J Forensic Sci, September 2009, Vol. 54, No. 5
doi: 10.1111/j.1556-4029.2009.01106.x
Available online at: www.blackwell-synergy.com

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Personal Identification by Morphometric Analyses of Intra-Oral Radiographs of Unrestored Teeth*

ABSTRACT: The aim of this study was to work out a biometric method for personal identification by comparing simulated antemortem and postmortem digital radiographs of unrestored teeth. Intra-oral radiographs of the inferior right first molar, without restorations, were acquired at two different times in 70 subjects using a standardized technique followed by a morphometric analysis. The program automatically supplied values of the absolute distances, relative distances, shape factors, moments, perimeter values, and the areas of the triangles, which were obtained by joining key reference points. The values for the homologous samples were compared with the heterologous samples. Statistical analysis was then carried out, resulting in a section point value of 0.9992. Higher correlation coefficients indicate positive identification, with less than 2% risk of false positives, and approximately 3% of false negatives. We have also tested the method on dental records from 30 patients in order to demonstrate the specificity and sensitivity of the system.

KEYWORDS: forensic science, forensic odontology, biometric, personal identification, digital radiograph, morphometric analysis

Routine means of identification include visual recognition, clothing, personal artifacts, fingerprints, DNA matching as well as skeletal and dental examinations (1–3). Intra-oral radiology in particular is an important tool in the identification of victims.

It is based on the comparison between antemortem and postmortem radiographs which look for individual distinctive features such as morphology and pathology of the teeth, alveolar bones, and details of dental restorations. Dental restorations leave individually characteristic features which, for the most part, are well depicted on intra-oral radiographs (4–6).

Nowadays, however, preventive interventions have resulted in a reduced number of dental restorations. This change in overall dental health status interferes with the potential ability of dental restorations to be used in personal identification and is apt to make conventional forensic dentistry less useful (7).

As a result, obtaining positive matches by using methods based on manual comparison of intra-oral radiographs without restorations is more difficult (8). The aim of this study was to work out a biometric method for personal identification comparing simulated antemortem and postmortem digital intra-oral radiographs of unrestored teeth by means of computer analysis of dental anatomical structures.

The application of such intra-oral radiographic techniques required the identification of some specific reference points corresponding to anatomical structures of the dental elements which would be unalterable over time (9). Such a choice justifies the necessity for constructing identical and superimposable geometric figures on any radiograph, regardless of when it was taken (10). Another condition which may not be disregarded was the use of a standardized technique in the acquisition of intra-oral radiographs which could be used repeatedly over time.

Materials and Methods

Two sets of intra-oral radiographs of the inferior right first molar with no restoration were acquired at two different times in 70 subjects. The sample consisted of Caucasian subjects from southern Italy, aged between 20 and 35 years (27 men and 43 women). After having undergone an initial visit, all the subjects underwent a second visit after a period ranging from between 6 months to one and a half years as a way of simulating antemortem and postmortem radiographs.

In order to take these radiographs, a standardized technique was used with the aim of obtaining identical and superimposable images. The radiographs were taken with RVG technology, using the long cone technique, Rinn aim rings, and bite-blocks. This allowed us to maintain constant parallelism and the distances between the radiogene tube, the dental element, and the radiographic sensor. This choice was made due to the improved visibility and simpler identification of the anatomical reference points on the dental elements of the inferior arch. Furthermore, the easy positioning of the Rinn ring in correspondence to the mandibular dental element prevented any disparallelism between the anatomical structures and the radiographic sensor while the radiograph was taken, and assured the standardization of the radiographic technique. Variations in the horizontal and vertical angulations during the execution of the intra-oral radiographs may in fact influence the correct superimposition of geometric images obtained in a negative way, rendering identification impossible.

In order not to invalidate the comparison over time, anatomical structures which do not change were chosen. It was for this reason that the points corresponding to the top of the coronal cuspids were

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*Presented at the 60th Annual Meeting of the American Academy of Forensic Sciences, February 18–23, 2008, in Washington, DC.

Received 2 April 2008; and in revised form 21 Aug. 2008; accepted 28 Sept. 2008.

excluded because they were subject to physiological wear over time. The following geometric structure was realized.

