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The Uniqueness of the Human Anterior Dentition: A Geometric Morphometric Analysis

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ABSTRACT: The analysis of bitemarks has a significant bearing on forensic odontology and has attracted an increasingly sophisticated array of techniques in its evaluation. Two postulates underlie all bitemark analyses: firstly, that the characteristics of the anterior teeth involved in the bite are unique, and secondly, that this uniqueness is accurately recorded in the material bitten. Here, we investigate the question of the uniqueness of the anterior dentition. To do this, we use geometric morphometric techniques based on landmark and semilandmark data. The incisor and canine occlusal surfaces of 50 randomly selected orthodontic casts of young individuals (17–20 years) of both sexes form the material for this study. We analyzed the sizes of these teeth by means of landmark and semilandmark analysis to calculate Procrustes distances between tooth outlines. In order to analyze shape variation among individuals, we carried out principal components analyses on the partial warp scores. These are derived from Partial Procrustes coordinates aligned by means of thin-plate spline decomposition based on the bending energy matrix. The results indicate that there is no sexual dimorphism in the shape of the upper or lower arches. Plots of centroid size and first relative warps show less superposition among individuals than in shape analysis. This means that, when the size and shape are considered together, the difference between arches increases. Procrustes superimposition between the two individuals located most closely (0.0444) and the two most separated (0.1567) along the first axis of relative warp analyses show that individuals are not only differentiated by the relative position of their teeth but also by their arch shape. In conclusion, it appears that the incisal surfaces of the anterior dentition are in fact unique.

KEYWORDS: forensic science, bitemark analysis, forensic odontology, tooth size and shape, semilandmarks

Bitemark evidence has become established as a useful and important tool in the administration of justice (1) and has attracted an increasingly sophisticated array of techniques in its analysis (2,3). There are two postulates that underlie all bitemark analyses: first, that the characteristics of the anterior teeth involved in the bite are unique, and secondly, that this uniqueness is accurately recorded in the material bitten (4). Sweet and Pretty (5) have stated that there is no agreement among forensic odontologists about the uniqueness (individuality) of the dentition. One of the first articles to address this problem was that of MacFarlane et al. (6), who suggested that one should differentiate between positive features (e.g., the presence of a tooth with an individualizing feature) and negative features (e.g., absence of a tooth). By evaluating 200 study casts of the upper and lower teeth of adult patients attending an outpatient clinic, these authors concluded that certain characteristics, such as the number and shape of each tooth, restorations, and tooth rotations, were not independent. For example, they found that mesio-palatal rotation of an upper central incisor was strongly related to the same rotation in the adjacent central incisor. This is a crucial point, as it provided evidence that the product rule could not be applied to the assessment of the uniqueness of the human dentition. However, the authors relied on highly subjective examinations of the casts by multiple examiners and also failed to publish a table of their results. These two points must be taken into account when studying the uniqueness of the anterior dentition, because interobserver error, randomization and repeatability of the study are crucial to its scientific acceptability.

The next frequently cited reference in support of dental individuality is that of Sognnaes et al. (7), who examined bitemark patterns of five pairs of male monozygous twins. Their conclusion was that in terms of occlusal arch form and individual tooth positions in the bites generated, even identical twins were not dentally identical. This study was, however, restricted to the measurement of radiographs of test bites, with no effort made to document the ways in which actual bites were standardized. Crucially, there was no reference to the pressure applied when creating test bites; yet, many of the features examined were in fact dependent upon the depth of penetration of the test bite into the substrate (4). Possibly, the most frequently cited paper in favor of the uniqueness of the dentition is that of Rawson et al. (8), who examined 397 test bites selected out of a sample of 1200 such bites generated by forensic dentists in the United States. Bitemark indentations were filled with zinc powder, radiographed, and traced onto overlays. From his in-depth analysis of Rawson's paper, Pretty (4) concluded that while it established that the human anterior dentition was unique, it did not do so in a mathematically sound fashion.

Thus, if human bitemark analysis is to be accepted as reliable scientific evidence, a major point still to be investigated is the question of the uniqueness of the anterior dentition. To do this, we use geometric morphometric techniques based on landmark and semilandmark (9) data in order to study the size and shape differences of the upper and lower anterior teeth.

Material and Methods

The incisor and canine occlusal surfaces of 50 randomly selected, postoperative orthodontic casts of young individuals (17–20 years) of both sexes formed the material for this study. Only individuals with postorthodontic normocclusion and unrestored teeth were selected, because we expected this group to display a lower level of individuality than the general population. Each set of casts was scanned on an "Epson Stylus" multifunction printer with flat bed scanner feature, model number CX3100 (Epson,

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Auckland, New Zealand), on the following scanner settings: resolution—300 dpi, document source—flatbed, scale—100%, exposure—1, γ—1.44, highlight—255, shadow—22, gray-scale intensity—100, and saturation—0. The scanned image was saved in JEPG format. The maxillary casts were positioned so that the incisal edges of the central incisors were touching the glass top of the scanner and the mandibular casts were positioned so that the incisal edges of the anterior incisors and the cusps of the most posterior molars were touching the glass surface of the scanner. Mandibular casts were trimmed in the retromolar region if the height of the cast prevented molar contact. This technique of positioning the casts ensures that the process can be repeated at a later stage if required with no variability in the angle of the scan and resulting image.

