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TECHNICAL NOTE

Dental superimposition: a pilot study for standardising the method

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Abstract Dental superimposition is becoming more and more important because of the increasing number of illegal immigrants (at least in Italy), with no clinical history, no personal effects or relatives useful for genetic comparison, whose friends and acquaintances can usually only produce photographs. Very few authors have been involved in devising and using this method. The goal of the present study is to establish whether it is possible, and under which conditions, to identify individuals by dental superimposition of teeth visible in an ante-mortem photograph and dental casts of an unidentified body, and to develop a protocol for the spatial orientation analysis of the dentition and qualitative and semi-quantitative analysis of superimpositions. A non-mathematical scoring system has been applied to each superimposition as a first step towards the optimisation of a cheap, quick, semi-quantitative method of identifying individuals when other more used methods are not applicable.

Keywords Forensic odontology · Identification · Dental superimposition

Introduction

Identification of cadavers, with all its moral and legal implications, must be pursued, for ethical and legal reasons with all means. Experts involved in identification are usually odontologists, geneticists and anthropologists. The role of forensic odontology is perhaps by far the most diverse because it involves comparing post-mortem dentition with various ante-mortem types of material: dental recorded information, dental casts, intra-oral X-rays, OPG, clinical pictures, palatal rugae, or even photographs (normal snapshots of smiling people). This last condition is perhaps the most difficult and consists of comparing the ante-mortem dentition (superior incisors and canines) visible in a picture of a smiling person, with the post-mortem dentition via superimposition. This method is becoming more and more important because of the increasing number of illegal immigrants in Italy, with no clinical history, particularly for the teeth, no relatives or personal effects useful for genetic comparison. Their friends and acquaintances can usually only produce photographs or videoclips of the missing person, hopefully smiling, useful for dental superimposition. This identification procedure could increase reliability of cranio-facial superimposition as hard tissues (teeth) are compared and superimposed to the same hard tissues while in cranio-facial superimposition hard tissues (skull) is compared and superimposed to different soft tissues (face of the presumed victim) [1–5]. Very few authors have been involved in devising and using this method. McKenna initially studied methods for enlarging photographs to life-size according to dental measurements and then published a method for orienting the cranium by trial and error. He then approached dental superimposition by studying only the occlusal margins of the dentition and stressed the peculiarity of each individual dentition [6–9]. However, no author has published a complete protocol, from spatial orientation of the head to qualitative and quantitative assessment of correspondence of two dentitions.

Craniofacial superimposition methods have been studied in greater detail; however, they rarely, apart from their use in spatial orientation, focus on a protocol for teeth [10–13].

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The goal of the present study is to establish whether it is possible, and under which conditions, to express an identification judgment via superimposition of teeth visible in an ante-mortem photograph and dental casts of an unidentified body, and to develop a protocol which goes from the spatial orientation analysis of the dentition to a qualitative and semi-quantitative judgment of superimpositions.

Spatial orientation of the cast

This is the first problem to solve because the cast should be photographed with the same orientation as the ante-mortem photograph [1, 3, 8]. Photographs are two-dimensional projections of three-dimensional objects; thus, objects are difficult to compare if the orientation is not practically identical. It is necessary to be able to establish the orientation of the head (in particular of the upper dental arch) of a subject starting from a photograph to be able to position the cast of the teeth in the same manner.

Only flexion (forward bending), extension (backward bending) and torsion (left-right rotation) of the cervical spine can affect the two-dimensional projection of the dental structure; the lateral bending of the cervical spine (i.e., rotation on an axis perpendicular to the photographic plane) does not cause deformation to the two-dimensional image. Thus, a way to obtain information on the degree of extension and the torsion of the upper dental arch must be found starting from the photograph.

As far as torsion is concerned, this should be performed by drawing a tangent to the most occlusal points of the distal profile of the two canines (straight line q, as shown in Fig. 1). The contact points of the straight line with the canine teeth are identified as A and B. A straight line (r) perpendicular to line q and tangential to the mesial surface of a central incisor tooth is drawn. This straight line intersects the straight line q at the point C. Torsion will cause a displacement of point C on the straight line q; the ratio AC/AB thus represents, besides supplying information about dentition asymmetry, the variation of torsion. This ratio will increase with left-hand torsion and will decrease with right-hand torsions. We decided to work on the ratio because it is independent from the photograph magnification factor (pictures are re-scaled during superimposition process). The ratio AC/AB, therefore, supplies information pertinent to torsion (Fig. 1).

