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Bitemarks

THREE DIMENSIONAL ANALYSIS AND COMPARISON OF HUMAN ANTERIOR TEETH AND EXPERIMENTALLY CREATED BITEMARK DEPRESSIONS*.

Análise tridimensional e comparação dos dentes anteriores e registros de marcas de mordidas produzidos experimentalmente.

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ABSTRACT
A system was proposed to scan dental models to record three-dimensional features seen in the anterior teeth to create a database of dental profiles. Dental casts were randomly selected to create indentations in cowhide leather. Reid Bite Reader was used to measure the bite forces generated by Reynolds Controlled Bite Force Generator to make the teeth impressions. Using the Immersion MicroScribe® 3D, information from the 53 bitemark depressions and 62 sets of dental casts were transferred to an Excel Spreadsheet. Software was developed to perform the 3D comparison using metric and pattern analysis. Statistical analysis showed 100% success when comparing both arches together of the dental casts with the bitemarks or different dental casts.

KEYWORDS
Forensic odontology; Bitemark; Three-dimensional analysis.

INTRODUCTION

An important role of the forensic odontologist is to analyze bite marks for the purpose of obtaining criminal evidence. In many cases the bite marks are essential to the resolution of the investigation[1-5].

Johnson et al. (2008)[6] have proposed a system to scan dental models to record two-dimensional and three-dimensional features seen in the anterior teeth. This information can theoretically be used to create a database of dental profiles.

One of the forensic dentistry dilemmas is to confirm that each person has a unique dentition[3-11]. Metcalf et al. (2008)[7] suggested the use of a MicroScribe® 3D scanner to investigate the uniqueness of the human dentition.

Tooth depressions in human skin occur at bite infliction and remain for varying periods of time. In the living the marks may fade, disappear altogether, or become raised in an inflammatory response. In deceased individuals' skin tooth indentations may remain until decomposition of the tissue[12-15].

In the cases in which the depressions made by teeth remain the model made from the bitemark impression can be very useful for analysis. The resulting model shows the curvature of the surface bitten, that may not be apparent in two-dimensional photographs[16,17]. Wright and Dailey (2001)[18] stated that the process of creating a 2D image from a 3D object leads to loss of information[7,10].

MATERIALS AND METHODS

Dental Models and Depressions on Leather

Fifty-three dental models were selected to make the indentations from sixty-two dental casts mounted on Hanau articulators from a New Mexico population of individuals between the ages of 20 and 80 years. The criteria were the presence of three or more teeth from the first premolar to the contra lateral first premolar in each arch, absence of open bite and significant overjet. The nine non-selected dental casts were used as control.

Males represented 60% of the population and 40% were females. The population mean age was 49.91 years old.

A square of 10x10cm cowhide leather with a single layer thickness of approximately 0.5cm was doubled to simulate the folding of skin caught between upper and lower teeth in some biting scenarios. Also a square of the same dimensions as the leather of corrugated fiberboard with a thickness of approximately 0.4cm simulated the sub-epidermal tissue.

The leather was wetted by soaking in water for 30 minutes, the corrugated fiberboard was placed in the inside portion of the leather and both were doubled. Compressed air pressure was applied by each set of dental models for 15 to 30 seconds using the Reynolds Controlled Bite Force Generator (RCBFG), a device developed in the late 80's by Gerald Reynolds, DDS, D-ABFO. To utilize this device, it is necessary to have the dental casts mounted on a Hanau articulator. The Reid Bite Reader (RBR) developed in 2006 by Proctor and Gamble specifically for Jacqueline Reid, DDS, D-ABFO, for her scientific research project[19], and further used for bite force testing by Robin Scheper, DDS, D-ABFO[20]. The RBR was used to measure in pounds per square inch the bite forces generated and to calibrate the RCBFG setting required to consistently apply forces that created the teeth impressions into the leather. Reid's research[19] results show a human bite force mean value of approximately 83.66 pounds (37.9 kg) – Figures 1-3.

The RBR Manual protocols were followed[19]; the RCBFG was set to 25 psi and recalibrated after the creation of every three bitemarks. The forces measured by the RBR were between 72 and 86 pounds (32.7 and 39 kg). The indentations depth produced were approximately 2mm.

Figure 1 - Reynolds Controlled Bite Force Generator on the left and Reid Bite Reader on the right. The display shows the bite force in pounds.

Figure 2 – Creating the indentations.

Figure 3 – Teeth impressions into the leather.

Scanning Process

The Immersion MicroScribe® 3D Digitizer is portable and has an articulated arm with a tactile point tip with distance discrimination approaching 0.009" (0.23mm).

Prior to the digitizing, objects are fixed to remain undisturbed during the scanning process. If the object drifts the process must be reinitiated. The dental models or the leather and the MicroScribe® device were stabilized with three or more clamps in a flat surface[7,16]. An operator was trained to digitize the dental casts as well the depressions in the leather. This same operator scanned all dental models and the bitemarks utilized in this research[16].

