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TECHNICAL NOTE

ODONTOLOGY

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Experimental Study of Bite Mark Injuries by Digital Analysis

ABSTRACT: This study was based on a morphometric analysis of bite marks starting from the quantitative definition of the anterior teeth by the geometric acquisition of the "injuries," using bite marks impressed on pig skin and plastic. Each mark was photographed and acquired. A dedicated program automatically supplied the values of the shape factors and the areas of the pattern geometric figures. The values obtained for the homologous samples were compared to the heterologous values. Statistical comparison was made of the sets by linear regression, determining the correlation coefficient and the determination coefficient for each value. Results showed only 4.8% and 2% of overlap between homologous and heterologous values. This study was carried out in attempting to quantitatively define the anterior teeth of the human dentition and the procedure described and the results obtained support the advantage of morphometric studies and computer-aided programs in this study of bite marks.

KEYWORDS: forensic science, bite marks analysis, forensic odontology, morphometric analysis, geometric figures, computer-aided program

Bite marks may be observed in cases of sexual attacks, child or domestic partner abuse, and offensive or defensive combat altercations. The injury pattern can provide an important link between the "bitemark" and the "biter." Indeed, although bite mark analysis by forensic odontologists has been considered controversial and has been the object of several review articles in the legal field, bite mark evidence has prompted the development of an increasingly sophisticated array of new techniques and procedures, for use in conjunction with older accepted protocols (1–5).

In fact, an essential component of the determination of the validity of bite mark analysis is validation of the techniques used in the physical comparison between the biter's dentition and the physical injury.

The ABFO (American Board of Forensic Odontology) Bite Mark Guidelines provide all the indications on how to collect, preserve, and analyze forensic bite mark evidence, based on the assumption that the bite perpetrator may be identified by studying unique features of his teeth, as well as additional information, obtained with more advanced techniques and procedures employed in the evaluation of bite mark evidence.

The most common methods for determining bite marks include techniques comparing the morphology of the dentition (shape, size, and position of teeth, together with the shape of the dental arches) with similar traits and characteristics present in life-sized photographs of the injury using transparent overlays or computer-aided programs (6,7). Other comparison methods include direct comparison of the suspect's study casts with photographs of the bite mark, comparisons of test bites produced by the suspect's teeth with the actual bite mark, and the use of radiographic imaging (8) and scanning electron microscopy (9,10).

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The aim of this study was to investigate the validity of an experimental computer-aided digital method of comparison of human bite marks, starting from the quantitative definition of the anterior teeth. The research was carried out using a metric method for identifying and comparing simulated bite marks impressed on pig skin and plastic, by a dedicated software (Facecomp).

Materials and Methods

Using 20 dental casts, two sets of bite marks were acquired. The dental casts were obtained from a sample of 20 alginate impressions of Caucasian subjects from southern Italy (15 men and five women).

The casts were set on a dental articulator in maximum intercuspidation (Fig. 1), and then simulated bite marks were impressed on pig skin and plastic of the same size (70×80 mm) and thickness, with a constant bite force of 50 N. In this way, two "bite marks" were obtained for each dental cast, yielding a total number of 20 bite marks "bittens" and 20 "biters" (Fig. 2).

After creating the bite mark, photographs were taken using a digital camera, in accordance with the standards and guidelines adopted by the American Board of Forensic Odontology (11–13).

A Nikon Coolpix 5550, 10 megapixel, with Nikkor 135-35 optic, was used (Nikon Corporation, Tokyo, Japan); two perpendicular rulers were placed on the same plane as the bite mark, and the digital camera was set up at a fixed distance of 10 cm using a special holder and positioning the back of the camera on the same plane as the bite mark and the two rulers. Two light sources from two directions were fixed to avoid any shadow in the photographs. Several photos were taken of each bite mark to select the most appropriate photograph for the comparison procedure (14).

The photographs were acquired using Adobe Photoshop and cut to the same size by a standardized procedure. Then, on each photograph, seven points were located on the six inferior teeth in the

FIG. 1—*The dental articulator used.*

FIG. 2—*A simulated bite mark with pig skin.*

intercanine area. So, geometric reconstruction was performed. We decided to perform our study on the inferior six elements of the intercanine area, so straight lines were drawn passing from the distal edge of each tooth and from the midline (the mesial contact point of the two central incisors) yielding a geometric figure with seven segments (sides) (Fig. 3).