To study extension and flexion (forward and backward bending) the following method has been adopted: a straight line is drawn from point A, tangential to a reference point easily identifiable in the picture, for example to the occlusal surface of tooth number 22 (upper left second incisor) or 21. Usually the occlusal profile of 22 is far enough from line q to produce an α angle wide enough to be measured, otherwise a different occlusal point could be chosen. This line forms an angle α, with line q (Fig. 1). Extension (backward bending) will cause an increase of the angle; flexion (forward bending) will cause a decrease of the angle. Lateral bending does not cause any alteration of the angle nor of the ratio AC/AB. Movement which does not involve rotation can affect the size of the image but not the angle or the ratio. In this manner, we have, thus, obtained information on the extension (angle α) and torsion (ratio AC/AB) (Fig. 1).

To compare two dentitions, one from a picture and another a dental cast from the cadaver, the first thing to do is to position the cast in such a way that, on a two-dimensional projection of the cast, the angle and the ratio are equal to those measured on the photograph.

To do this, the cast model must be mounted on a stand which permits accurate recording of flexion, extension, and torsion of the cast and oriented in a position similar to that in the photograph. A picture of the cast in this position is then taken on which the α angle and the AB/AC ratio are measured. Then, the AB/AC ratio and angle α are measured on the photograph of the person in a smiling position. Finally, orientation of the cast is readjusted until the ratio and angle are the same as those in the picture of the smiling person. At this point, if the cast belongs to the person in the photo, we have an image of the model with the same orientation of the dental arch of the subject shown in the photo. Tests on several casts confirmed that it is possible to position the cast in the same orientation of the dentition of the person in the picture with an error of 2° both in torsion and in flexion.

Superimposition method

Now that correct orientation of the two images which are to be superimposed has been obtained, it is necessary to find a method to achieve the best possible superimposition of the two images [14, 15]. By using the various Photoshop

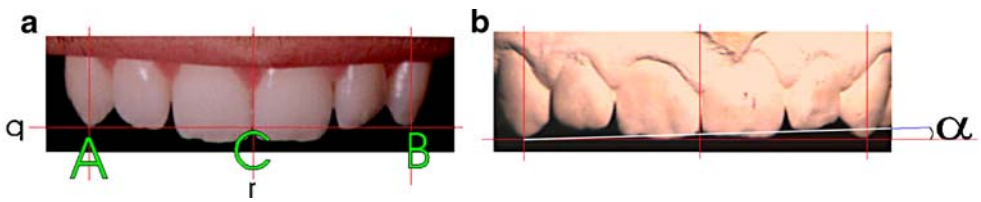

Fig. 1 **a** Determination of the AB/AC ratio. **b** The evaluation of the angle α

functions the profile of the cast is enhanced and superimposed to that of the corresponding smiling individual re-scaling the cast profile so as to superimpose A and B points of the cast to the corresponding points in the picture of the smiling individual (Fig. 2). If there is sufficient contrast between oral cavity and teeth, the "magic wand" tool is used to select the dark area between upper and lower arches setting tolerance parameter by trial and error. The selection is then expanded of 2 pixels; the previously selected dark area is then subtracted to the expanded selection. The result is a selection representing the occlusal profile of the visible teeth. A new layer is then created. Occlusal profile is drawn just using the filling tool to fill the selection previously made by subtraction. On this new layer, the mesial and distal profile of each tooth is drawn using a 2-pixel pencil. If the magic wand tool does not work well because of low contrast, the magnetic lasso tool is used setting its tolerance so that it stitches to the teeth edges. In this way, it was possible to create an outline of each tooth for all casts.

Once that cast is correctly oriented and its outline superimposed on the photograph of the smiling person, the outline of the outer margins of every tooth is evaluated as well as the presence of any possible peculiarity of the elements characterising the individuality of each dental arch and, hence, of each individual. Characteristics like the dimensions of the arch from canine to canine are not taken into consideration because their correspondence in the overlapping between casts and photos would be a "forced" one as cast outlines have been re-scaled as to superimpose its A and C points to those in the picture.