Geometric Morphometric Analyses

In the evaluation of tooth morphology, investigators have typically relied on measurements of selected distances, angles, or ratios between subjectively identified "landmarks" (10). Inferences based on these measurements were then made using standard univariate and multivariate statistical methods (11). However, recent advances in digital imaging have facilitated the location of landmarks as coordinates. These landmark configurations can then evaluated by geometric morphometric methods, which allow for the investigation of both shape and size. Aided by a wide availability of computer software as well as an accessible literature, these methods have now become increasingly popular in a variety of disciplines. Recently, Robinson et al. (10) have provided details of how this method may be used on dental measurements. Geometric morphometric methods allow a quantitative analysis of shape by capturing the geometry of morphological structures of interest and preserving this information throughout statistical analyses (12). One important contribution of geometric morphometry is the clear mathematical definition of shape and size (centroid size). The former is defined as "all the geometric information that remains when location, scale, and rotational effects are filtered out from an object" (13), whereas the centroid size is defined as the square root of summed squared distances from each landmark to the configuration centroid. These definitions clearly separate both components of biological form and allow the development of methods for measuring the size and shape differences independently. The geometry of the structure is captured through configurations of Cartesian coordinates of landmarks (defined for the geometric characteristics of soft or hard tissue, 14) and semilandmarks (points are arbitrarily distributed along a homologous contour, 9).

We used two landmarks and two semilandmarks located on each occlusal surface to describe the upper and lower anterior dentition. While landmark 1 corresponded to the most mesial extreme point, landmark 2 was located on the most distal extreme of the occlusal surface of each of the teeth considered. According to Bookstein (14), these landmarks are classified as Type III, because they are placed at extreme points of one structure. Because there are few anatomical features on the occlusal surface, the use of landmarks is not sufficient to capture aspects of the morphology that are relevant to this study (e.g., differences in occlusal surface width between individuals). Hence, we used two semilandmarks located at the medial points on the labial and lingual sides of the occlusal surface (semilandmarks 3 and 4). Figures 1*a* and *b* show the points digitized in the maxilla and mandible, respectively. Both landmarks and semilandmarks were digitized using tpsDig 1.40 (15).

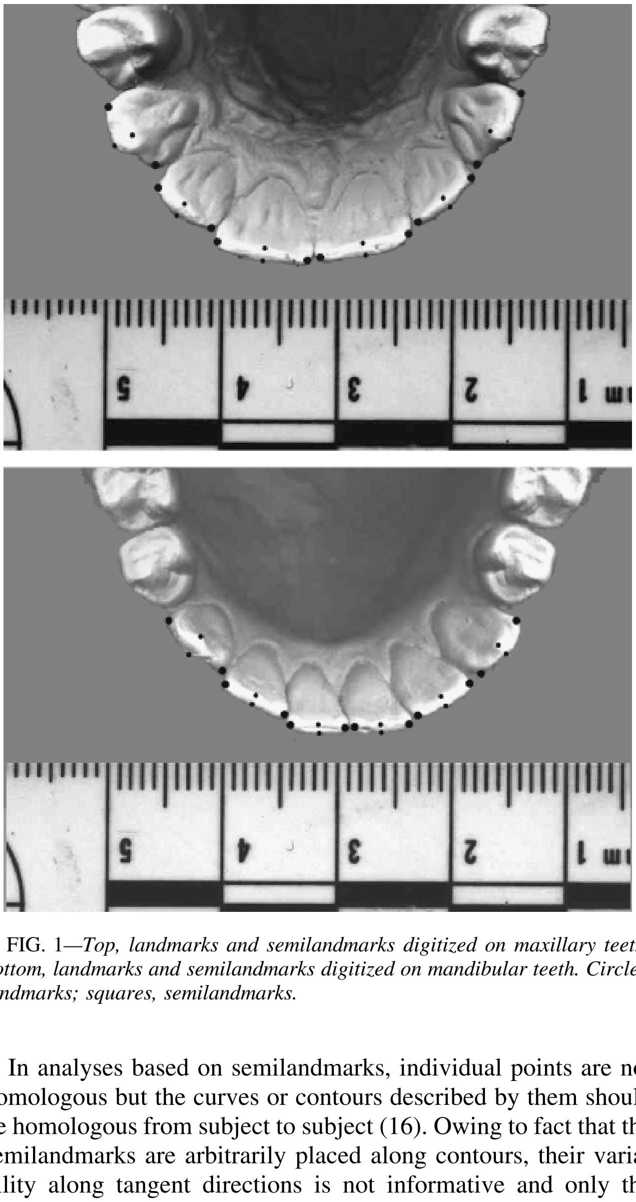

FIG. 1—*Top, landmarks and semilandmarks digitized on maxillary teeth; bottom, landmarks and semilandmarks digitized on mandibular teeth. Circles, landmarks; squares, semilandmarks.*