These figures were drawn on the bite marks impressed on the pig skin and on plastic, and then a comparison was made between homologous (the bite marks obtained from the same subject) and heterologous bite marks using dedicated software (Facecomp) designed by the engineering department. This software was able to compare two geometric figures starting from the position of the seven established points (Figs 4 and 5).

So, in accordance with the operative protocol, the seven previously located reference points were identified and marked by the software on each acquired photograph, and the program then automatically supplied values for the absolute distances, relative

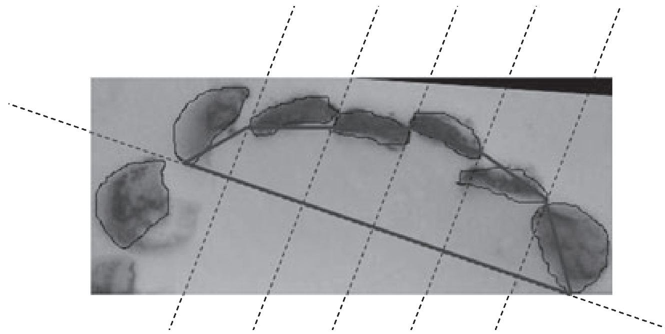

FIG. 3—*The geometric reconstruction on the inferior six elements of the intercanine area.*

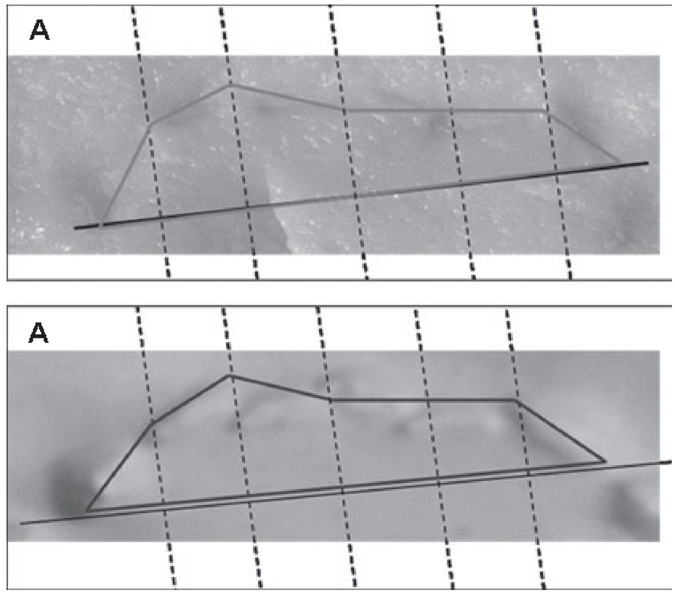

FIG. 4—*A homologous comparison between the two bite marks on the pig skin and on the plastic.*

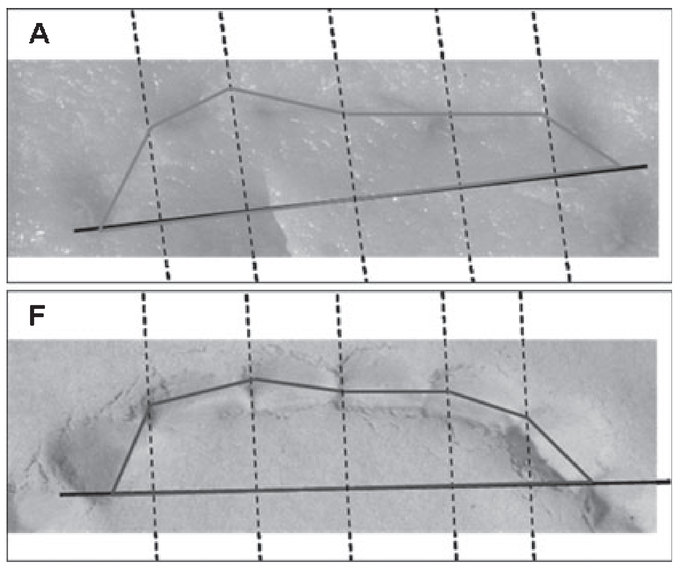

FIG. 5—*A heterologous comparison.*

distances, shape factors, moments, perimeter values, and the areas of the polygons obtained by joining the points. The algorithms parameters were calculated as follows:

TABLE 1—*An example of homologous comparison (A–A) with all values (for the absolute distances, relative distances, shape factors, moments, perimeter values, and the areas of the polygons) supplied by the program.*

Homologous comparison A–A	
Absolute distances	
Correlation coefficient	0.99203
Determination coefficient	0.98854
Relative distances	
Correlation coefficient	0.99213
Determination coefficient	0.98364
Perimeters	
Correlation coefficient	0.99324
Determination coefficient	0.96778
Areas	
Correlation coefficient	0.98921
Determination coefficient	0.97933
Shape factors	
Correlation coefficient	0.97832
Determination coefficient	0.93896
Moments	
Correlation coefficient	0.99992
Determination coefficient	0.99944

TABLE 2—*An example of heterologous comparison (A–F) with all values (for the absolute distances, relative distances, shape factors, moments, perimeter values, and the areas of the polygons) supplied by the program. The bolded values are the most significant (areas and shape factors).*

Heterologous comparison A–F	
Absolute distances	
Correlation coefficient	0.99347
Determination coefficient	0.99239
Relative distances	
Correlation coefficient	0.99532
Determination coefficient	0.98315
Perimeters	
Correlation coefficient	0.98991
Determination coefficient	0.99632
Areas	
Correlation coefficient	0.94672
Determination coefficient	**0.90031**
Shape factors	
Correlation coefficient	**0.84397**
Determination coefficient	**0.68382**
Moments	
Correlation coefficient	0.99994
Determination coefficient	0.99996

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:

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

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 form factor, is a no dimensional value and describes the irregularity of the represented geometric figure (15).

Four numerical sets (determination coefficients and correlation coefficients for areas and shape factors) were thus obtained for each image.

The values obtained for each of the four sets of the bite marks on the pig skin were then compared with the bite marks obtained from the same cast (from the same subject) on the plastic (homologous correlations) (Table 1). Following this, the values obtained for each of the four sets for the bite marks obtained from the other casts (from different subjects) were compared (heterologous correlations) (Table 2).

Statistical comparison was made of the sets by linear regression, determining the correlation coefficient and the determination coefficient for each value (15).

Cross-analysis was made of each of the four numerical sets obtained from the 40 images (20 "victims" and 20 "suspects"), yielding 1600 comparisons for heterologous correlations and 80 comparisons for homologous correlations.

In brief, the software (Facecomp) includes the following functions:

- Interactive *repere point fixing* for the morphometric analysis;
- Computing and visualization of *parameter sets* for each image analyzed;
- Automatic calculation and presentation of comparison results.

Inter- and intra-observer error was assessed by getting two odontologists to locate the reference points and the construction of the polygons at two different times. There were no significant differences among the results of the comparisons carried out by the two different operators.

Results and Discussion

In this study, it was decided to consider for the comparisons the shape factors and the areas, because they showed the most significant values. And, it is for this 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 0.9632 and between 1 and 0.9218 for the areas; between 1 and 0.8756 and between 1 and 0.7749 for the shape factors.

The results for the second class were found to be between 0.9632 and 0 and between 0.9218 and 0 for the areas; between 0.8756 and 0 and between 0.7749 and 0 for the shape factors.

The results showed a high probability that the coefficients were superior to the values of 0.9632 and 0.8756 for the areas (section points) in the homologous category, while the same probability was very low in the heterologous category.

Similarly, if the coefficients were superior to the values of 0.8756 and 0.7749 for the shape factors (section points), the subject belonged to the homologous category, while the same probability was very low in the heterologous category.

The results can be summarized as follows:

Areas. The homologous correlation values all belonged to the first class (1–0.9632 for the correlation coefficient and 1–0.9218 for the determination coefficient), while only 4.2% (correlation coefficient) and 4.8% (determination coefficient) of the heterologous correlations belonged to the first class (Fig. 6).

Shape factors. The graph shows that the homologous correlation values all belonged to the first class (1–0.8756 for the correlation coefficient and 1–0.7749 for the determination coefficient), while only 2% (for both coefficients) of the heterologous correlations belonged to the first class (Fig. 7).