For each tooth of the model, the degree of correspondence of the above-mentioned characteristics (basically the shape of every margin of the tooth) with the corresponding element of the photo on which it is overlapped, is evaluated. To do this, the outline of the outer margin of each tooth is divided into three components: distal, occlusal and mesial profiles. If even a single superimposed component of the model profile is incompatible with the underlying component of the dental profile of the smiling individual, an exclusion judgment is expressed. According to the degree of correspondence, a score of 0–2 is assigned to each component of the cast. If distinctive anomalies (in shape or position, fractures, etc.) are noticed both in the cast and in the photographed smile, a further maximum score of 2 for each tooth is given. This is true also in the case of the same missing dental element both on the model and on the photo. Scores are given according to the following criteria: 0 for non valuable portion (for instance missing tooth in chalk model or non visible tooth in picture), 1 for compatibility and 2 for full correspondence. We speak of incompatibility when the overlapping of the dental profile does not correspond. When a component of the dental profile or an anomaly of the cast coincides with the characteristics seen in the photo, 2 points are assigned. More complex is the case of compatibility (score=1). Such a score is given when a component of the dental profile or an anomaly is not very clear, for example when it is out of focus in the photo, but looks similar to the cast. A score of 1 is also assigned in cases of small discrepancies of the profile which could be due to several factors, such as wear of dental elements with time or errors made during the production of the casts. The most apical portion of the mesial and distal components of the dental profile is a function of the gingival margin: this could easily be subjected to alterations, especially because of inflammatory phenomena. A different morphology of this portion of the profile is, therefore, considered compatible (score=1). In the case of one or more missing teeth in the cast, a score of 0 is given. The same applies when one or more teeth are not visible in the photo because they are out of focus, or not properly illuminated and therefore barely visible. When the absence of a tooth in the photo and the presence of the corresponding natural element in the cast are noted during the study of the superimposition, this area is considered incompatible.

Each element of the cast can, then, be given a total score of 0–8. Thus, if we consider the cast from canine to canine and add up all the scores, we obtain a global score (*d*) ranging from a minimum of 0 to a maximum of 48 (called *d*, which "quantifies" the correspondence between photo and cast).

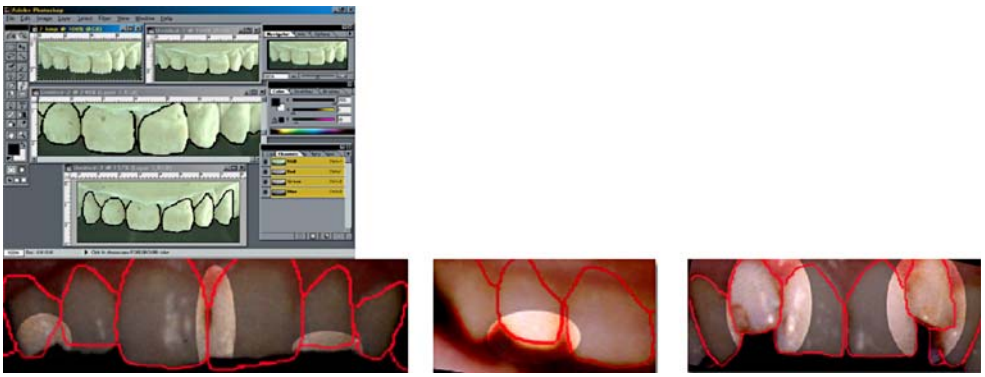

Fig. 2 Example of enhancement and definition of the dental profile of the cast model

The value d is then turned into a more easily read percentage value. Thus an index of correspondence (I.C.) was established: I.C. $= d \times 100/48 = d/0.48$.

A purely theoretical grading scale was developed, from the following considerations: I.C. has a value of 37.5 when in a superimposition there are no peculiarities and each component of the dental profile has a value of 1 (d=18); I.C. is equal to 50 when there are teeth without anomalies and with an average of one correspondence per tooth (d=24); I.C. is equal to 75 if each component of the dental profile has a rating of 2 (d=36). Therefore, theoretically, on the grounds of the I.C. value, if the cast model has not been excluded because of an incompatibility, we can express a hypothetical judgement: high probability with an I.C. greater than 75 (each part of the superimposed profile of six teeth match, and there is at least one correspondent peculiarity); probability with an I.C. greater or equal to 50 and smaller or equal to 75 (in superimposition there is at least one matching surface per each of six visible teeth); compatibility corresponds to an I.C. greater than 37.5 and smaller than 50 (at least each component of the outline of the superimposed six teeth are compatible); insufficient evidence corresponds to an I.C. smaller or equal to 37.5 (some teeth are missing or not clearly visible).