The MicroScribe® Model G2X recorded the information from both the bitemark depressions and the dental casts into Microsoft Excel Spreadsheets using auto scan proprieties. Three models were rescanned with a MicroScribe® G2LX to evaluate consistency and reliability. The auto scan was set to capture points at 0.5mm intervals, resulting in an average of 3000 recorded points for each model arch and between 300 and 500 for each bitemark arch. Modifying the point capture distance to 0.2mm the number of points was doubled with some of the points significantly close and paradoxically, some large spaces with no point recorded. Using 1mm recorded intervals reduced to half the number of registered points. For this research the optimal results were obtained utilizing 0.5mm recording intervals – Figure 4.

Figure 4 – Microscribe ® Model G2X and dental model mounted on Hanau articulator are stabled with clamps.

A systematic method for digitizing from the first premolar to the contra lateral first premolar was developed: The point tip applied with light pressure touches the surfaces of the teeth or the indentations in the leather whenever the foot pedal is depressed. The whole of the tooth crown visible outside the gingiva is digitized. The X, Y and Z information from each recorded point is automatically transferred to the computer spreadsheet[7,21].

The patterned injury's dental depressions datasets were entered and considered to be the unknowns and the dental cast datasets considered to be the known. By the use of unique numbers, the data is entered automatically into the database. Eleven models were scanned twice to evaluate consistency. In the sixty-two sets of dental models two sets were from the same individual taken two years later than the original set. During the two year's period three anterior teeth were restored using dental composite restorative materials.

Grantos Bitemark Software

The Grantos Bitemark Software developed in 2008 by Alex A. dos Santos, BCS, and Cristina M. Dalle Grave, DDS, D-ABFO, and used in this study is available as freeware and can be downloaded from this link: www.grantosbitemark.autolyrix.com. The software performs the 3D comparison using metric and pattern analysis. Selected XYZ axis points recorded for each individual tooth and each tooth depression in the bitten substrate were analyzed. The dental data from the various models can also be compared.

The analysis images can be rotated into various orientations for viewing and to facilitate the examination. A comparison can be made between any individual point and another individual point or a combination of points. In addition, the display of points can be adjusted to show all the points, the most prominent points, or various different levels from the incisal to the cervical of the tooth's crown.

The software generates a report quantifying the statistical similarity of the two or more sets of data.

There are eight pre-programmed methods to compare a bitemark with sets of dental casts: Comparison between a specific bitemark's area and specific model's area (tooth Z1 at X1% height), mesiodistal angulation of tooth X1, area's center point between tooth X1 and next (tooth X2), area's center point of each tooth's area, area's center point between tooth X1 and contra lateral tooth X2, collision test of tooth X1 of model centered by tooth Z1 (of bitemark), distance between area's center point of tooth X1 and tooth X2, and distance between area's center point of tooth X1 and next (tooth X2). The software allows operators to choose between the manual mode and the automatic mode. In the manual mode, the user selects one or more methods of comparison. All the methods were tested separately and the best results were found with five combined methods presented in the automatic mode.

The software automatically superimposes the images of the bitemark and the dental cast. The smart tool initiates the comparison from the incisal/occlusal surface contact point (highest point or points) and moves in the direction of the gingival line; during the process the software recognizes each individual bitemark depression and associates it to the specific model's tooth.

The first method in the automatic mode is the evaluation of the center points between tooth X1 and next (tooth X2). The software measures the distance between the center point of one tooth and the adjacent tooth. In the second method the software measures the distance between the center point of one tooth and the contra lateral tooth. A collision test of tooth X1 of model centered by Z1 (of bitemark) is calculated by the number of model points inside of the bitemark area divided by the number of total bitemark points times 100. In the distance between area's center point of tooth X1 and the next tooth X2 method, the Pythagorean theorem is used to calculate a diagonal line between the two area's center points. Finally, the distance between area's center point of tooth X1 and tooth X2 method is used to measure the distance from each tooth center point to all other teeth center points.

Nine methods were used to compare the dental data from the various models to generate an index of similarity between different dental model data sets. Those nine methods include: Arch of highest point of each tooth, arch of center point of each tooth, center point between a tooth and its contra lateral tooth, faciolingual width of a tooth, distance between area's center point of tooth X1 and tooth X2, area of tooth X1 at X2% height, diastema between tooth X1 and X2 at X3% height, mesiodistal width of tooth X1 at X2% height, and mesiodistal angulation of tooth X1 at X2% height – Figures 5-7.

In the automatic mode between two dental casts or two bitemarks three methods are used. In the first method the software measures the distance between the area's center point of one tooth and the adjacent tooth forming an arch. The second method measures the distance between the area's center point of one tooth and the contra lateral tooth. Finally, the software measures the distance from each tooth's center point to all others teeth's center points.

