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A Technique to Capture, Analyze, and Quantify Anterior Teeth Rotations for Application in Court Cases Involving Tooth Marks

ABSTRACT: Anterior teeth within the human dentition have a specific numerical rotation value. Bite marks show an array of angled indentations, abrasions, microlacerations, and contusions. These marks generally represent the incisal surfaces of the suspect's dentition reflecting the rotation values of the teeth in the dental arch. This study described a method for capturing and analyzing anterior dental rotations. The rotations of individual anterior teeth within the study population were categorized as common, uncommon, and very uncommon according to Allen's classification. In the absence of a large number of incisal patterns present in a bite mark, a single but heavily weighted tooth rotation could be of equal discriminatory potential to several common rotation values. No prevalence studies quantifying individual tooth rotations are available. The measurement of each individual tooth rotation together with its individual discrimination potential will enhance the evaluation of the concordant features observed in bite marks.

KEYWORDS: forensic sciences, odontology, tooth rotations, metric analysis, tooth marks, court cases

Anterior teeth within the human dentition have a specific numerical rotation value. Bite marks found at crime scenes show an array of angled indentations, abrasions, microlacerations, and contusions. The tooth patterns observed on skin and in inanimate objects generally reflect the incisal surfaces of the suspect's dentition and reflect the rotation values of the teeth present in the dental arch. Bites thus inflicted are inadvertently left as clues at crime scenes, and can be used to convict or exonerate suspects (1,2). Skin bite marks are generally present on the body of the victim and inflicted by the assailant, but in some cases the wounds are self-inflicted or inflicted by the victim on the assailant (3). A variety of foodstuffs and inanimate objects with bite marks have been investigated as part of crime scenes, *inter alia*, cheese (4,5), a pink iced lamington (6), chocolate (7), bread sandwich (8), apples (9), and a bullet (10). The bites may be inflicted as a result of differing degrees of anger, revenge, sexual frustration, wrath, righteous indignation, and punishment (11). The location of the tooth marks observed on victims is related to the nature of the crime e.g., sexual assault, child abuse, burglary, or kidnapping (12). It has also been shown that in 48% of cases where tooth marks are involved, multiple marks were present (13). Suspects can be physically linked to or exonerated from crime scenes through fingerprints, DNA samples, and tooth marks (14). The validity of DNA evidence is, however, regularly challenged, and the role of tooth marks as substantive evidence is thus of great importance.

The following dental features have been cited in the literature as useful in tooth mark examination and comparison: crowding, rotated teeth, asymmetry, pathological displacement (15), extracted, unerupted, and filled teeth (16), attrition and grooves on incisal edges (17), supernumerary teeth, fractured teeth, diastemas (18), and relative position of one tooth to the next (19). Dental arches may contain one or a combination of the above features, but there is always some degree of dental rotation present within the anterior arches. The accurate measurement of each individual tooth rotation within the anterior arch makes the matching of tooth marks found on victims to the dentition of the possible suspects possible. Teeth rotations in the anterior dentition may be the result of physical trauma, discrepancies in the relationship between tooth size and arch size (20), late incisor crowding (21), emergence of the third molars, severe periodontitis, and other pathological conditions like cleft lips and agenesis of teeth (22,23). No prevalence studies quantifying individual tooth rotations are available.

The aim of this study was to develop a technique that could accurately record and measure individual tooth rotations in the anterior dental arch and classify them according to their occurrence within a specific population.

Materials and Methods

The research was conducted in the Bronkhorstspruit area of South Africa. The volunteer profile reflected the age, race, and sex ratios established by the population census of 1996. The sample consisted of 155 men and 145 women aged between 16 and 75 years old. The majority numbering 87 were between 25 and 34 years old. To achieve the required ratios, selected institutions were targeted. These institutions were approached at least 2 weeks before the envisaged sampling date. During the initial contact, the relevant person or persons were briefed on all the aspects of the research project. They were then given a week to consult with shareholders, foremen, workers, and employee unions and to confirm their participation or not in the project. They were also asked to explain the essence of the research project to all participating