At the outset, two points of the cement-enamel junction (CEJ1-CEJ2) were identified by tracing a straight line which joined those points. This line was then carried perpendicularly from the distal cement-enamel junction, intersecting the profile of the distal root at the most apical point (R1). From this point, the parallel line was carried to the horizontal line CEJ1-CEJ2, intersecting the profile of the mesial root at the most external point (R2). By tracing the straight line, connecting R2 and CEJ2, the diagonals of the obtained quadrilateral were drawn; this locates the radicular furcation point (F) (Fig. 1). Then each quadrilateral was subdivided into four triangles wherein geometric characteristics were analyzed during the subsequent phase of our operative protocol.

Both steps, the acquisition of the intra-oral radiographs and the drawing of the lines were carried out by digital systematic research using specialized dental software (Kodak Dental Software, Carestream Health, Rochester, NY). Following the operative protocol, five previously located reference points were identified and marked by the same software on each acquired intra-oral radiograph. An additional software, used for the purpose of data comparison by the engineering department following the acquisition of the images (Fig. 2), automatically supplied values for the absolute distances, relative distances, shape factors, moments, perimeter values, and the areas of the triangles obtained by joining the points. Six numerical sets were thus obtained for each image.

The values obtained for each of the six sets of the first molar radiograph of each subject were then compared with the images obtained at his/her second visit (homologous correlations). Following this, the values obtained for each of the six sets for the radiographs obtained from different subjects were compared (heterologous correlations) (Fig. 3). Statistical comparison of these sets was made by the linear regression, determining the correlation coefficient. Cross-analysis was performed on each of the six numerical sets obtained from the 140 images, yielding 29,400 comparisons for heterologous correlations and 420 comparisons for homologous correlations.

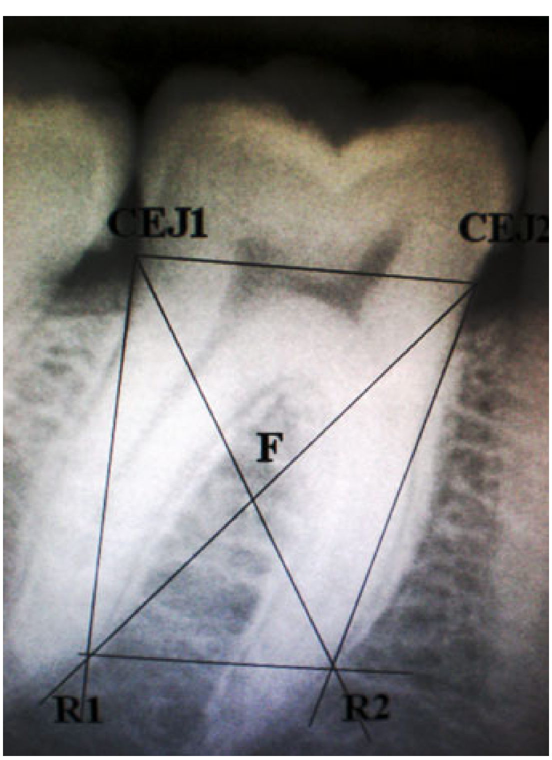

FIG. 1—*Geometric construction on the intra-oral radiograph.*

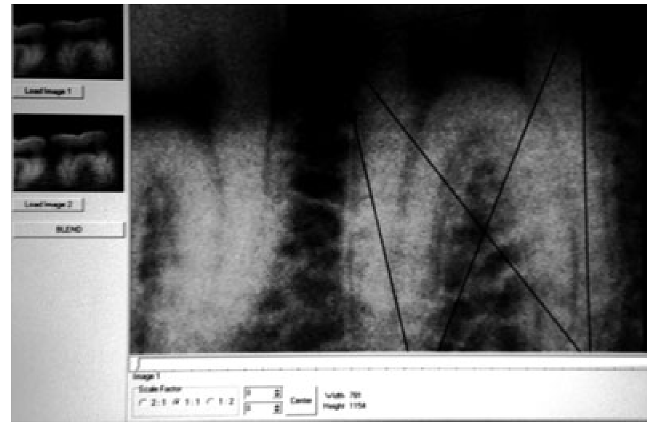

FIG. 2—*Example of the acquisition of image by the program for the comparisons.*

Inter- and intra-observer error was assessed by having two odontologists locate the cement-enamel junctions and the construction of the quadrilateral at two different times. The differences in the results of the comparisons carried out by the two different operators were not significant.