Geometric morphometric methods perform a quantitative analysis of shape by capturing the geometry of the morphological structures

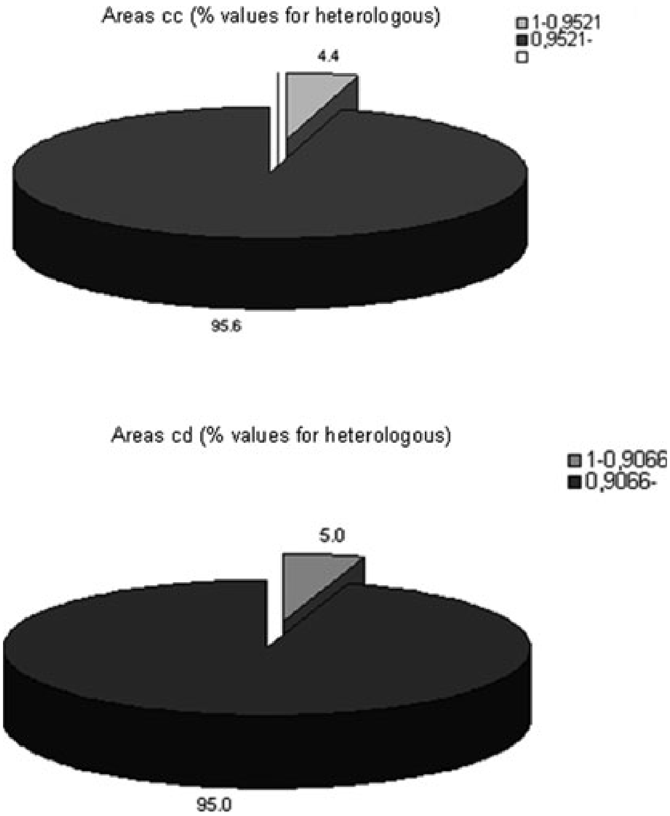

FIG. 6—*The values of the areas.*

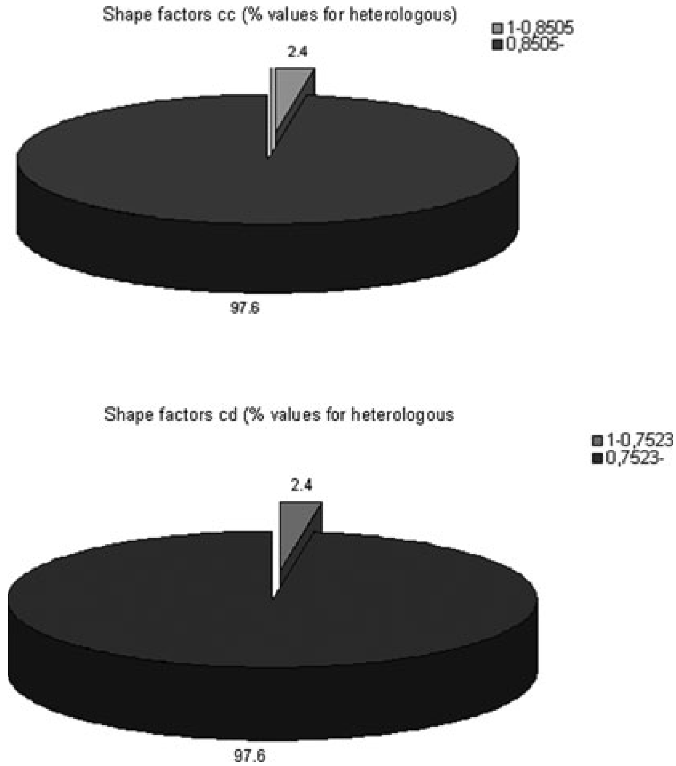

FIG. 7—*The values of the shape factor.*

of interest and preserving this information during statistical analysis. In fact, this method was able to capture subtle differences of both morphology and the relative spatial location of the individual occlusal surfaces (e.g., inter-tooth spacing, rotation, and winging) of the lower anterior dentition, eliciting the characteristics of the anterior teeth involved in the bite (16). Moreover, although the arrangement of many different intra-arch tooth positions could render similar relative areas yet shows significantly different tooth positions creating the area of the polygons, shape factor in these cases were different.

Conclusions

It can be concluded that if comparison between bite marks yields a higher correlation coefficient than the minimum threshold for autocorrelation of the areas of polygons and the shape factors, particularly if carried out on the lower arch, then the identification could be positive.

