Raymond D. Rawson,[1] D.D.S., M.A.; Ronald K. Ommen;[2] Gordon Kinard,[3] D.D.S.; Jay Johnson;[4] and Angelo Yfantis,[5] Ph.D.

Statistical Evidence for the Individuality of the Human Dentition

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ABSTRACT: A general population sample of bite marks in wax is used to demonstrate mathematically the individuality of the human dentition. The general principles of probability are discussed and applied to the analysis of teeth using a precise method of measurement. The unique nature of the human dentition is confirmed.

KEYWORDS: odontology, bite marks, individuality, uniqueness

The science of comparing bite marks on the skin of victims to the dentition of assailants is well established [*1*, p. 113]. The first bite mark investigation to appear in the literature was in 1874 [*2*], and since that time many investigators have described methods of analysis of the human bite mark [*3,4*]. Various techniques for the actual comparison of dentition to marks left on skin or other inanimate objects have been described in the courtroom, and legal decisions suggest acceptance of the procedures used [*1*, p. 121].

It has been reported that the techniques currently used are at least as valid as fingerprint technology [*5*]. The Frey case [*6*] points to the standard of acceptance of new techniques, and while most forensic odontologists support the current state of the art, there are those who suggest a waiting period until standards are described and procedures scientifically validated [*7*]. It was recently suggested that bite mark evidence should be excluded from the courtroom because of the lack of scientific reliability and the highly prejudicial nature of the evidence [*8*].

The author is not aware of any cases where bite mark evidence has not been admitted for the reasons listed above, yet there has been little work establishing the unique nature of the human dentition. Vale et al [*9*] suggested the possibility of similarity between relatively small populations, when they indicated the need to consider at least six possible positions for each tooth to demonstrate individuality. Sognnaes et al demonstrated the uniqueness of identical twins [*10*] by computer comparison techniques and Keiser-Neilsen [*11*] has elucidated the theory of probability for duplication of the human dentition, but there has been a lack of scientific base of statistics to confirm the unique nature of an individuals dentition. The purpose of this in-

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[1] Supervising dentist, Clark County Community College, Dental Hygiene Program North Las Vegas, NV and adjunct professor, University of Nevada, Department of Anthropology, Las Vegas, NV.

[2] Dental student, Northwestern Dental School, Chicago, IL.

[3] Instructor, Clark County Community College, Dental Hygiene Program, North Las Vegas, NV.

[4] Dental student, University of the Pacific, School of Dentistry, San Francisco, CA.

[5] Professor of mathematics, University of Nevada, Department of Mathematics, Las Vegas, NV.

vestigation is to establish the scientific base for the statistical analysis of the uniqueness of the human dentition.

Methods and Materials

It was determined that a population sampling of human bite marks could be analyzed to demonstrate similarities or differences between individuals. The sample size was determined by the use of combinations and permutations. The original sample was based on the premise that there would be twelve teeth analyzed and that each tooth has six possible positions. Those positions are buccal, lingual, mesial, distal, mesial rotation, and distal rotation.

The basic problem can then be understood by looking at twelve teeth of one person and comparing them to a similar twelve teeth of another person. The question can be stated: what is the probability of two people having exactly a certain number, say six, teeth of matching positions?

Assuming that each one of the six tooth positions are equally likely, then the probability for a specific tooth of a person having a fixed specific position is 1/6. One reason for developing a population sampling is to determine if that assumption of equally likely positions is valid. The probability of the second person having exactly six teeth match with the first person is found by using the formula

$$P(X = k) = \binom{n}{k} \cdot p^k (1-p)^{n-k} = \frac{n!}{k! \cdot (n-k)!} p^k (1-P)^{n-k}$$

which translates into the probability of having K successes with n trials when the probability of success is p.

Also $n!$ (n factorial) $= n \cdot (n-1) \cdot (n-2) \ldots 2 \cdot 1$ and $k!$ (k factorial) $= k(k-1) \cdot (k-2) \ldots 2 \cdot 1$.