In analyses based on semilandmarks, individual points are not homologous but the curves or contours described by them should be homologous from subject to subject (16). Owing to fact that the semilandmarks are arbitrarily placed along contours, their variability along tangent directions is not informative and only the coordinate normal to the outline carries information about differences between specimens or groups (9,16). As a consequence, Green and colleagues (16,17) have proposed the sliding semilandmark method to capture and analyze outlines as an extension to the standard Procrustes superimposition procedure. In addition to optimally translating, scaling, and rotating landmarks, the semilandmark points are slid along the outline curve until they match as well as possible the positions of corresponding points along an outline in a reference configuration. The semilandmarks are slid along its tangent to the contour minimizing one of various possible criteria, such as the bending energy (16) or the Procrustes distances (16,18). In our study, the last criteria, referred to as perpendicular projection criteria or minimum Procrustes distances, were used for sliding the points along outlines. This method slides the points to minimize the distances between the curve on the reference and each individual in the sample. The perpendicular projection criterion removes the difference along the curve in semilandmark positions between the reference form and each specimen by estimating the tangent direction to the curve and removing the component of the difference that lies along the tangent to the curve (18). The semilandmarks were aligned along their respective curves using tpsRelw 1.40 (15).

In order to analyze shape variation among individuals, we carried out a principal components analysis (PCA) on the partial warp scores, plus uniform components derived from the Partial Procrustes aligned landmark and semilandmark coordinates by means of thin-plate spline decomposition based on the bending energy matrix (19). Partial warps are shape variables that depict localized shape changes (14), whereas the uniform component estimates the global shape variation (20). A PCA carried out on the covariance matrix of the shape variables is called a relative warp (RW) analysis and was performed using tpsRelw 1.40 (15). Then, to represent the differences in form among individuals, the first RW axis that summarizes the main variation in shape was plotted against the centroid size. The differences in relative landmark and semilandmark locations between the nearest and most distant individual along the first RW were plotted and the Partial Procrustes distances between them were calculated using the TwoGroup6 program (21,22).

Given that certain traits such as tooth size/shape may be strongly associated with one another (23,24), we explored the covariation between tooth size and the shape of anterior arch both in the upper and lower arches. We used a partial least square (PLS) analysis (25,26) to find correlated pairs of linear combinations (singular vectors) between centroid size and shape. The singular vectors are constructed in the form of new, paired variables called singular warps, which account for as much as possible of the covariation between the two original sets of variables. These vectors express the maximal covariance between both the variables within their set and with the variables of the other set (26). The coefficient r, which measures the correlation of the scores of specimens along the singular axes of the two sets of variables, was used as a measurement of correlation between size and shape of each arch. PLS analysis was performed using tpsPLS 1.13 software (13).

Intraobserver error associated with the placement of point coordinates was evaluated by one of the authors (V. B.), who digitized the landmarks and semilandmarks on a subsample of 20 mandibles twice with a week in between the scoring sessions. The sets of point coordinates obtained each time were used to perform RW analysis and the ordinations obtained were compared. This was done by comparing the score of each specimen in the first RW, which accounted for the greatest amount of explained variation, using an intraclass correlation coefficient (ICC) (27,28). The intraclass correlation assesses rating reliability by comparing the variability of different ratings of the same object with the total variation across all ratings and all objects.

Results

Of the 50 sets of dental casts, only 33 maxillas and 49 mandibles from male and female individuals were analyzed. This small reduction in the number was due to some teeth not having their occlusal surfaces clearly visible. The results of ICC analysis show an excellent agreement (ICC = 0.95) (22) between the two series performed, and significant at a p-level of 0.01. This indicates a high level of intraobserver consistency in landmark placement.

Figure 2 plots the first two RWs calculated from the maxillary landmarks and semilandmarks, which account for 66.28% of the explained variance. The first RW explains 52.57% of the variance and reflects mainly the differences in the depth and width of anterior arch (Fig. 3). The results indicate that there is no sexual dimorphism in the shape of the upper arch. The plot of centroid size and the first RW (Fig. 4) for maxillary data show lesser superposition among individuals than in shape analysis. This means that when the size and shape are considered together, the difference between arches increases. Finally, it is important to point out that both sexes are not as overlapped as in shape analysis (e.g., RW analysis; Fig. 2).

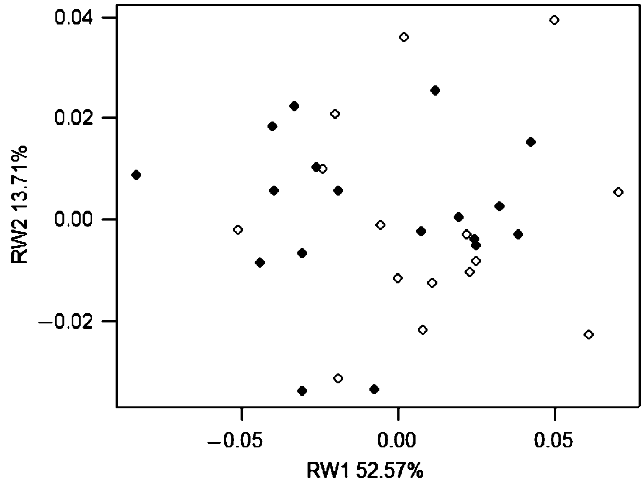

FIG. 2—*Relative warp (RW) analysis of maxillary landmarks and semilandmarks (n = 33). Filled diamonds, female; empty diamonds, male.*

