software. The results confirm the ability of Facecomp software to identify even the smallest variations in dental elements to reach a positive identification. The method is useful in forensic practice since a forensic inquiry may obtain plaster models from cadavers for comparison with photographs of missing people's anterior teeth.

INTRODUCTION

The usefulness of teeth for personal identification lies mainly in their vast individual variability, making them virtually unique for every subject.[1]

Therefore, dental identification represents a useful technique for personal identification based on ante-mortem records comparison (such as x-rays, plaster study models, palatine rugae and information contained in dental/medical records) with post-mortem records. However, obtaining adequate ante-mortem dental records is not always possible and this is particularly true in Italy where the number of illegal immigrants are on the rise. Indeed, in such cases, most of the available material is represented by photographs obtained from friends and acquaintances through which we attempt to identify an unidentified body. This can be achieved through the technique of photographic superimposition. Such a technique is even more reliable than craniofacial superimposition where the comparison is carried out between facial soft tissues and cranium skeletal structure.[2-6] With dental profile superimposition, the only skeletal elements, teeth are compared, even in a living subject.

There is little evidence of studies employing dental superimposition.[7,8] The purpose of this study is to offer an additional contribution by testing a superimposition methodology as standardised and reproducible as possible using photographs of selected smiling subjects, where teeth are sufficiently visible and then compared with plaster model photographs obtained from the subjects' dental records. Furthermore, the procedure of records' acquisition and model production is reproducible on cadavers.

MATERIALS AND METHODS

A set of 10 photographs of 10 subjects (5 males and 5 females) were taken. They were asked to smile in a natural manner to expose their upper teeth, from canine to canine. Photographs were taken with a high-resolution camera (*Canon, model EOS 500D*).
Dental records were also obtained from the same subjects so that a plaster model could be made for each individual. All models obtained were then photographed in occlusion, using the same camera.
The photographs were uploaded onto a computer and a first comparison between the subjects and the study models was carried out by using Adobe Photoshop software (*Adobe Systems, Version 7.0 pro, San Jose, California, USA*). With such software, the photograph of each subject was superimposed on that of the relevant study model.
The image obtained was superimposed while keeping the same proportions ("block proportions" tool), then two levels of superimposition were created where one image was in the forefront compared to the other:
- Level 1: study model;
- Level 2: subject's teeth.

Thanks to the "blending" effect, superimposition was gradually processed (starting from 0% and rising to 50% and 100%).
Such a procedure was necessary to avoid distortion by obtaining a photograph of the teeth and the model of the same size for each subject.
Images obtained with Photoshop were uploaded onto Facecomp software. This software, designed by the engineering department of Bari University, is able to compare two geometric figures starting from selected points on the photographs. This software allows matching two geometrical figures through selected points, such as certain anatomical landmarks. These are identified and marked on each photograph (of natural teeth and of models) and the software automatically supplies measurements on: absolute distances, relative distances, shape factors (a value that numerically describe the shape of a particle, independent of its size), moments (a quantitative measure of the shape of a function), perimeter, and area of a polygon obtained by joining landmarks.[9]
For example, the algorithms parameters for perimeter and shape factors were calculated as follows:
Let x_i and y_i be the generic coordinates of a point, I, J and K the points of a generic triangle, and p_{ijk} the perimeter of the triangle; the area can be obtained in the following way:

$$area\_tri = 1/2\,Abs\left(\begin{vmatrix} x_i & y_i & \\ x_j & y_j & \\ x_k & y_k & 1 \end{vmatrix}\right)$$

Where *Abs* is the method for the solution of general linear algebraic systems.
The related compactness index is as follows:

$$comp\_ind = area\_tri / p2ijk$$

The index, as a shape factor, is a dimensionless value and describes the irregularity of the represented geometric figure[10].
The software Facecomp includes the following functions:
-Interactive landmark point fixing for the morphometric analysis;
-Computing and visualization of parameter sets for each image analysed;
-Automatic calculation and presentation of comparison results.
The photographs of the 10 smiling subjects and those of the study models (100% opacity) were then uploaded onto Facecomp. Then, one examiner selected 5 anatomical landmarks in order to carry out the next comparison. The anatomical landmarks were selected as (Figure 1):
1. and 2. Landmarks for the two upper canines (left and right), on the cusp tip, called *left canine* and *right canine*;
3. One in the middle of the interdental area between the two upper central incisors, locating it at half the coronal length of the incisors, called *median line*;
4. and 5. Landmarks in the intersection of the central incisor's distal margin with the lateral incisor's mesial margin to the right and to the left respectively, called *right incisor* and *left incisor*.
The 5 points were identified, for each subject, on both pictures (Figure 2) imported with Facecomp.