In our case the number of trials n is 12, the probability for success is $p = 1/6$ and the number of success is exactly 6. Thus the probability of having six successes or matches is

$$P(X - 6) = \binom{12}{6} \left(\frac{1}{6}\right)^6 \cdot \left(\frac{5}{6}\right)^6 = \frac{12!}{6!6!} \left(\frac{1}{6}\right)^6 \cdot \left(\frac{5}{6}\right)^6 = 0.0066325$$

To determine the probability for any one position the population sampling or number of measurements was found to be 384 bites. That number was structured to include various racial, sexual, and age groups representative of the general population. Samples numbering 1200 were collected by forensic odontologists from various parts of the United States and the sampling was then processed by the authors to determine the statistical base.

Each bite consisted of a custom-made and standardized wafer of Kerr® boxing wax 1 mm thick on a cardboard (Zellerback Paper Co., Las Vegas, NV), base, (Fig. 1) that was numbered to correlate with a questionnaire provided (Fig. 2). Instructions were given to record the bite in protrusive so the incisal edges of the six maxillary and six mandibular anterior teeth would be recorded. The wax was 1 mm thick on each side of the 1-mm hard cardboard. The instructions called for a hard bite to register all incisal edges to the maximum limited depth. A Boley Guage® set to 1 cm was pressed into the wax to leave a scale mark close to the tooth indentations.

To precisely transfer the information of the bite and scale marks, the indentations were completely filled with Baker ® reagent grade zinc dust being careful not to allow the zinc to overflow onto the wax. The wafers were then radiographed using an S. S. White® 90 kvp, 15-m X-ray machine and Kodak® ultraspeed X-ray film. The distance was standardized at 41 cm (16 in.) from the focal spot of the cathode ray tube. The film was placed in contact with the wax to overcome elnargement and the central ray was directed at 90° to the wax surface. Figure 3 graphically demonstrates the low percentage of magnification produced by using parallel

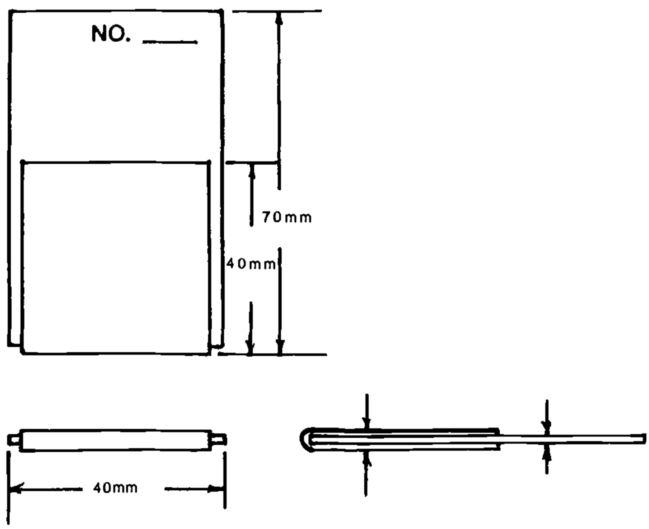

FIG. 1—*Wax bite card designed for uniform impression of incisal edges of the twelve anterior teeth.*

radiographic techniques. The mathematics of that example show a magnification of less than 0.5%.

$$\frac{\text{Distance from target to wax}}{\text{Distance spread from target}} = \frac{\text{Distance from target to film}}{\text{Distance spread from bite}}$$

$$\frac{406 \cdot 4 \text{ mm}}{40 \text{ mm}} = \frac{408 \cdot 4 \text{ mm}}{X}$$

$$X \cdot 406 \cdot 4 = 40 \cdot 408 \cdot 4$$

$$X = \frac{40 \cdot 408 \cdot 4}{406 \cdot 4}$$

$$X = 40.196$$

$$\text{Percent magnification} = 100 \cdot \frac{40.196 - 40}{40.196} = 0.49\%$$

After radiographing one side of the wax the zinc dust was removed and the procedure repeated for the opposing side. The finished radiographs representing a precise transfer of the incisal edges were then saved with the information questionnaires.