Figure 5 shows the Procrustes superimposition between the two individuals most closely located (similar) and the two most separated (dissimilar) along the first axis of RW analysis obtained from maxillary landmarks and semilandmarks. The Procrustes distance between the individuals most close in RW is 0.0444 and between the individuals most separated is 0.1567. As can be seen in Fig. 5, even though the distance between two individuals is small, there are differences in the relative position of teeth. When the distances are greater, the individuals are not only differentiated by the relative position of their teeth but also by their arch shape (Fig. 5).

Figure 6 displays the first two RWs calculated from the mandibular landmarks and semilandmarks, which account for 55.13% of the explained variance. The first RW explains 46.02% of the variance, and reflects mainly the differences in the depth and width of anterior arch (Fig. 7). The results indicate that there is no clear sexual dimorphism in the shape of the lower arch. The plot of centroid size and the first RW (Fig. 8) for mandible data indicates that there is a large superposition between both sexes.

Figure 9 shows the Procrustes superimposition between the two most similar individuals and the two most dissimilar along the first axis of RWs analysis obtained from mandible landmarks and semilandmarks. The Procrustes distance between the most alike individuals in RW is 0.0387 and between the individuals most dissimilar is 0.1718. As can be seen in Fig. 9*a*, even though the distance between two individuals is small, there are differences in the relative position of teeth. When the distances are greater, the individuals are not only differentiated by the relative position of teeth but also by the arch shape (Fig. 9*b*).

The results of PLS analysis indicate a low and nonsignificant covariation between size and shape, both in the upper ($r = 0.38$; $p = 0.35$) and lower ($r = 0.52$; $p = 0.08$) arches. Thus, in the sample analyzed it seems that the shape of the anterior arches is not strongly correlated with the tooth size.

Discussion

Forensic comparative techniques, such as bitemark, handwriting, tool mark, and hair morphology analyses, continue to perturb

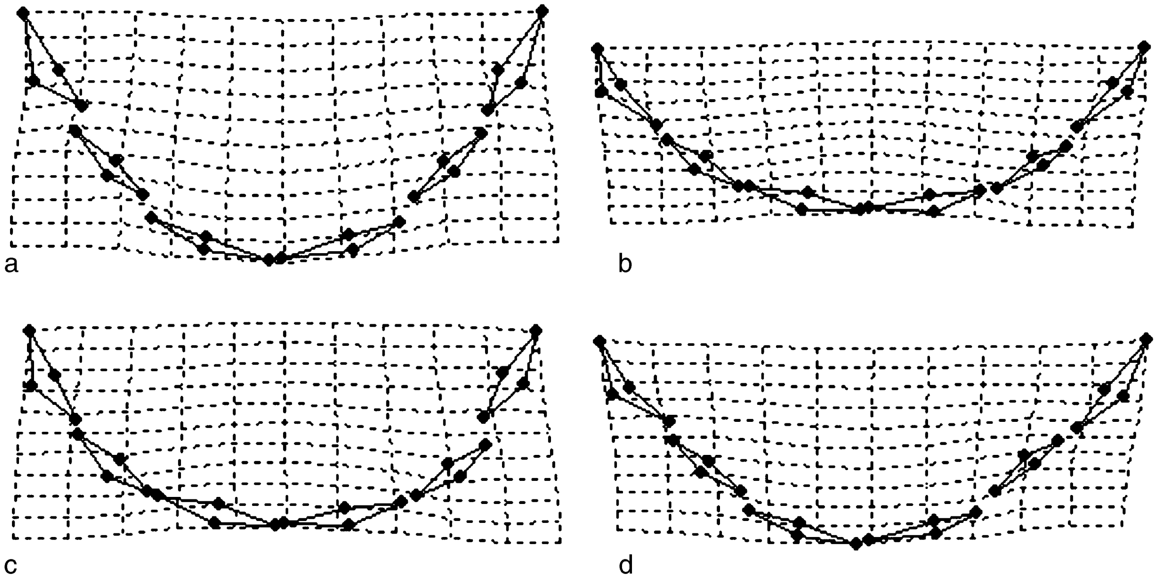

FIG. 3—*Deformation grids representing the morphological variation along the first two relative warp (RW) axes obtained from maxillary landmarks and semilandmarks. These grids show the transformation of the mean shape at the extreme points of both axes; (a) deformation at the most negative extreme along first RW; (b) deformation at the most positive extreme along first RW; (c) deformation at the most negative extreme along second RW; (d) deformation at the most positive extreme along second RW. The lines connecting landmarks and semilandmarks are only for visualization.*

both the forensic and the legal communities (29). These are non-exact sciences whose evidential value is not underpinned by large, statistically relevant numbers but rather depend on the identification and comparison of class and individual characteristics (30). Even the long-established practice of fingerprint analysis has recently been called into question (31). What these comparative techniques have in common is a reliance on a number of variable characters that must often be evaluated in an inductive (experience based) rather than the deductive (mathematical) manner that is intuitively more appealing to jurors and lay-persons (32).