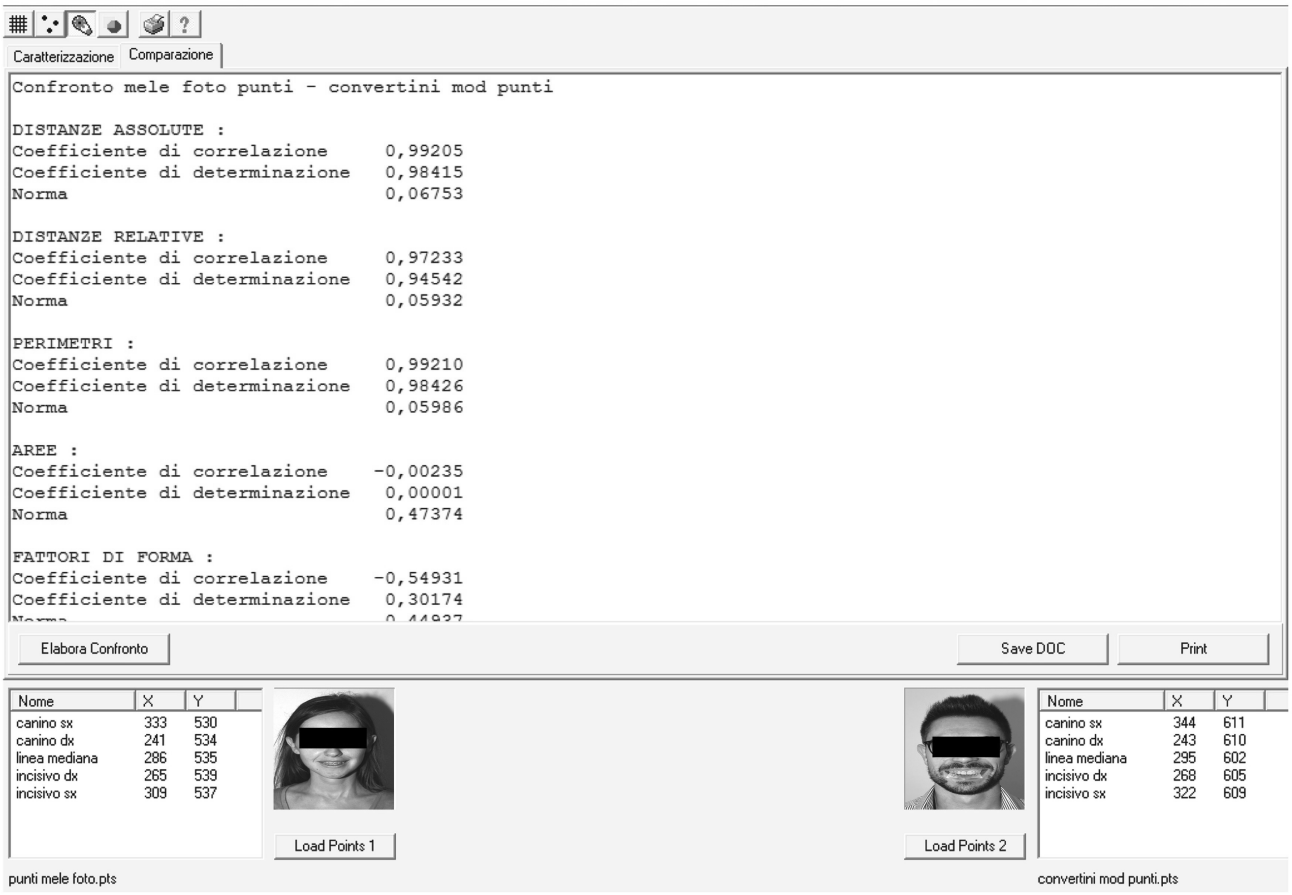
Figure 1. Anatomical landmarks

Figure 2. Examples of superimposition study and positioning of anatomical landmarks

The comparison was carried out with homologous pairs (photograph of the subject smiling with their superimposed plaster model) and with heterologous pairs (photograph of the subject smiling with the study model belonging to a different subject) to identify possible differences in data obtained.