Each film was enlarged three times normal size and traced onto specially prepared computer sheets consisting of 1-mm cross rulings. The arches were arbitrarily oriented with the distal of the cuspids touching a baseline and a perpendicular line drawn from the baseline to the mesial of the right central incisor (Fig. 4). A center point for each tooth was established by drawing a line from the greatest mesial to the greatest distal point and measuring one half the distance to the absolute linear center. The x and y coordinates for each center point were then read and recorded (Fig. 4).

The angle of rotation of each tooth was determined by continuing the mesio-distal center

Bite Number __________ Color of Eyes __________

Today's Date __________ Color of Hair __________

Birth Date __________ Preferred Foods __________

Height________ft.________inches

Weight________lbs. Sex: M F

Race -White
-Black
-Oriental
-Hispanic
-Indian
-Other

Investigator notes

Restored teeth __________________________

Missing teeth __________________________

Broken teeth __________________________

Dental frequency __________________________

Other comments __________________________

FIG. 2—*Questionnaire used to gather information for correlation with test bites.*

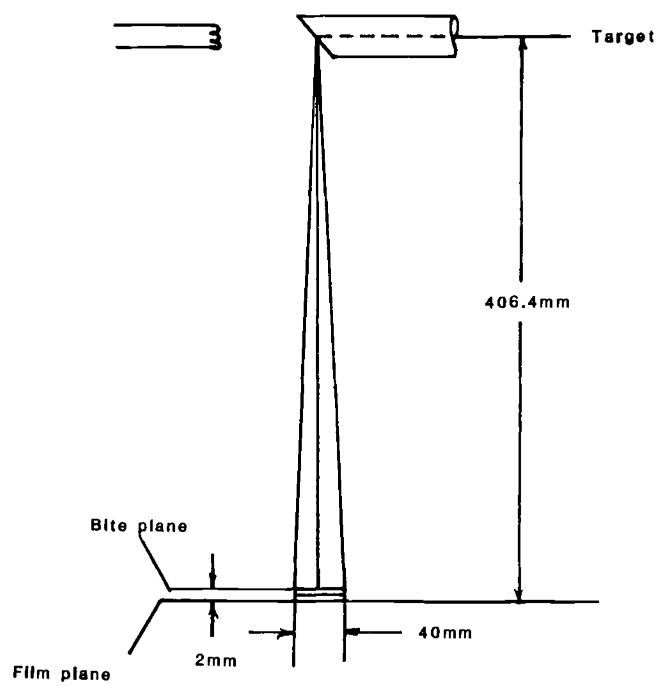

FIG. 3—*Demonstration of the low percentage of image magnification using parallel or long cone techniques.*

