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Technical Note

Quantification of the Individual Characteristics of the Human Dentition: Methodology

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Abstract: This study provides a method for comparing six individual human dentition characteristics using the standard measuring tool in Adobe Photoshop CS2 as compared to measuring individual characteristics with an automated software program under development at Marquette University, which has been adapted for bitemark analysis. The algorithm identifies color-specific pixels and automatically calculates the measurements.

Introduction

Increasingly, the comparative sciences such as fingerprints, document examination, and bitemark analysis have been asked to provide hard science to support their interpretation of the evidentiary value of their objective observations. In spite of being able to visually and physically demonstrate the correlation of the characteristics of the unknown pattern to the known standard, the critics are now asking for the ability to quantify the existence of the specific pattern. Under a grant from the National Institute of Justice, via the Midwest Forensic Resource Center (MFRC), Iowa State University, Ames, Iowa, a two-year pilot study was accomplished in answer to this challenge.

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A literature search reveals several early studies that attempt to demonstrate that the human dentition is unique [1, 2]. Several other studies have been recently completed, including a study on arch width [3] and angles of rotation of the anterior teeth [4]. Other studies [5] apply only to the data sets established by decayed, missing, and restored teeth, terms used in dental identification rather than being used to quantitatively relate patterned injuries to a dentition.

Although it is possible to visually demonstrate to the court a complete match of a suspect's dentition with the pattern in a bite mark, the odontologists are limited to opinion testimony [6]. Currently, forensic odontologists, in the analysis of bitemark evidence, are not able to quantitatively state the frequency that a given set of dental characteristics occurs in the population. That is, what is the probability that another individual would have the same characteristic pattern? Without the ability to quantify the frequency, the conclusions of the examiner regarding a match between patterned injuries (bitemarks) and the teeth of a suspect lack a scientific basis for an expression of probability and are limited to exclusion, consistency, or a subjective opinion of probability. This project used empirical comparisons for examining several remarkable characteristics of the teeth in a manner very similar to that used for the database generation of mitochondrial DNA (mtDNA). This research will provide the forensic odontologist with an objective tool in stating the probability that another individual would have the same pattern.

Theoretical Basis

Rawson et al. [2] state that each of an individual's six maxillary and six mandibular anterior teeth can occupy a minimum of 150 positions and that each tooth's position is independent of any other tooth's position. If this is true, then any pair of teeth can take on a minimum of 22,500 (150^2) positions and the probability of two teeth of two individuals matching is one divided by 22,500 (i.e., 0.000044).

Controversy has existed for many years as to whether an individual's dentition is actually unique. The aim of this pilot study was to begin the generation of statistics that will enable the forensic odontologist to quantitatively state the frequency with which a given set of dental characteristics (data sets) occurs

in a homogenous population. The study's goal was to use empirical comparison of six remarkable characteristics of the teeth, in a technique very similar to that used for the database generation for mitochondrial DNA (mtDNA). Adams [5] suggests that "it is appropriate to compare the diversity of dental patterns formed by combinations of missing, filled, and unrestored teeth with the diversity of mtDNA sequences formed by combinations of variants at multiple polymorphic sites within the mtDNA sequence". The same principle can be applied to such dental characteristics as arch width, tooth size, labial-version (anterior displacement) or lingual-version (posterior displacement) in the dental arch, and the degree of positive or negative rotation of individual teeth. By adding characteristics such as spacing, accidental damage, and the pattern of missing teeth, a sufficient number of specific data sets of remarkable characteristics were studied in order to demonstrate statistical significance. Because some dental characteristics are more likely to occur than others, one of the criticisms of Rawson's study was that he considered all of the possible positions of each tooth as occurring with equal random frequency. A data set on the frequency distribution of a commonly observed characteristic in the human dentition has to begin with an empirical study upon which to build. It may be possible over several years to eventually expand this study to establish a database similar in size to that of mtDNA. Unlike the database for mtDNA, the data in this study is not linked to a specific individual. The purpose is only to be able to statistically calculate the frequency with which a specific characteristic, or a group of them, would occur in a particular population. From the extensive professional experience of the principal investigator, the preponderance of human bite marks have been inflicted by males, therefore, only males were sampled in this pilot project.

This research sought to demonstrate that the frequency with which each of the patterns of 419 imprints (exemplars) occurs in the population is predictable. This project initiated the development of a data set that can be used to justify further research on the frequency a given set of dental characteristics occurs in the general population.