To test the method, dental records from 30 patients, in which the same, nonrestored, tooth was radiographed twice during normal procedures, were selected. We interspersed the radiographs between subjects in order to challenge the system with both positive and negative IDs. From this we obtained 30 homologous correlations and 434 heterologous correlations, the purpose of which was to demonstrate the specificity and sensitivity of the method.

Specificity establishes, in terms of percentage, the method's ability to precisely recognize homologous relationships, that is to say, to establish positive IDs using two different radiographs from the same subjects. Sensibility, on the other hand, establishes the method's ability to precisely recognize heterologous relationships.

Results and Discussion

Analysis showed that the areas of the triangles, the shape factors, and the moments were not useful for identification purposes. But in reality, cross-comparison of the correlation coefficients for the sets of absolute and relative distances, and perimeters showed that they could potentially be useful after all, possibly in association with other types of analysis, for identification purposes. It is for this

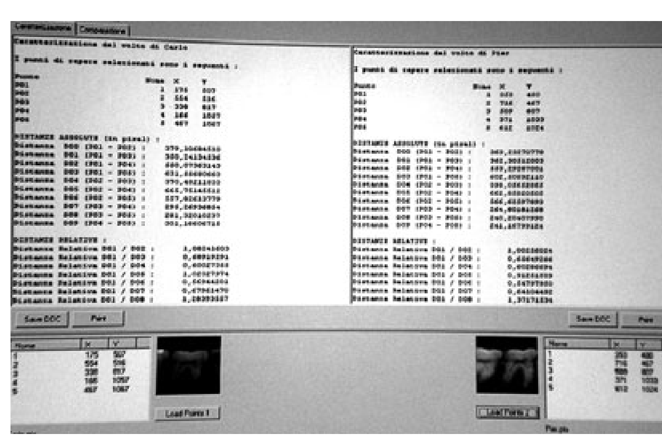

FIG. 3—*Example of a heterologous comparison.*

reason that these variables were chosen for statistical analysis by means of cumulative relative frequency observation. In this way it was possible to verify in which of two classes the correlation values and determination coefficients should be placed. The results in the first class were found to be between 1 and 0.9992; the results for the second were found to be between 0.9992 and 0.

The results showed a high probability that the coefficients were superior to the value of 0.9992 (section point) in the homologous category, while the same probability was very low in the heterologous category.

The results can be summarized as follows:

Absolute distances*:* The homologous correlation values belong to the first class, while only 1.9% (correlation coefficient) and 0.9% (determination coefficient) of the heterologous correlations belong to the first class (Fig. 4).

Relative distances*:* The graph shows that all the homologous correlation values belong to the first class, while only 1.2% (correlation coefficient) and 0.5% (determination coefficient) of the heterologous correlations belong to the first class (Fig. 5).

Perimeters*:* The graph shows that only 2.9% (determination coefficient) of the homologous correlation values belong to the second class, while only 1.9% (correlation coefficient) and 0.7% (determination coefficient) of the heterologous correlations belong to the first class (Fig. 6).

In brief, the section point for the output of comparison of all the parameters is 0.9992; higher correlation coefficients indicate positive identification, with less than 2% risk of false positives and approximately 3% of false negatives. The results of the test performed demonstrated a sensitivity (positive IDs) of 97%, with only one inaccuracy related to radiographs belonging to the same subject; and a specificity (negative IDs) of 95% with an inaccuracy rate of 5% among the comparisons. In the cases where inaccuracies were recognized due to the overlapping of values, it was impossible to establish positive identification. The findings of our test are reported in Table 1.