Forensic odontologists have long recognized the importance of bitemark evidence. However, some have argued that it may not be as accurate as it had been claimed (33), an assertion supported by those who suggested that the human dentition may in fact not be as unique as was previously supposed (34). The evidential

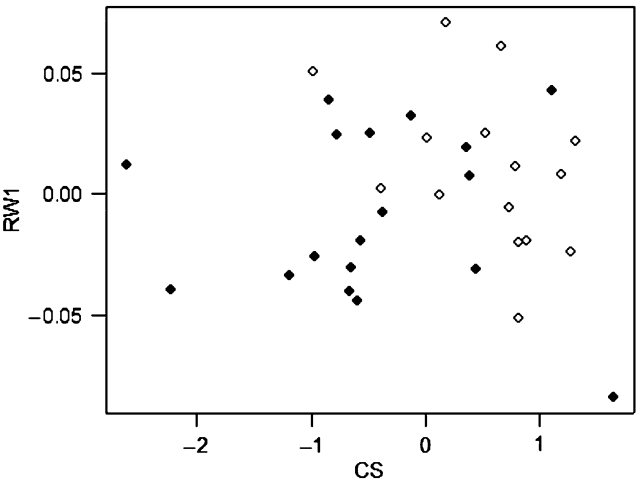

FIG. 4—*Scatterplot summarizing relations between the size (centroid size [CS]) and shape (relative warp [RW]) variation between individuals in the anterior dentition of the maxilla. The first RW explains 52.57% of shape variation (n = 33).*

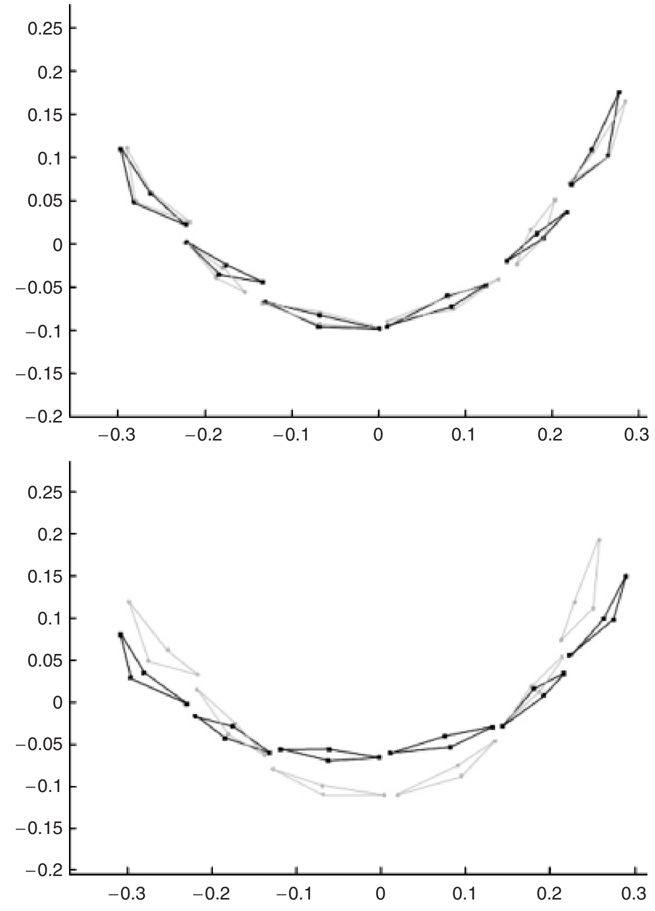

FIG. 5—*Procrustes superimposition between (a) the two most closely located (i.e., similar) and (b) the most separate (i.e., dissimilar) individuals along the first axis of the relative warp analyses obtained from maxillary landmarks and semilandmarks.*

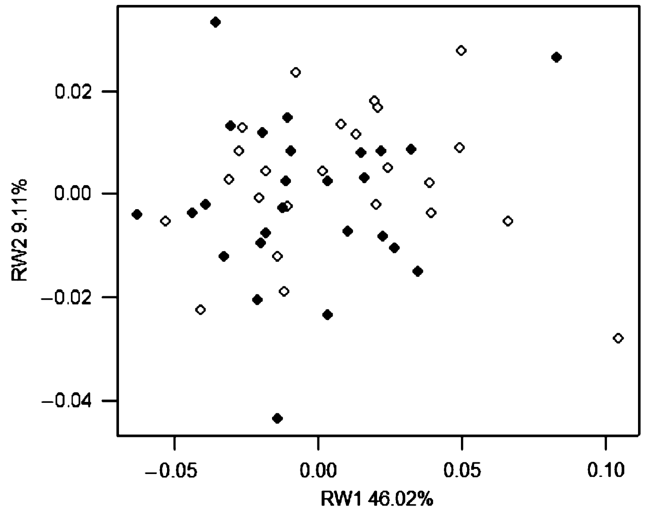

FIG. 6—*Relative warp (RW) analysis of mandibular landmarks and semilandmarks (n = 49).*