This project provides the forensic odontologist and the criminal justice system with the beginning of a valuable tool in providing hard science for the objective statement of probability in either exculpating or incriminating a suspect from patterned injuries caused by human teeth. It also will provide the means

of developing a dental profile from a bitemark pattern when a suspect has not been identified, allowing investigators to concentrate their resources. Although DNA could be associated with a human bite, it cannot always be recovered as a means of linking a suspect to the bite.

Materials and Methods

A multidisciplinary team was assembled for this research consisting of two forensic odontologists, a professor of evidence, a biostatistician, a computer programmer, two crime laboratory forensic imaging specialists, a graduate student, and two dental students. This study used exemplars of the biting edges of the teeth of a sample of four hundred nineteen male volunteers between the ages of 18 and 44. Each imprint consisted of an upper and a lower arch. The sample size (n=400) [7] was derived from power calculations by a biostatistician using nQuery Advisor (Statistical Solutions, Saugus, MA). The volunteer samples were randomly derived from the University's dental clinic patients and two military reserve dental clinics, representing an ethnically diverse population.

A total of 500 samples were collected to allow for 100 samples that were not accurate enough for interpretation. Bite patterns of each individual were evaluated by the principal investigators for distortions and adequate representation of the six anterior teeth in each arch. The accuracy of the exemplar registration material has been established by the American Dental Association Standards Committee on Dental Products (ADA SCDP). Depth of penetration was controlled by the design of the exemplar having a foil center at 1.5 mm from the surface. All samples and a brief history were recorded and designated by a number to protect identity and preserve confidentiality. Acceptable imprints of the biting edges of the dentition were scanned at a resolution of 300 ppi together with an ABFO # 2 scale for reference [8] on a professional grade scanner (Epson Expression 1680 Pro) and saved as read-only images in a .psd file format (Adobe Photoshop Document). Original scans were archived on the Marquette University server. Two imaging specialists, assigned to the project by the Wisconsin Department of Justice Crime Laboratory, assured the digital analysis followed the guidelines of the Scientific Working Group on Imaging Technology (SWGIT). They also calibrated the scanner for accuracy and reliability. Duplicate images were imported into an imaging

software program, Adobe Photoshop CS2, where a working file of each exemplar was created by correcting any angular orientation in the registration process [9] and adding an X and Y axis (Figure 1). The "X" axis was placed between the distal-most point of the first molar teeth in each arch. The "Y" axis was placed perpendicular to this line one-half the distance between the distal points of the contra-lateral first molar teeth.

This adjustable X and Y template was placed on the image in a layer and positioned on the image using the Photoshop CS2 commands Edit> Transform> Rotate and sized to the dimensions of each exemplar using the command Edit> Transform> Scale. In Class II malocclusions, the maxillary first molar is likely to be mesially rotated, requiring an alternate method of placing the X axis [10]. Measurements were taken and logged for each of the following observations:

1. The mesio-distal width of each of the maxillary and mandibular incisor teeth

2. The presence of spacing between each of the teeth (diastemata that is greater than 5 mm)

3. The arch width from the center point of one canine to the opposite canine, where the center point represents the center of the canine imprint buccal-lingually and mesio-distally

4. The existence of accidental or decay damage to each of the anterior teeth

5. The degree of rotation of each of the maxillary and mandibular incisor teeth

6. The alignment (displacement) of each of the maxillary and mandibular incisor teeth in the arch (labial-version and lingual-version) to a generated native curve to the individual arch using a polynominal curve calculation from the incisal center points of the two lateral and two central incisors

Each step in the analysis was also digitally recorded by a screen capture and saved in a separate image file in Joint Photographic Experts Group .jpeg format. These screen captures visually recorded the on-screen computer settings and measurements of the analysis at each stage for the reproducibility of the study by others. A written log of procedures was also kept to

assist in reproducibility. Each investigator was provided with an individual copy of the working files. Measurements were taken and entered on a data entry worksheet for each of the observations.

The method compared measurements taken in Adobe Photoshop CS2 with those calculated by a Beta version of the automated program, dubbed Tom's Toolbox. It recognizes individual pixel shades of green in an RGB format. The automated program automatically identifies each unique RGB marker and calculates measurements of the six characteristics (e.g., arch width, tooth width, and angle of rotation for each maxillary and mandibular sample). Measurements manually taken with the measure tool in Photoshop CS2 were entered on a data entry sheet and documented by a screen capture image saved in .jpeg format in a separate image file. A student was tasked with the data entry into a spreadsheet. A biostatistician then analyzed the data.