Thus, a comparison between each pair of photographs was carried out obtaining data relevant to the different parameters provided by the software *(absolute distances, relative distances, shape factors, moments, perimeter, and area of the polygon)* (Figure 3).

Figure 3. Elaboration of comparison in an example of heterologous comparison: results obtained by Facecomp software.



STATISTICAL ANALYSIS

Data were reported in an Excel database and statistical analysis was performed using Stata12MP (StataCorp LLC, College Station, Texas).

Quantitative variables with normal distribution were compared using the Student's t-test, the Mann-Whitney U test was used for non-normally distributed variables. For all tests, a p value of <0.05 was considered as significant.

RESULTS

On the 10 subjects recruited in the study, 10 homologous and 90 heterologous comparisons were carried out. Therefore, the total number of observations amounts to 100. A comparison between the data obtained in the homologous match and that obtained in the heterologous match were compared using statistical analysis. The results of data collected and of the univariate analysis are reported in Table 1 where values with statistical significance (p<0.05) have been underlined.

Table 1. Median and average values of variables on total sample, homologous group and heterologous group and comparison between groups.
There was no statistical significance in the comparison between homologous and heterologous match for the values related to absolute distances, relative distances, perimeters, and moments. Data was obtained with statistical significance for the values related to areas and shape factors.