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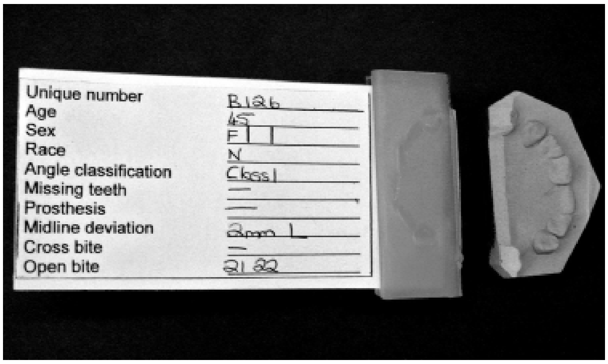

FIG. 1—*Wax wafer with information label attached to upper surface.*

individuals. On confirmation of their participation, dates, times and venues were arranged. Only oral consent was deemed necessary as the procedure maintained patient anonymity and was non-invasive. This was in accordance with the guidelines on ethics in biomedical research, determined and published by the South African Medical Research Council in 1993.

Wax wafers were used to record the anterior teeth in which tooth rotations and a selection of other dental features could be analyzed. The wax wafers used were a modification of the technique used by Rawson et al (24). They consisted of pink dental modeling wax No. 4 (Associated Dental Products Ltd., Purton, Swindon, England) folded double and bent around one side of a cardboard strip. On the remaining cardboard, a label was applied and glued down using Pritt glue (Henkel KgaA, Dusseldorf, Germany) for recording the unique number, age, gender, race, angle classification, missing teeth, prosthesis present, midline deviation, cross bites present, and any teeth with an open bite as shown in Fig. 1. The reverse side of the label was used to document any additional notes. The standard wax wafer had a wax-biting surface, which measured 25 mm × 60 mm and was 6 mm thick. The wax sheets were 1.5 mm thick but were folded double and then around the cardboard, giving a total thickness of 6.15 mm. The cardboard measured 55 mm × 115 mm and was 0.15 mm thick. The labels measured 50 mm × 88 mm and were glued down during the construction of the wax wafers A wooden tongue spatula with custom-made metric analysis labels was used to measure selected features during the examination as shown in Fig. 2. In the case of individual homes, the entire process was carried out in one visit. Individual homes were only targeted when specific age, race, and gender groups were under-represented in the sample. The houses targeted were determined with the help of local residents.

The bites were taken at a central point, which was convenient to both researcher and management. Where possible, an inside, well-ventilated venue was chosen. It was found that taking the bites around midday, between 10:00 AM and 3:00 PM, when the ambient temperature was higher, was advisable, as the wax was warmer and therefore easier to work with. The research was carried out during the months of October to March, which are summer months in the southern hemisphere, and thus rather warm. It was observed that volunteers, who wore full dentures, generally found it difficult to bite sufficiently hard enough to leave good prints. It was thus standard practice to warm, the wax for all denture wearers prior to biting.

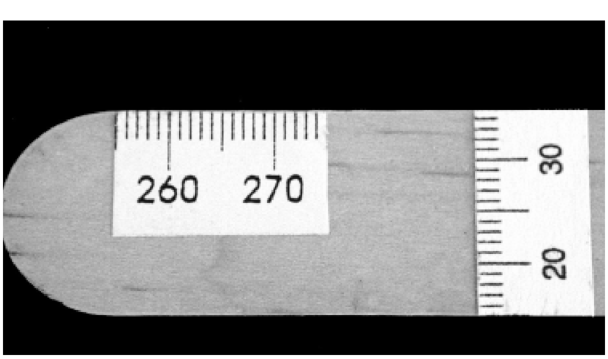

FIG. 2—*Wooden tongue spatula with custom-made metric analysis labels.*

After the volunteer had bitten into the wax, the quality and clarity of tooth marks were inspected. Where necessary, the bite was repeated. The operator assisted the volunteers throughout the procedure. All tooth registrations at a given venue were carried out on the same day to avoid volunteer duplication. Approximately 25 examinations and tooth mark registrations were carried out per hour. On completion of the sample collection the bite wafers were stored in a cooler box with ice bricks.