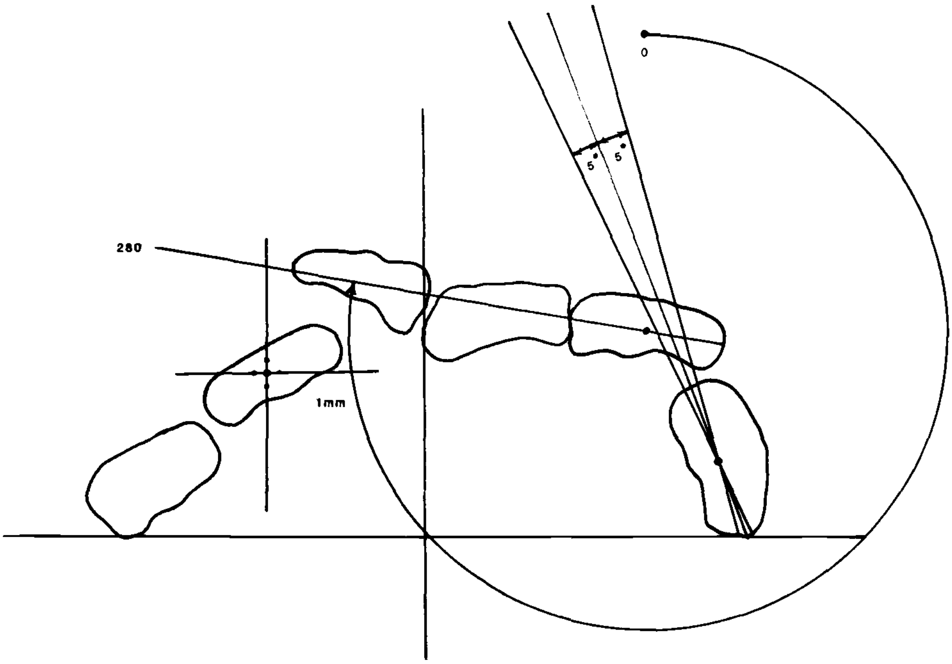

FIG. 4—*Diagramatic representation of the orientation of the arches to the* x *and* y *axis. The center points were established and the angle determined for later analysis.*

line to the mesial and reading the angle produced from a zero point on the y axis. The determined angle was read and recorded (Fig. 4).

The recorded information was entered into an Apple® II plus microcomputer along with the information obtained by the questionnaire and the information was then analyzed. The computer programs were specially designed to give information compatible with the standard Statistical Package for the Social Sciences [*12*] and are available for the interested researcher.

Results and Discussion

An initial sample size of 1200 bite marks was screened for clarity and accuracy of the marks and completeness of the questionnaire to produce the final sample size of 384 that was used to match the theoretical number required for statistical confidence to 0.1. That number was then increased to 397 to test observer error. The sex and racial breakdown of the sample is shown in Table 1, and the maximum, minimum, and average arch sizes are shown in Table 2. The sam-

TABLE 1—*Breakdown of the population sample used for statistical analysis.*

	Number	Percent
Male	222	55.9
Female	175	44.1
White	301	75.8
Black	28	7.1
Oriental	33	8.3
Hispanic	24	6.1
Other	11	2.7

TABLE 2—*Maximum, minimum, and average dimensions for maxillary and mandibular arches.*

Of the 397 Bites Found Out of 397 Bites Searched
The maximum maxillary arch width is 41.0 in Bite 19 Record 75 File 1
The minimum maxillary arch width is 21.3 in Bite 511 Record 31 File 2
The average maxillary arch width is 32.3
The maximum mandibular arch width is 33.0 in Bite 19 Record 75 File 1
The minimum mandibular arch width is 11.6 in Bite 908 Record 105 File 1
The average mandibular arch width is 25.0
The maximum maxillary arch depth is 16.0 in Bite 513 Record 213 File 1
The minimum maxillary arch depth is 5.6 in Bite 910 Record 106 File 1
The average maxillary arch depth is 10.6
The maximum mandibular arch depth is 12.0 in Bite 162 Record 171 File 1
The minimum mandibular arch depth is 2.6 in Bite 285 Record 199 File 1
The average mandibular arch depth is 7.6

ple may be considered to be small in comparison to the population of the world, but it has been designed to represent a general cross section of the United States and it follows arithmetic indicators for sample size.