Variable	TOTAL	HOMOLOGOUS	HETEROLOGOUS	P
	Mean ± DS (Range) Median (IQR)	*Mean ± DS (Range) Median (IQR)*	*Mean ± DS (Range) Median (IQR)*	
Absolute distances				
Correlation coefficient	0,9948 ± 0,0045 (0,975 - 0,9997) 0,9962 (0,9926 - 0,998)	0,996 ± 0,0039 (0,9891 - 0,9997) 0,9978 (0,9918 - 0,9989)	0,9947 ± 0,0046 (0,975 - 0,9997) 0,9961 (0,9926 - 0,9978)	0,24§
Coefficient of determination	0,9897 ± 0,0089 (0,9506 - 0,9996) 0,9924 (0,9852 - 0,9959)	0,992 ± 0,0078 (0,9783 - 0,9995) 0,9955 (0,9837 - 0,9977)	0,9895 ± 0,0091 (0,9506 - 0,9996) 0,9923 (0,9853 - 0,9956)	0,24§
Relative distances				
Correlation coefficient	0,9831 ± 0,0133 (0,9326 - 0,9991) 0,9868 (0,9734 - 0,9932)	0,9866 ± 0,0117 (0,9667 - 0,999) 0,9911 (0,9737 - 0,9967)	0,9827 ± 0,0134 (0,9326 - 0,9991) 0,9868 (0,9732 - 0,9926)	0,31§
Coefficient of determination	0,9666 ± 0,0259 (0,8697 - 0,9982) 0,9738 (0,9476 - 0,9865)	0,9735 ± 0,0229 (0,9345 - 0,9981) 0,9822 (0,9481 - 0,9935)	0,9658 ± 0,0262 (0,8697 - 0,9982) 0,9738 (0,9471 - 0,9852)	0,31§
Perimeters				
Correlation coefficient	0,993 ± 0,0075 (0,9585 - 0,9998) 0,9954 (0,9915 - 0,9975)	0,9937 ± 0,007 (0,9824 - 0,9996) 0,9973 (0,9865 - 0,9988)	0,9929 ± 0,0075 (0,9585 - 0,9998) 0,995 (0,9918 - 0,9975)	0,41§
Coefficient of determination	0,9861 ± 0,0147 (0,9187 - 0,9995) 0,9907 (0,9832 - 0,9951)	0,9876 ± 0,0139 (0,9651 - 0,9992) 0,9947 (0,9732 - 0,9976)	0,986 ± 0,0148 (0,9187 - 0,9995) 0,9901 (0,9838 - 0,995)	0,41§
Areas				
Correlation coefficient	0,4031 ± 0,4523 (-0,6857 - 0,9994) 0,5382 (0,1179 - 0,7503)	0,6577 ± 0,4001 (-0,2474 - 0,9865) 0,8173 (0,5827 - 0,9113)	0,3748 ± 0,4508 (-0,6857 - 0,9994) 0,4896 (0,0413 - 0,7306)	0,02§
Coefficient of determination	0,365 ± 0,2883 (0 - 0,9989) 0,3283 (0,0904 - 0,563)	0,5767 ± 0,3368 (0,0248 - 0,9732) 0,6684 (0,3395 - 0,8304)	0,3415 ± 0,2746 (0 - 0,9989) 0,2903 (0,079 - 0,5338)	0,03§
Shape factors				
Correlation coefficient	0,3004 ± 0,5112 (-0,8768 - 0,9997) 0,4149 (-0,0809 - 0,7255)	0,6155 ± 0,4599 (-0,545 - 0,99) 0,8077 (0,4507 - 0,8728)	0,2654 ± 0,5068 (-0,8768 - 0,9997) 0,3565 (-0,1343 - 0,6761)	0,02§
Coefficient of determination	0,3502 ± 0,2972 (0 - 0,9995) 0,2548 (0,0898 - 0,5796)	0,5692 ± 0,2908 (0,0925 - 0,9802) 0,6524 (0,2971 - 0,7617)	0,3258 ± 0,2894 (0 - 0,9995) 0,2257 (0,0797 - 0,5406)	0,01§
Moments				
Correlation coefficient	0,9999 ± 0,0001 (0,999 - 1) 1 (0,9999 - 1)	1 ± 0 (0,9999 -) 1 (1 - 1)	0,9999 ± 0,0001 (0,999 - 1) 1 (0,9999 - 1)	0,06§
Coefficient of determination	0,9999 ± 0,0002 (0,9992 - 1) 0,9999 (0,9998 - 1)	0,9999 ± 0,0001 (0,9998 - 1) 1 (0,9999 - 1)	0,9999 ± 0,0002 (0,9992 - 1) 0,9999 (0,9998 - 1)	0,05§

§ Mann - Whitney test

* Student's t-test

DISCUSSION AND CONCLUSIONS

The study demonstrated that the coefficients of determination and correlation of *absolute distances* and that of *relative distances* do not present statistical significance. This can be explained by ethnic anatomical characteristics: the sample includes only Caucasian subjects and, in individuals of the same race, the distance between dental landmarks does not differ substantially[11].

On the other hand, the groups of values with statistical significance are those related to *areas of the polygons* and *shape factors*. These results confirm other studies[9,10]. This pilot study demonstrated the ability of Facecomp software to identify even the smallest variations in dental elements such as length, rotations, diastema as well as the presence of orthodontic devices (present in one of the 10 subjects) and to reach a positive identification even with variable degrees of exposure to dental elements in the natural smile. Therefore, the results obtained have an importance in the identification field. This method may be used in real cases since (after the discovery of a cadaver and following an initial presumptive identification) it is possible to carry out a digital photographic superimposition of dental profile between the photograph of the subject presumptively identified and that of the study model obtained from the cadaver's skull.

It would be appropriate to repeat the study broadening the sample, even to identify a cut-off value above which homology between cast and photograph can be ascertained. Also, different examiners selecting reference points should be tested.

Moreover, in this study, all pictures were taken with the same camera and this enabled us to obtain higher quality photographs compared to common cameras, including mobile phones. Therefore, it would be interesting to assess the superimposition quality obtained with blurrier images or with lower image resolution.

The main aim of this study was carried out in attempting to evaluate a new computer-aided technique of identification, applied with the aim of improving the precision and reliability of personal identification.

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