After each session the bite registrations were transported in a cooler box to Highveld Dental Laboratory in Middelburg, Mpumalanga. The wax bites were treated with a wetting agent, WAX-IT (Dugussa Dental, Hanau, Germany) before the stone was poured. Plaster models of the registrations were cast from Gyproc ultra hard yellow stone, type 3 (Pre Vestdenpro Ltd., Digiana, Jammu, India). These models were marked with the same unique numbers as the bites. The models were stored as pairs on the wax-bite registrations. A digital image of each cast was created with the use of an Olympus SZ-CTV stereomicroscope (Olympus, Tokyo, Japan) and a Nikon COOLPIX 950 digital camera (Nikon, Tokyo, Japan). The models were positioned on a glass slab with the help of Prestik (Permoseal (Pty) Ltd., Cape Town, South Africa) in such a manner that the occlusal plane was parallel to the focal plane of the microscope. The glass slab was shifted horizontally until the model was positioned under the objective. The models were illuminated with a double fibre-optic HIGHLIGHT 2000 light source (Olympus Optical Co., Hamburg, Germany). The two flexible arms were positioned to obtain the best image with optimal shadowing at a brightness setting of approximately two on a scale of zero to five. A linear scale was placed next to, and in the same plane as the incisal edges of the teeth on the model and held in position with Prestik (Permoseal (Pty) Ltd). The digital images of the anterior upper and lower teeth were then transferred to a computer and analyzed with AnalySIS 3.0 Software Imaging System (Soft imaging System GmbH, Munster, Germany). Functions within the analysis program were used to assist in the metric analysis of the features. The lines used to measure each feature could be the same color, or vary from tooth to tooth as required. The color combinations used remained constant throughout. PhotoImpact, a 32-bit image editor was used to manipulate the image where necessary (Ulead systems Inc., Taipei, Taiwan). An Excel data sheet was used for the initial capture of the data.

A rotated tooth was defined as one with a mesial or distal rotation around its long axis. The degree of rotation was determined by the angle created by a line joining the mesial and distal incisal edges of each tooth and a cord on the linear curve created by joining the anterior teeth from canine to canine. The linear curve was constructed to pass through the cusp tip or central facet area of both canines, and a point between the central incisors, determined by the mean anterior/posterior position between the central incisors. The line joining the mesial and distal incisal edges of each tooth and the cord always shared a common point on the linear curve as demonstrated in Fig. 3. Teeth positioned out of the

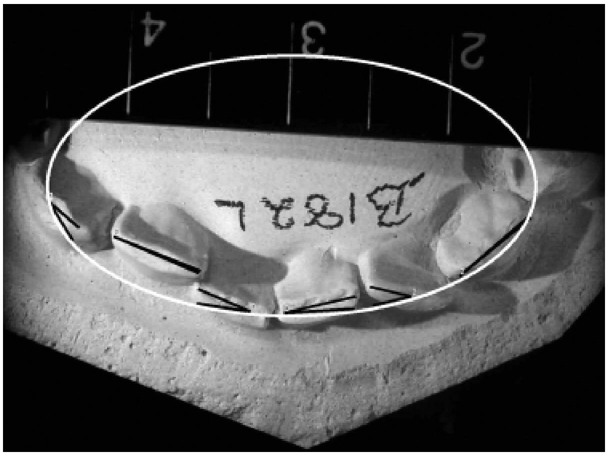

FIG. 3—*Dental model demonstrating the analysis of individual tooth rotations.*

arch were analyzed in the same way except that the cord was positioned parallel to the arch and not on the arch. Mesial rotations were documented as positive, while distal rotations were recorded as negative.

TABLE 1—*Illustrates the mandibular teeth of female Negroids aged between 15 and 35 years.*

Upper Teeth	*n* Value	Mean	Standard Deviation	Minimum Value	Maximum Value
Right canine	50	4.94	13.53	− 26.000	+75.00
Right lateral incisor	50	− 0.50	9.70	− 22.00	24.00
Right central	50	0.60	9.18	− 27.00	19.00
Left central	49*	− 0.16	8.63	− 16.00	21.00
Left lateral incisor	50	− 0.08	9.23	− 24.00	35.00
Left canine	50	3.86	8.98	− 12.00	36.00

* Left central was absent in one volunteer.