We speak of exclusion when a cast presents at least one element of incompatibility. There are, however, some exceptions. There are, in fact, several circumstances which determine an alteration of the teeth with the time. It is, therefore, of primary importance that before surveying the cast, for example during the post-mortem examination, operators take notice of any dental prosthesis, periodontal diseases, enamel fractures, or of any pathology or factor that can modify the position and the morphology of teeth. In this case (i.e., apparent incompatibilities), the final judgement will not be of exclusion, but it will be based on the I.C. and inconsistent data will only lower in these cases the I.C. as if they were missing elements of the cast.

The various scores assigned to each cast are registered on an appropriately devised chart (Fig. 3). Furthermore, the maximum error of 2° because of the orientation of the cast must be taken into account. Tolerance of the error was tested in the following manner. Ten casts were superimposed on each other (same cast on same cast) with an orientation error of 0°, 2°, 4° and 6° in extension/flexion and torsion. Final judgment was influenced only with different orientation error over 2°. Thus, an error in orientation of up to 2° does not influence the result (I.C. value).

Validation of the superimposition method

After having developed a spatial orientation technique of the models and after having devised a method by which to score the superimposition, the method was validated.

Materials

Fifteen pictures of smiling individuals were used (snapshots in which the upper dental arch from canine to canine was visible). A total of 28 cast models were then selected among which were those of the 15 individuals whose photographs had been acquired. All material was provided by a dental clinic that was able to associate via a code each picture to the appropriate cast.

Method

For each photo, a series of casts was selected for superimposition. Those casts, clearly incompatible at first sight with the dentition in the photograph, were excluded from the test series. Thus, each photograph (15 were used in total) was superimposed with an average of 14 casts, for a total of 207 superimpositions.

For each superimposition, a single operator calculated the I.C. and gave the relative judgment concerning identification (i.e. exclusion, insufficient evidence, compatible, probable, highly probable).

Results

For each photographed subject all superimposed models were always excluded apart from one. Practically the non-excluded model always proved to belong to the subject on which it was overlapped. The matching between casts and pictures obtained from each of 207 superimpositions proved correct. Furthermore, to the correctly matching cast a score which was higher than I.C. 50 was attributed in all cases. In spite of such conclusions, it does not seem appropriate to place a judgment of certainty based on the non-exclusion.

Discussion and conclusions

It is becoming more and more important to use odontological identification and ageing methods [16–21] in the study of human remains. It is not a rare circumstance to have to identify a person where there is very little ante-mortem data, as is the case of illegal immigrants. At times, DNA identification is not possible because there are no relatives or personal effects, or DNA cannot be extracted from the remains because it is degraded or because of PCR inhibitors. Identification performed on information from the teeth is based on the comparison of post-mortem data with ante-mortem data, but this latter material (dental charts, casts and radiographs) may not be available among the poorer population. It is very likely, on the other hand, that