Conclusions

It can be concluded that if the comparison of two intra-oral radiographs yields a higher correlation coefficient than the minimum threshold for autocorrelation of the absolute distances, relative distances and triangle perimeters, then identification is positive. In border-line cases, positive identification could result in greater accuracy if the interdependencies among the variables were observed altogether. Moreover, this study offers the possibility of

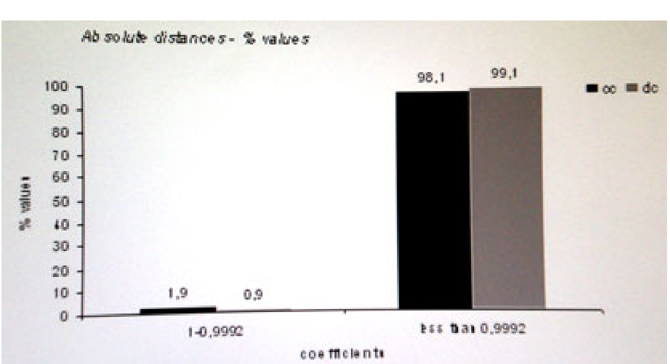

FIG. 4—*The graph shows the values of absolute distances for heterologous.*

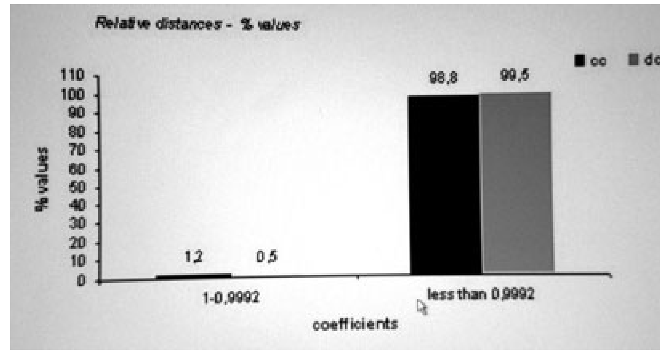

FIG. 5—*The graph shows the values of relative distances for heterologous.*

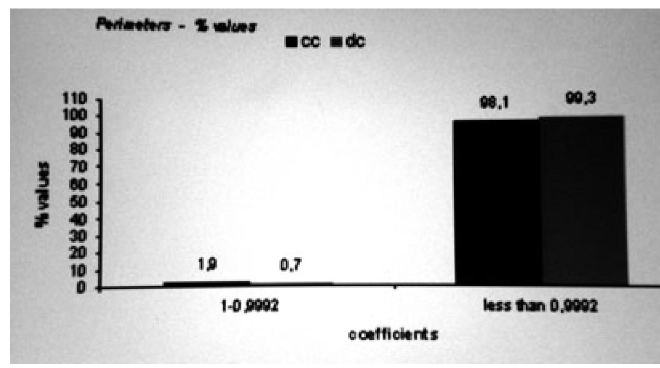

FIG. 6—*The graph shows the values of perimeters for heterologous.*

TABLE 1—*The test made on a selection of 30 dental records which have been interspersed in order to verify positive and negative identifications.*

Outcome ID Test*	Number of ID+	Number of ID−	Total Number
T+	29	411	440
T−	1	23	24
	30	434	464

*Positive and negative number of test responses using our method.

T+ when homologous correlations belong to the first class and heterologous to the second one; and T− when there is an overlapping between the homologous and heterologous values, for positive and negative identifications.

extending the comparisons with subjects with crown restorations which do not include cement-enamel junctions.

Image acquisition procedures are uncomplicated and fast, and digital technology assures a standardized method of acquisition and comparison. Another advantage of this technique is that the operator needs only to locate two points (the cement-enamel junctions) because the others are construction points, thereby offering a lower probability of errors.

A limitation of this study is the various angulations of antemortem radiographs, or various types of acquired radiograms (for example antemortem ortopantomograph). Future studies will be necessary in order to test this program against images acquired from various X-rays in order to simulate real situations in routine cases of identification.

Utilizing films where no aiming device was used, along with a standardized technique, could be of great value in testing for the existence of variations in their comparisons and results. However, the results we have obtained support the advantage of a morphometric study as an adjunct to an exclusively morphological study of tooth shape, particularly if they have not undergone restorations, and they indicate the need for better and larger studies on this topic.

Acknowledgments

We are grateful to Professor Giuseppe Mastronardi and his staff at the Electronic and Electrotechnic Department of the Polytechnic Institute of Bari for their support in the elaboration of the software used in the comparisons. The authors would also like to thank Michael Kolk for his help in the preparation of this manuscript.

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