TABLE 2—*Illustrates the mandibular teeth of male Negroids aged between 15 and 35 years.*

Lower Teeth	*n* Value	Mean	Standard Deviation	Minimum Value	Maximum Value
Right canine	73	0.7	8.22	− 38.00	21.00
Right lateral incisor	72*	0.64	6.63	− 22.00	22.00
Right central	73	1.64	8.64	− 23.00	23.00
Left central	73	1.95	7.37	− 14.00	19.00
Left lateral incisor	73	0.32	7.98	− 18.00	16.00
Left canine	73	0.01	4.96	− 19.00	32.00

* Right lateral incisor was absent in one volunteer.

The tooth rotation values were determined for different age race and gender groups. Two age groups, namely 16 to 35 years and 35 years and older were used to determine the mean, standard deviation, minimum (negative distal rotations) and maximum (positive mesial rotations) values of rotation for each of the anterior teeth. The mean, standard deviation, minimum and maximum degrees of rotation for gender and race were also determined. The 1, 5, 95, and 99 percentiles for dental rotations of each tooth within the anterior dental arch were determined for the group. This was then used to classify the degrees of rotation as common, uncommon, and very uncommon events according to Allan (25). Accordingly, an event that occurred equal to or less than five times out of a 100 possible events was regarded as an uncommon event, and an event that occurred equal to or less than one time out of a 100 was a very uncommon event. Events occurring more than five times out of a 100 were thus regarded as common.

An analysis of variance (ANOVA) program was applied to rotation values to determine the effect of race and gender. Statistical differences, p values ≤ 0.05 were noted and highlighted.

Results

This technique allowed the operator to metrically determine the rotation of individual teeth within the upper and lower dental arches.

For volunteers between 15 and 35 years -52° and $+75^\circ$ represented the extreme rotation values in the lower arch, whereas for volunteers above 36 years -39° and $+35^\circ$ represented the extreme values in the lower arch. For volunteers between 15 and 35 years -80° and $+50^\circ$ represented the extreme rotation values in the upper arch, whereas for volunteers above 36 years -35° and $+48^\circ$ represented the extreme values in the upper arch.

The mandibular teeth of female Negroid aged between 15 and 35 years had a minimum rotation value of -27° and a maximum value of $+75^\circ$ and a mean value of 0.62°, Table 1. Male Negroid in the corresponding age group had a minimum rotation value of -38° and a maximum value of $+32^\circ$ and a mean value of 0.88°, Table 2. Similar data were available for the other Negroid age groups as well as the Caucasian male and female age groups.

The common, uncommon, and very uncommon values of tooth rotations observed in the upper and lower teeth in the research sample are illustrated in Tables 3 and 4.

The results of the ANOVA analysis to determine the statistical differences, p value ≤ 0.05 of race and gender are illustrated in Tables 5 and 6.

Discussion

The need to determine accurately the frequency of selected dental features for application in forensic dentistry is well documented (13,26–29). The prevalence of individual anterior tooth rotations within the South African population has never been

TABLE 3—*Common, uncommon, and very uncommon values of tooth rotations observed in the maxillary six anterior teeth in the research sample (n = 300).*

Upper Teeth	Very Uncommon Negative Rotation Values	Uncommon Negative Rotations Values	Common Rotation Values	Uncommon-Positive Rotations Values	Very Uncommon-Positive Rotation Values
Right canine	< -34	-34 to < -16	≥ -16 to <15	≥ 15 to ≤ 34	>34
Right lateral incisor	< -22	-22 to < -15	≥ -15 to <15	≥ 15 to ≤ 24	>24
Right central	< -27	-27 to < -16	≥ -16 to <15	≥ 15 to ≤ 23	>23
Left central	< -16	-16 to < -13	≥ -13 to <19	≥ 19 to ≤ 24	>24
Left lateral incisor	< -24	-24 to < -15	≥ -15 to <16	≥ 16 to ≤ 29	>29
Left canine	< -39	-39 to < -10	≥ -10 to <17	≥ 17 to ≤ 32	>32

TABLE 4—*Common, uncommon, and very uncommon values of tooth rotations observed in the mandibular six anterior teeth in the research sample (n = 300).*