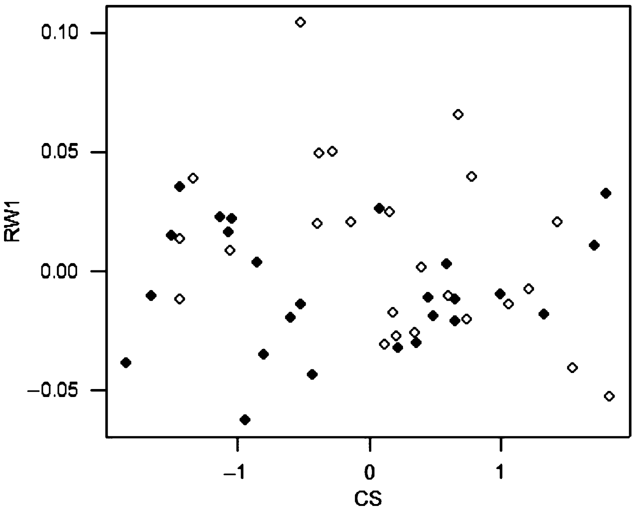

FIG. 8—*Scatterplot summarizing the size (centroid size [CS]) and shape (relative warp1 [RW1]) variation between individuals in the anterior dentition of the mandible. The first RW explains 45.89% of the shape variation.*

reliability of bitemark evidence relies heavily on two tenets: firstly, that the sizes, shapes, and arrangement of the occlusal surfaces of the upper and lower anterior teeth are specific to each individual, and secondly, that an accurate impression of the biter's teeth is generated in the material bitten (35,36). While there is a relatively large body of literature focused on tooth size, shape, and position (reviews (37,38)), their uniqueness has never been established with scientific rigor (39,40). Clearly, in the absence of a sound scientific foundation for the assertion of individuality of the dentition, frustration awaits those attempting to use bitemark evidence in court.

It is important to note that our study only focused on one of the aforementioned tenets—that of individuality. It does not address the viscoelastic response of skin to biting. The question we asked here is: "What is the evidence that the occlusal surfaces of the anterior teeth are unique to each individual?" We are not asking: "What is the probability of finding a sufficiently similar set of occlusal surfaces in a target population?" To answer the latter would require the development of appropriate statistical models to capture all aspects of variability of the salient occlusal features of the anterior dentition. As in the case of fingerprints, this still remains beyond our reach (41).

We used a new family of geometrical morphometric methods to capture subtle differences about both the morphological variation and the relative spatial location of the individual occlusal surfaces (e.g., intertooth spacing, rotation, winging) of the upper and lower anterior dentition as well as a good description of overall arch form. Importantly, landmark and semilandmark analysis has been shown to allow occlusal shape differences among samples to be explored in greater detail than linear measurements (42).

Our study shows that there are clear differences in the anterior dental arcade, both in shape and form. The main shape variation, summarized by RW analysis, seems to be related to general changes in the depth and width of the arcades. These differences are greater than those due to the relative position of teeth or their individual morphology. However, when individuals with very

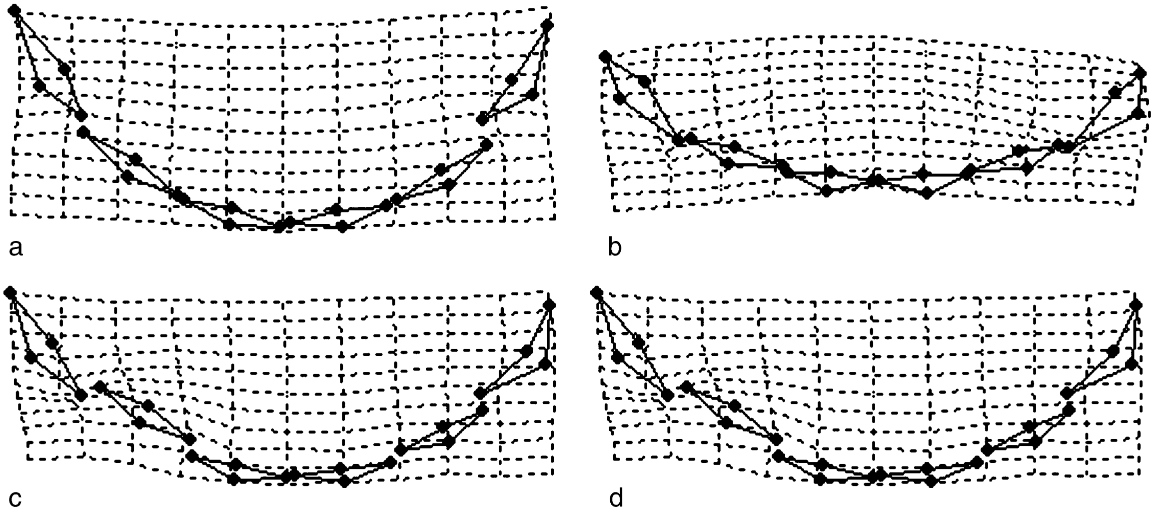

FIG. 7—*Deformation grids representing the morphological variation along the first two relative warp (RW) axes obtained from mandibular landmarks and semilandmarks. These grids show the transformation of the mean shape at the extreme points of both axes; (a) deformation at the most negative extreme along first RW; (b) deformation at the most positive extreme along first RW; (c) deformation at the most negative extreme along second RW; (d) deformation at the most positive extreme along second RW. The lines connecting landmarks and semilandmarks are only for visualization.*