The automated program utilizes a palette of ten pixels, each having a different green color value from 1 to 250 (Figure 2). The makers (pixels) were inserted at the starting and ending point of the areas to be measured. Each completed file was saved in Tagged Image File (.tiff) format and was then read by the automated software. The software program recognizes the different green color pixels by column and row and mathematically calculates distance and angle of rotation. A favorable comparison of the manual measurements recorded in Adobe Photoshop technique with those calculated by the automated program was used to validate the accuracy and reliability of the automated program. Final calculations were accomplished using SAS Statistical Analysis Software (SAS Institute, Cary, NC).

Testing of intra-operator consistency was accomplished for the investigators by selecting ten percent of their completed files on a random basis and having them retake their measurements from their working files. Inter-operator consistency was accomplished in the same manner by having each investigator retake the measurements of ten percent of a co-investigator's files. The comparison was calculated by using the statistical software in the validating accuracy. A written log of procedures was kept to assist in reproducibility.
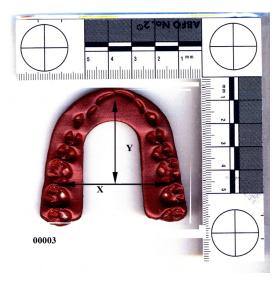
Figure 1

*A working file of each exemplar was created by correcting any angular
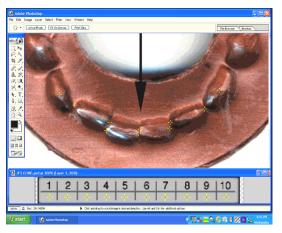orientation in the registration process and adding an X and Y axis.*

Figure 2

*At a screen magnification of 300%, a one pixel marker, from a palette
of ten in Tom's Toolbox, is inserted in the image in a specific order.
The automated application recognizes the specific green value of the
marker, calculating the width and angle of rotation.*

Discussion and Conclusion

There is a large body of case law in which bitemark evidence played a role in the prosecution of the accused. No jurisdiction has ever denied admissibility. The principal investigator of this research is board-certified in forensic odontology by the American Board of Forensic Odontology, is certified as a law enforcement instructor, and is a senior crime scene analyst, certified by the Crime Scene Certification Board of the International Association for Identification. He has extensive professional and courtroom experience. In two of the numerous trials in which he has testified, bite marks played a pivotal role. Both of these convictions were appealed, affirmed by the appeals court, and recommended for publication as case law [11, 12]. The ability to be able to scientifically express the linkage between a bite mark and a suspect will demonstrate the validity of this investigative tool. Creating a data set for this comparative science reduces the reliance on subjective assessments. What presently can be expressed only as opinion will transition to a logical basis of science, establishing credibility for the bitemark analysis. The long-term goal for this initial project is to continue to expand the sample size, transition into laser surface scanning, and involve collaboration as other sources of exemplars to expand the data sets. Following the development of these data sets, a second study could be conducted to demonstrate the applicability of the statistics to actual, clearly registered, human bite marks.

Although there have been meaningful studies that touch on the characteristics of the human dentition, none have been established that correlate tooth size, angulations, spacing between teeth, rotation, and displacement in a single study. The technique provides a template for pattern analysis. The material gathered from this project will give foundation to the concept that the human bite can be quantified in a systematic way, using methods that are repeatable between observers as well as individually, thus providing a data set that has a statistically validated reliability. The care in duplicating the scanned information in a read-only format ensures that original scans cannot be corrupted. The scanner instrumentation in this pilot study was routinely calibrated by imaging specialists in cooperation with the state crime laboratory. The registration of the exemplars in an American Dental Association-accepted material ensures that accuracy was within the accepted standards of the profession for bite registrations in a wax compound.

The mechanism of capture and storage of the data is significant enough to merit continuing beyond the pilot study. With individual measurements numbering more than 36 possibilities, the calculated repetition in the adult population would provide a distribution of individuality in the one in a trillion categories, if the probability of random correspondence were utilized in calculating Gaussian distribution and minutia location with vonMises orientation.

In addition to lifting the restrictions of age and sex in the pilot study, the data sets need to be broadened to provide information on a multinational level. It would be practical to include multiple institutions in the United States and abroad to widen the population study based on the research criteria set forth in the methodology portion of this study. Newer technology (laser surface scanning) to gather and register incisal widths and arch widths should make the data gathering of a larger study more efficient.

For a larger sample size of a heterogeneous population, the level of precision mandates a larger "n" than the pilot study. This pilot study did not include a heterogeneous population but one that was homogenous so that the sample "n" required to achieve a given level of 95% precision was calculated to be 400. The measurement of all of the exemplars has been finished; the data is being compiled by the biostatistician and will be reported in a subsequent paper.

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