In border-line cases, a positive identification could be made with a greater accuracy if all the interdependencies among the variables were observed together.

This experimental study is limited by the fact that the bite marks considered are stationary and cannot take into account the use of the tongue and the absence of distortion of the soft tissue (a bite mark can be distorted by the biomechanical properties of skin), and, finally, the effects of edema, hemorrhage, and inflammation on bite mark production observed in living tissue (17–19). The method is also conditioned by the depth of the marks impressed on the skin.

However, this study was carried out in attempting to quantitatively define the anterior teeth of the human dentition and the procedure described, and the results obtained support the advantage of morphometric studies and computer-aided programs as an additional aid in the morphological study of bite marks, applied with the aim of improving the precision and reliability of identification of a suspect.

Further studies in a larger sample are needed. Finally, it is important to stress the importance of experience and training in the analysis of bite mark injury patterns on the successful outcome of such investigations.

References

1. Mc Namee AH, Sweet D. Adherence of forensic odontologists to the ABFO guidelines for victim evidence collection. J Forensic Sci 2003;48(2):1–4.
2. Pretty IA. Development and validation of a human bitemark severity and significance scale. J Forensic Sci 2007;52(3):687–91.
3. Dubowitz H, Bennet S. Physical abuse and neglect. Lancet 2007;369:1891–9.
4. Herschaft EE, Alder ME, Ord DK, Rawson RD, Smith ES. Manual of forensic odontology, 4th edn. Lubbock, TX: American Society of Forensic Odontology, 2006.
5. Sweet D, Lorente JA, Lorente M, Valenzuela A, Villanueva E. An improved method to recover saliva from human skin: the double swab technique. J Forensic Sci 1997;42:320–2.
6. Sweet D, Parhar M, Wood RE. Computer-based production of bitemark overlays. J Forensic Sci 1998;43:1046–51.
7. Sweet D, Bowers CM. Accuracy of bitemark overlays: a comparison of five common methods to produce exemplars from a suspect's dentition. J Forensic Sci 1998;43:362–7.
8. Rawson RD, Bell A, Kinard BS, Kinard JG. Radiographic interpretation of contrast-media-enhanced bite marks. J Forensic Sci 1979;24(4):898–901.
9. David TJ. Adjunctive use of scanning electron microscopy in bitemark analysis: a 3-D study. J Forensic Sci 1986;31:1126–34.
10. Jakobsen J, Holmen L, Fredebo L, Sejrsen B. Scanning electron microscopy, a useful tool in forensic dental work. Forensic Odontol 1995;2(13):36–40.

11. American Board of Forensic Odontology Inc. Body identification guidelines. JADA 1994;125:1244–54.
12. Hyzer WG, Krauss TC. The bite mark standard reference scale—ABFO N°2. J Forensic Sci 1988;33(2):498–506.
13. Bowers CM, Joansen RJ. Photographic evidence protocol: the use of digital imaging methods to rectify angular distortion and create life size reproductions of bitemark evidence. J Forensic Sci 2002;47(1):178–85.
14. Al-Talabani N, Al-Moussawy ND, Baker FA, Mohammed HA. Digital analysis of experimental human bitemarks: application of two new methods. J Forensic Sci 2006;51(6):1372–5.
15. Mastronardi G, Introna F, Dellisanti Fabiano M, Venosa A. Personal identification of bank robbers by morphometric image analysis—an Italian experience. In: Lesavich S, editor. Proceedings of the Third International Conference Law and Technology; 2002 Nov 6–7; Cambridge, MA. Alberta, Canada: International Association of Science and Technology for Development, 2002;108–11.
16. Bernitz H, Owen JH, van Heerden WFP, Solheim T. An integrated technique for the analysis of skin bite marks. J Forensic Sci 2008;53(1): 194–8.
17. Kieser JA, Bernal V, Waddell JN, Raju S. The uniqueness of the human anterior dentition: a geometric morphometric analysis. J Forensic Sci 2007;52(3):671–7.
18. Bush MA, Raymond GM, Bush PJ, Dorion RBJ. Biomechanical factors in human dermal bitemarks in a cadaver model. J Forensic Sci 2009;54(1):167–76.
19. Pretty IA. Reliability of bitemark evidence. In: Dorion RBJ, editor. Bitemark evidence. New York, NY: Marcel Dekker, 2005;531–63.

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