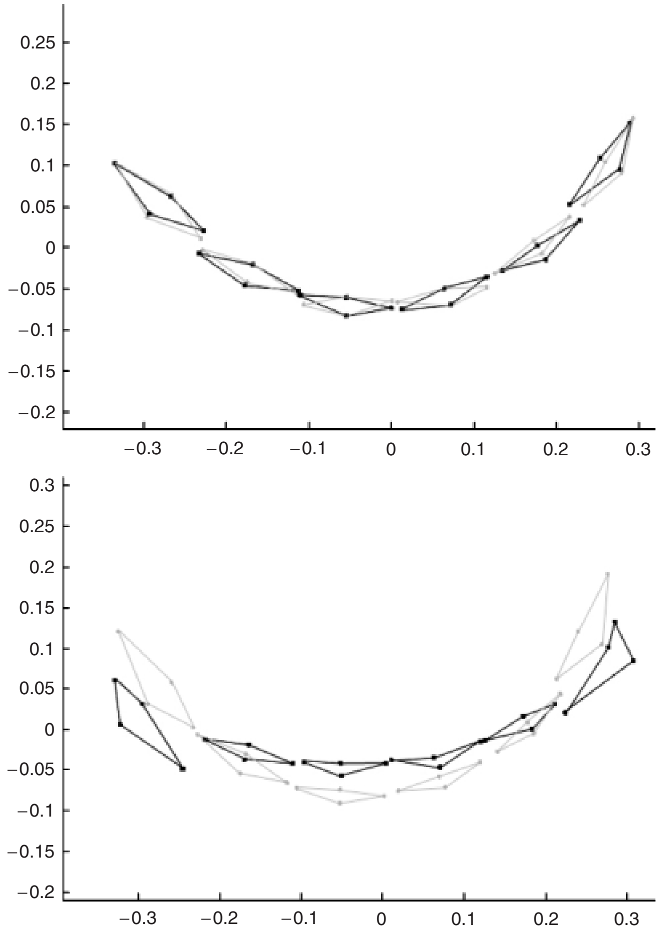

FIG. 9—*Procrustes superimposition between (a) the two most closely located (i.e., similar) and (b) the most separate (i.e., dissimilar) individuals along the first axis of the relative warp analyses obtained from mandibular landmarks and semilandmarks.*

similar arcade shape are superimposed, differences in tooth orientation are still evident (Figs. 6*a* and 9*a*). Hence, it can be said that in the present sample, specifically selected to have lower levels of individuality than the general population, there are no two individuals with identical tooth morphology.

We only examined the occlusal surfaces of the anterior teeth in a small sample of convenience. No attempt was made to evaluate how these surfaces might create a bite pattern either in wax or on skin. With these provisions in mind, what are the implications of our results for our understanding of the evidential reliability of bitemark analysis? Firstly, our study supports the notion of the individuality of the human anterior dentition. Secondly, our results suggest a low, nonsignificant level of correlation between dental size/shape and arch shape, which means that the product rule can be applied to the assessment of these data. Finally, our study does not suggest that the unique features of the anterior incisal surfaces documented here would necessarily be transferred to a bitten substrate.