Discriminate function analysis demonstrated no statistically significant indicators of race, age, or sex. A scattergram (Fig. 5) demonstrates a uniform distribution of the center point of tooth marks that would appear to suggest a high frequency of matching marks. Figure 6 demonstrates a frequency distribution of the angle and center point position of each tooth that was

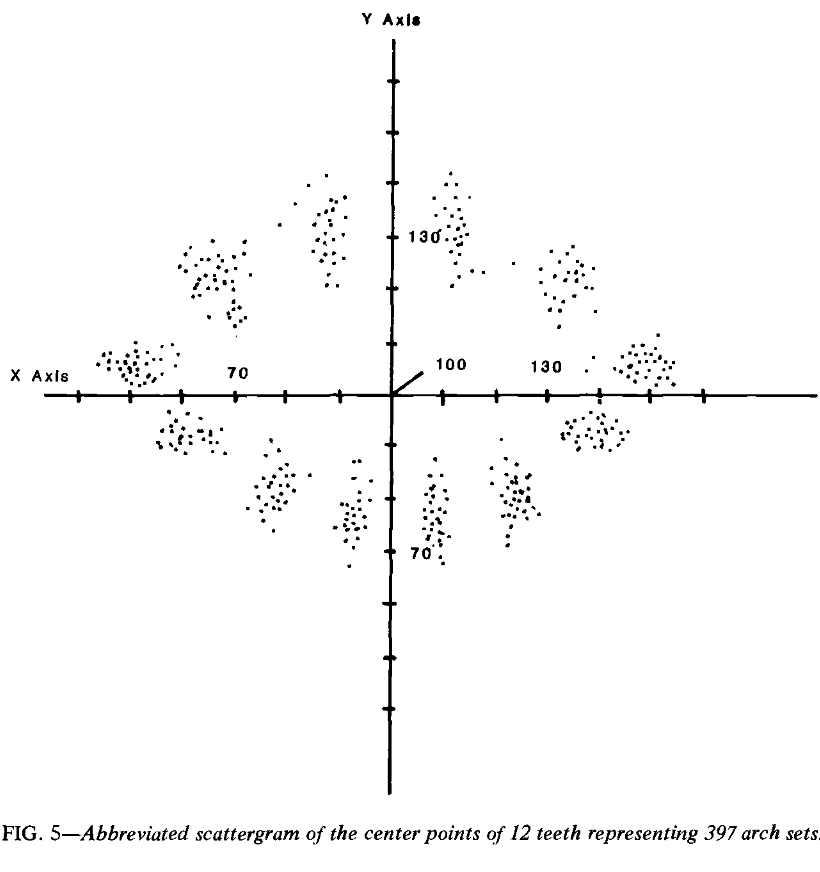

FIG. 5—*Abbreviated scattergram of the center points of 12 teeth representing 397 arch sets.*

```
132
133
134
135
136 ### 3
137 ### 3
138
139 ## 2
140 ###### 6
141 ###### 6
142 ###### 6
143 ######### 9
144 ##################### 21
145 ################################ 32
146 ####################################### 39
147 ############################## 30
148 ###################################### 38
149 ##################################### 37
150 ############################################################### 63
151 ########################### 27
152 ###################### 22
153 ####################### 23
154 ############# 13
155 ###### 6
156 ###### 6
157
158
159 #### 4
160
161 # 1
162
163

250 MATCHES OUT OF 250 IN FILE 1
397 TOTAL MATCHES OUT OF 397
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FIG. 6—*Representative frequency distribution of the* x*-axis centerpoint of Tooth 6 used in the determination of the number and frequency of position that a tooth may occupy.*

used to determine the number of positions that each tooth can occupy (Table 3). Each center point allowed a plus or minus 1-mm variance from center and each angle measurement allowed a plus or minus 5° variance. It was found that these values were well within the observational abilities of the experimenters, and the final determinations are shown graphically in Fig. 7.

By determining the actual number of positions that each tooth type can occupy, the mathematics of probability become factual determinations rather than theoretical considerations. The minimum number of positions of the X center point, the Y center point, and the angle in which any one tooth type can be found is 150 for Tooth 6. The greatest number of positions is

TABLE 3—*Tooth by tooth listings of the number of positions possible for* x *and* y *axis and angle following the criteria described in the text.*[a]

Tooth No.	x	y	Angle	Total Positions
6	5.0	2.5	12.0	150.0
7	4.1	3.9	10.1	161.5
8	3.5	6.0	7.9	165.9
9	4.5	5.6	6.9	173.9
10	5.1	4.9	9.6	239.9
11	6.3	2.6	8.1	132.7
22	4.3	2.9	8.6	107.2
23	4.0	5.1	10.0	204.0
24	2.5	5.1	9.1	116.0
25	3.1	5.5	9.0	153.5
26	4.0	4.0	9.4	150.4
27	4.1	2.5	10.1	103.5

[a] Maxillary = 2.2×10^{13}, mandibular = 6.08×10^{12}, and both = 1.36×10^{26}.

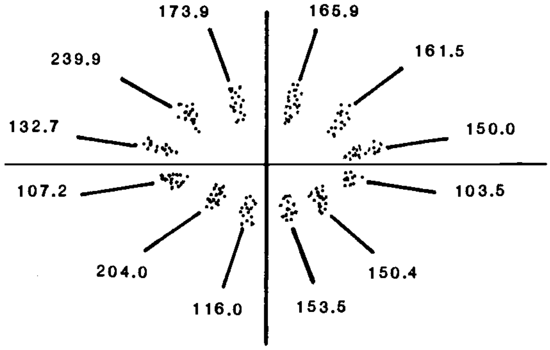

FIG. 7—*Demonstration of the total positions possible as described in the text.*