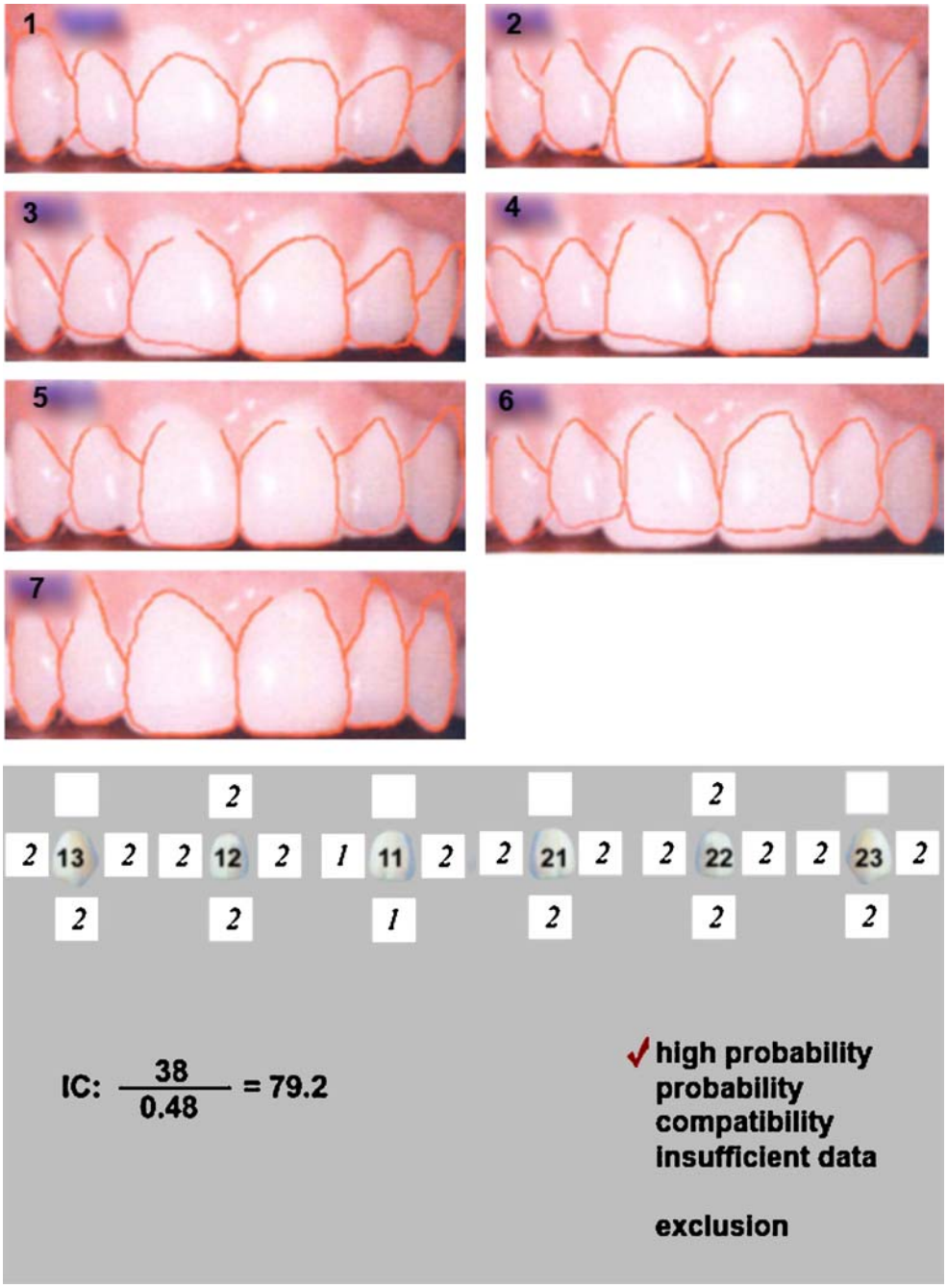

Fig. 3 Example of one picture on which the outline of seven different casts is superimposed (*1–7*): one can notice the inconsistencies of the dentition in the picture with casts *1* to *6* and the correspondence with cast number *7* (the last one on the left). Below is represented the scoring chart for cast number *7*. For each tooth, the *number to the left*, *to the right* and *below* represents the score for the single profile component (0, 1, 2); *above each tooth* is a box for additional scores concerning anomalies. I.C. is then calculated and the final I.C. score equated to the final judgment

acquaintances have photos of the presumed victim. The use of superimposition methods at this point becomes crucial [22–24] as they may be the only methods which may allow positive identification. Cranio-facial identification has some limits, as mentioned above. Dental superimposition, if we are fortunate enough to have a picture in which the person is smiling, could be more reliable as the only skeletal part visible in a living individual (teeth) is compared and superimposed to skeletal remains (teeth) that need to be identified. However, very little literature exists showing attempts at standardising the method (which, on the contrary, has been done with bite mark analysis) [25–27]. This study provides a protocol (which is preliminary and needs further standardisation) for evaluating dental superimposition. It is a first step towards the optimisation of a cheap, quick method of identifying individuals when other more commonly used methods are not applicable.

Further research will aim at improving the scoring system by examining a bigger population and taking into consideration possible factors for two dental arches being similar as in twins, siblings and after similar orthodontic therapies. Moreover, scored anomalies need to be classified

to achieve inter-observer agreement in anomaly judgment. The number of visible teeth in the picture, photo quality and possible morphological alterations of the teeth, occurring between the period the photo was taken and death, will considerably influence the I.C. value and will represent real limits to identification. In an identification study it is, therefore, of the utmost importance to use photos whose characteristics will approach, as much as possible, ideal ones; in particular, the essential requirement lies in the focus of the dental elements.

It should be stressed that before making the cast, all factors which may alter morphology (dental prostheses, crown fractures, paradontal disease, etc.) must be identified by an accurate odontological examination of the corpse's teeth because these may not be clearly visible on the cast.

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