References

1. Vale GL. History of bitemark evidence. In: Dorion RBJ, editor. Bitemark evidence. New York: Marcel Dekker, 2005:1–29.
2. Pretty IA, Sweet D. The scientific basis for human bitemark analyses—a critical review. Sci Justice 2001;41:85–92.
3. Kieser JA. Weighing bitemark evidence: a postmodern perspective. Forensic Sci Med Pathol 2005;1:75–80.
4. Pretty IA. Reliability of bitemark evidence. In: Dorion RBJ, editor. Bitemark evidence. New York: Marcel Dekker, 2005:531–63.
5. Sweet D, Pretty IA. A look at forensic dentistry—Part 2. Teeth as weapons of violence—identification of bitemark perpetrators. Br Dent J 2001;190:415–8.
6. MacFarlane TW, MacDonald DG, Sutherland DA. Statistical problems in dental identification. J Forensic Sci Soc 1974;14:247–52.
7. Sognnaes RF, Rawson RD, Gratt BM, Nguyen NBT. Computer comparison of bitemark patterns in identical twins. J Am Dent Assoc 1982;105:449–51.
8. Rawson RD, Ommen RK, Kinard G, Johnson J, Yfantis A. Statistical evidence for the individuality of the human dentition. J Forensic Sci 1984;43:245–53.
9. Bookstein FL. Landmark methods for forms without landmarks: localizing group differences in outline shape. Med Image Anal 1997;1:225–43.
10. Robinson DL, Blackwell PG, Stillman EC, Brook AH. Planar procrustes analysis of tooth shape. Arch Oral Biol 2001;46:191–9.
11. Kieser JA, Groeneveld HT, McKee J, Cameron N. Measurement error in human dental mensuration. Ann Hum Biol 1990;17:523–8.
12. Adams DC, Rohlf FJ, Slice DE. Geometric morphometrics: ten years of progress following the 'revolution'. Ital J Zool 2004;71:5–16.
13. Kendall DG. The diffusion of shape. Advances Appl Prob 1977;9:428–30.
14. Bookstein FL. Morphometric tools for landmark data: geometry and biology. Cambridge: Cambridge University Press, 1991.
15. Rohlf FJ. Tps series software. Ecology and Evolution, SUNY at Stony Brook, Available at http//life.bio.sunysb.edu/morph/, 2004.
16. Bookstein FL, Streissguth AP, Sampson PD, Connor PD, Barr HM. Corpus callosum shape and neurophysiological deficits in adult males with heavy fetal alcohol exposure. NeuroImage 2002;15:233–51.
17. Green WDK. The thin-plate spline and images with curving features. In: Mardia KV, Gill CA, Dryden IL, editors. Proceedings in image fusion and shape variability techniques. Leeds: Leeds University Press, 1996:79–87.
18. Sheets HD, Keonho K, Mitchell CE. A combined landmark and outline-based approach to ontogenetic shape change in the Ordovician Trilobite *Triarthrus becki*. In: Elewa A, editor. Applications of morphometrics in paleontology and biology. New York: Springer, 2004:67–81.
19. Rohlf FJ. Relative warps analysis and an example of its application to Mosquito wings. In: Marcus LF, Bello E, García-Valdecasas A, editors. Contributions to morphometrics. Madrid: Monografías del Museo Nacional de Ciencias Naturales, 1993:132–59.
20. Rohlf FJ, Bookstein FL. Computing the uniform component of shape variation. Syst Biol 2003;52:66–9.
21. Sheets HD. IMP-integrated morphometrics package. Buffalo, New York: Department of Physics, Canisius College, 2003.
22. Goodall C. Procrustes methods in the statistical analysis of shape. J Roy Stat Soc B 1991;53:285–339.
23. Dayan T, Wool D, Simberloff D. Variation and covariation of skulls and teeth: modern carnivores and the interpretation of fossil mammals. Paleobiology 2002;28:508–26.
24. Dempsey PJ, Townsend GC, Martin NG, Neale MC. Genetic covariance of incisor crown size in twins. J Dent Res 1995;74:1389–98.
25. Bookstein FL, Streissguth AP, Sampson PD, Connor PD, Barr HM. Corpus callosum shape and neuropsychological deficits in adult males with heavy fetal alcohol exposure. NeuroImage 2003;15:233–51.
26. Rohlf FJ, Corti M. The use of two-block partial least-squares to study covariation in shape. Syst Zool 2000;49:740–53.
27. Shrout PE, Fleiss JL. Intraclass correlations: uses in assessing rater reliability. Psychol Bull 1979;2:420–8.
28. Fleiss JL. Statistical methods for rates and proportions. 2nd ed. New York: John Wiley, 1981.
29. Taupin JM. Forensic hair morphology comparison—a dying art or junk science? Sci Justice 2004;44:95–100.
30. Saferstein R. Criminaslistics—an introduction to forensic science. 5th ed. Englewood Cliffs, NJ: Prentice-Hall, 1995.
31. Pollak J. US v Plaza, Acosta and Rodriquez Cr. No. 98-362-10,11,12, District Court of Pennsylvania, Order 13 March, 2002.
32. Grieve M, Wiggins K. Fibres under fire: suggestions for improving their use to provide forensic evidence. J Forensic Sci 2001;46:835–43.
33. Sweet D, Bowers CM. Accuracy of bite mark overlays: a comparison of five common methods to produce exemplars from a suspect's dentition. J Forensic Sci 1998;43:362–67.
34. State v. Garrison, 120 Arizona 255,585 P.2d 563.
35. Naru AS. Methods for the analysis of human bitemarks. Forensic Sci Rev 1995;9:123–39.

36. Aksu MN, Gobetti JP. The past and present legal weight of bitemarks as evidence. Am J Forensic Med Pathol 1996;17:136–40.
37. Kieser JA. Human adult odontometrics. Cambridge: Cambridge University Press, 1990.
38. Lucas PW. Dental functional morphology. Cambridge: Cambridge University Press, 2004.
39. Kieser JA, Tompkins GR, Buckingham D, Firth NA, Swain MV. Bitemarks: presentation, analysis and evidential reliability. Forensic Path Rev 2005;3:157–79.
40. Kittelson JM, Kieser JA, Buckingham DM, Herbison GP. Weighing evidence: qualitative measures of the importance of bitemark evidence. J Odonto-Stomatol 2002;20:31–7.
41. Budowle B, Buscaglia JA, Schwartz-Perlman R. Review of the scientific basis for friction ridge comparisons as a means of identification: committee findings and recommendations. Forensic Sci Comm 2006; 8:1–11.
42. Bernal V. Size and shape analysis of human molars: comparing traditional and geometric morphometric techniques. J Comp Hum Biol, in press.

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