Lower Teeth	Very Uncommon Negative Rotation Values	Uncommon Negative Rotations Values	Common Rotation Values	Uncommon Positive Rotations Values	Very Uncommon Positive Rotation Values
Right canine	< -11	-11 to <0	≥ 0 to <28	≥ 28 to ≤ 47	>47
Right lateral incisor	< -25	-25 to < -17	≥ -17 to <12	≥ 12 to ≤ 20	>20
Right central	< -25	-25 to < -17	≥ -17 to <12	≥ 12 to ≤ 20	>20
Left central	< -26	-26 to < -16	≥ -16 to <12	≥ 12 to ≤ 18	>18
Left lateral incisor	< -48	-48 to < -28	≥ -28 to <10	≥ 10 to ≤ 18	>18
Left canine	< -11	-11 to < -0	≥ -0 to <17	≥ 17 to ≤ 35	>35

documented. It was previously not possible to estimate the possibility of occurrence of anterior tooth rotation values with any level of certainty when giving evidence in bite mark–related court cases. Tooth marks are not always clear, and are usually caused by only a limited number of teeth. In the absence of a large number of features present in the bite mark, a single but heavily weighted feature could be of equal discriminatory potential to several common features in linking a suspect with a bite mark (30). Researchers regard individual features to carry equal weight as no statistical evidence on the frequency of specific features is known within the respective population groups. Forensic odontologists usually rely on their experience when weighting features, a practice which can be questioned and challenged in a court of law. In order to establish the perpetrator of tooth marks, the probability of another individual showing the identical print or combination of features must be beyond any reasonable doubt. Identity is highly probable when sufficient similarities, coupled with no unexplained differences, are noted in the compared entities. In the analysis of tooth marks no exact figure has been established for "sufficient similarities." The scientific approach has been to estimate the minimum number of concordant features that is large enough to remove the risk of duplication beyond the statistical confidence limit and into practical negligibility. Acharya and Taylor (30) do not support the concept of a fixed number of concordant features in the identification of forensic suspects. They state that each case should be analyzed on its individual merits, and identification established irrespective of the number of concordant features present. The number of concordant features can therefore vary from one unique feature to several common features (30).

No physical feature is in itself unique (31). For a feature to be truly unique, it would have occurred in only one particular individual. On the other hand, while never unique *per se,* any given physical feature does possess a certain distinguishing quality or discrimination potential according to its frequency of occurrence. The occurrence of dental features varies from country to country as well as within different age, race and gender groups (31). In addition, the dentition of any individual will change with time. In an affluent society with ready access to orthodontic treatment, the incidence of tooth rotations within the dental arches would be expected to decrease. In this study the spectrum of socioeconomic groups was wide, and the effect of orthodontic treatment was considered to be minimal. This study quantified the rotations present and did not investigate the cause of rotations. Dentures wearers were included in the study, as they could not be excluded as possible suspects in bite mark–related crimes. Many of the dentures examined were old, with large tooth chips, teeth missing, and gold metal clips placed interproximally between the central incisors for aesthetic purposes, and these features would be interpreted in tooth mark cases as uncommon or very uncommon features. In an attempt to construct natural looking dentures, dental surgeons routinely rotate anterior teeth, and these rotations would be measurable in a bite mark.

During the biting process, it is the tooth's incisal surface, or cutting edge, that produces the characteristic pattern (32). The analysis of the dental rotations in this study was in fact an analysis of the incisal surface rotations of the individual anterior teeth, thus simulating the analysis of the rotations observed in tooth mark cases.

The digital images created with the aid of the stereomicroscope and digital camera created an accurate and reproducible method for recording, storing, and measuring dental study models. The technique reduced the problems associated with space and cost involved in the long-term mass storage of dental study models. It also eliminated the possibility of model fracture. A linear scale was included during the digital capture of each image so that the images could be calibrated for analysis of the study models. The software program allowed for accurate, repeatable, user-friendly analysis. The program only required the operator to select the

TABLE 5—*Results of the analysis of variance (ANOVA) for upper arch rotations in different race and gender groups, measured in degrees, illustrating those values where p ≤ 0.05 with an asterisk.*

	Race			Gender		
Tooth Rotation	Mean Caucasian	Mean Negroid	*p* Value	♂	♀	*p* Value
Right canine	2.73	3.23	0.764	1.77	4.47	0.5589
Right lateral	−0.35	−1.64	0.5957	−1.40	−1.01	0.5632
Right central incisor	−0.13	2.94	0.0001*	2.57	1.22	0.2439
Left central incisor	−2.31	0.77	0.4850	0.11	−0.66	0.2306
Left lateral	−7.24	−5.43	0.5962	−5.76	−6.32	0.6847
Left canine	1.22	1.62	0.3256	1.43	1.55	0.1192