found for Tooth 9 at 239.9. By using 150 as the number of positions for all teeth the statistical calculations will follow the most conservative case. The probability of finding two sets of dentition with six teeth in the same position, plus or minus 1 mm for center point and plus or minus 5° angle difference, is 150 to the sixth power or 1.4 × 10 to the 13th. The actual total probability can be calculated by multiplying the individual probabilities. There are various positions that may have higher probabilities individually, but the total number of positions for the maxillary arch would then be the product of the individual positions or 150.0 × 161.5 × 165.9 × 173.9 × 239.9 × 132.7 = 2.2 × 10 to the 13th and the mandibular arch is 107.2 × 204.0 × 116.0 × 153.5 × 150.4 × 103.5 = 6.08 × 10 to the 12th. The total positions of twelve teeth is calculated to be 1.36 × 10 to the 26th. The population of the world is listed at over four billion, which would only require an accurate match of five teeth in a bite mark case to have confidence that there would be no other set of teeth capable of producing the same mark. Therefore, the concordance of eight specific tooth marks to eight specific teeth would very safely be considered as characteristic or unique for a single person. One would have great confidence that no other person was capable of producing the same marks.

Summary and Conclusions

This paper is a study of the individuality of the human dentition by the use of a precise registration of that dentition into another material. The technique is thus appropriate for the calculations of individuality as well as actual bite mark investigation if there is a mark on skin or other material of sufficient quality to allow proper measurements. There have existed two major concerns in the field of forensic odontology to date. First, there is a concern over uniqueness. Is the human dentition unique enough to say that there are no two sets of dentition alike? This mathematical evaluation of a general population sample demonstrates the uniqueness of the human dentition beyond any reasonable doubt, thus placing the odontologist's statements about individuality beyond the realm of theory and into the realm of supported fact. The problem of uniqueness of the human dentition should now be of less concern than the second problem of whether there is a representation of that uniqueness in the mark found on the skin or other inanimate object.

The real concern now is the determination of the match between the dentition and the impression or bruising of the skin or other material. If the correlation is high between the dentition and the mark then there can be an assurance that no other set of teeth could have caused the mark, and that assurance can be justified as long as the individual tooth marks are within a ±1 mm by center point and a ±5° angle variation of each individual tooth.

Although those standards are strict, the author has worked on criminal cases where there has been that degree of representation. Those measurements appear to be within the limits of actual observation. The direction of the future will be to test the observational limits and to develop a better understanding of the distortion that is often seen in actual bite mark cases.

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Address requests for reprints or additional information to
Dr. Raymond D. Rawson
4121 W. Sahara Ave.
Las Vegas, NV 89102