TABLE 6—*Results of the analysis of variance (ANOVA) for lower arch rotations in different race and gender groups, measured in degrees, illustrating those values where p ≤ 0.05 with an asterisk.*

	Race			Gender		
Tooth Rotation	Mean Caucasian	Mean Negroid	*p* Value	♂	♀	*p* Value
Right canine	−0.74	1.59	0.2811	0.30	1.40	0.9908
Right lateral	1.29	0.57	0.9656	1.67	−0.12	0.1593
Right central incisor	0.35	0.98	0.9314	1.29	0.22	0.9281
Left central incisor	2.53	1.21	0.0479*	1.72	1.57	0.0934
Left lateral	0.98	0.51	0.9332	0.81	0.50	0.7426
Left canine	−0.42	1.38	0.1465	0.40	1.19	0.8741

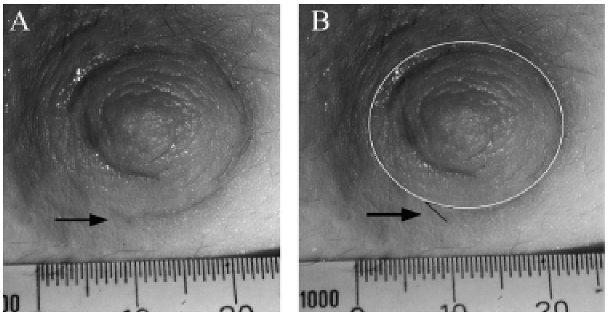

FIG. 4—*Skin bite mark on left nipple of rape victim. (A) The tooth mark of 32 clearly rotated within the arch indicated by arrow. (B) The rotation of the 32 is metrically analyzed by the described technique (arrow).*

appropriate points to be measured, which greatly enhanced the accuracy of the model analysis. Linear curves could be constructed in an accurate and repeatable manner, allowing for the analysis of tooth rotations within a standardized dental arch. The analytical lines used by the program to measure the rotations could be the same color or vary in color from tooth to tooth. The color combination remained constant indicating the sequence of analysis. Having all images digitized, allowed the operator immediate access to all previously analyzed images.

The frequencies of individual dental rotations were documented. The 1, 5, 95, and 99 percentiles were determined for each of the anterior teeth. These percentiles were used to classify the rotation values according to Allan's classification of common, uncommon, and very uncommon events (25). The rotation of each tooth in the bite mark can be determined and compared with the rotation of each tooth in the suspect's dentition. The rotation values can then be classified according to the frequencies within the respective populations as demonstrated in Tables 2 and 3. The results of this study will enhance the ability of forensic dental experts to accurately demonstrate the concordance of individual tooth rotations present in the tooth marks. It will also weight each individual rotation, thus enhancing the level of probability of a match or mismatch in each case. In the case of tooth marks left in inanimate objects, metric analysis of rotations can be performed with a higher level of accuracy. Practical experience in numerous cases with tooth marks in skin has shown the value of measuring rotations. A case study is included to demonstrate the technique. A bite mark on the left nipple of a rape victim clearly shows a rotated 32, which is metrically analyzed by the technique described. According to the data in this research sample, this rotation value could be regarded as uncommon; see Figs. 4 and 5.

FIG. 5—*Model of suspect illustrating the concordant rotation of 32.*

Conclusion

This research was a direct result of the increase in violent crime and the concurrent increase in court cases in which evidence included marks caused by rotated anterior teeth. It was a consequence of the inadequacies experienced by the author when testifying in such cases.

The sample of 300 volunteers is not large enough to be regarded as fully representative of the population studied. The results are therefore an indication of the rotation values of this sample and must be followed up by a much larger research project. This research however lays the groundwork for further investigations.

The frequency of dental rotations will no longer be based on intuition and years of experience, but will be scientifically based. Computer technology has made it simpler to record, calibrate, analyze, and store dental images accurately. Scientifically based knowledge of the frequency of anterior dental rotations in a specific population will make a substantial contribution to the discipline of Forensic Dentistry.

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