This last feature may be used to support the uniqueness of the anterior human dentition.

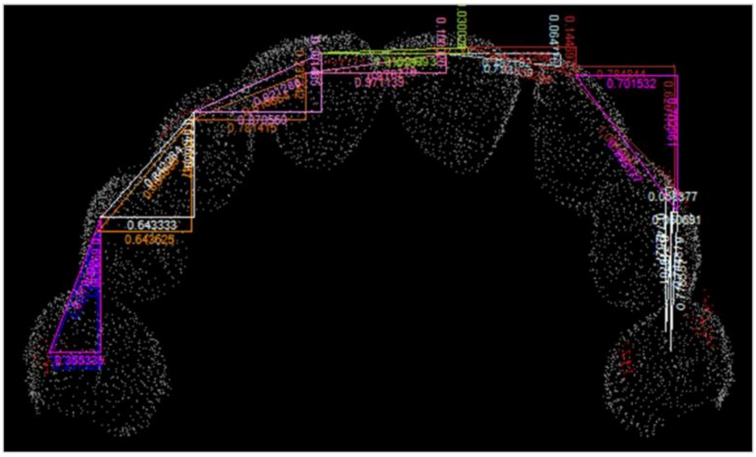

Figure 5 – Distance between area's center point of tooth X1 and the next tooth X2 method.

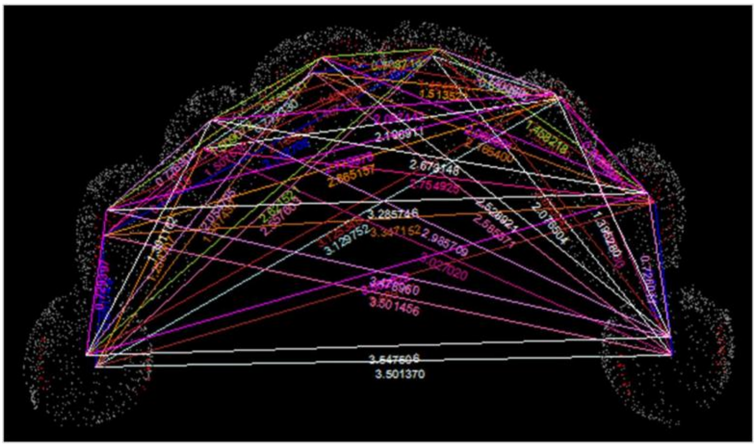

Figure 6 – Distance between area's center point of tooth X1 and tooth X2 method.

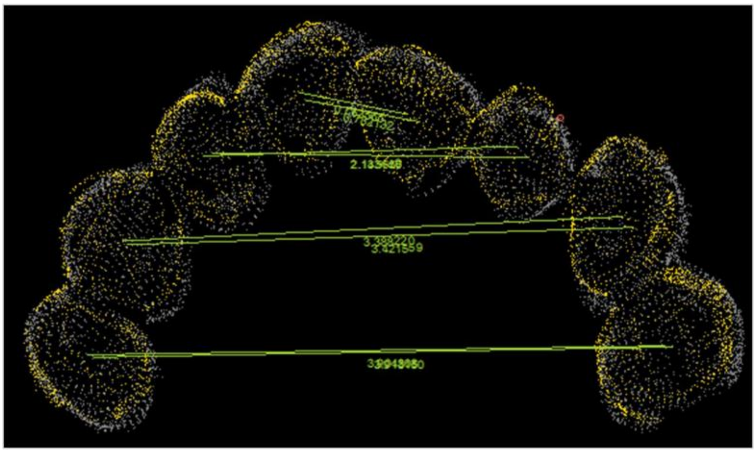

Figure 7 – Distance between the area's center point of one tooth and the contra lateral tooth method.

RESULTS

The features of the incisal and occlusal surfaces from the dental casts were transferred to the wet leather and the MicroScribe® 3D Digitizer was able to record accurate three-dimensional information from both depressions created by teeth and the teeth that may have created those depressions.

Blind testing with the bitemark and dental cast databases eliminated some forms of expectation bias which is very important in evidence based studies.

The resulting data were statistically evaluated when comparing the casts with bitemarks and casts with casts. Rates for four result types were calculated: true positive, false positive, false negative, and true negative. The true positive rate refers to the percentage of obtaining a match for casts and bitemarks or casts and casts that in fact do match. True negative rate is the percentage of obtaining a non-match for casts and bitemarks or casts and casts that do not in fact match. The false positive rate corresponds to the percentage of the occurrences in which the software considered a match for models and bitemarks or models and models that did not in fact match. False negative rate is the percentage of occurrences of a non-match for dental casts and bitemarks or casts and casts that were in fact matching[16].

The values of sensitivity represent the proportion of actual matches which are correctly identified as matches; and the values specificity refers to the proportion of non matches which are correctly identified as non matches. The optimum results are 100% sensitivity 100% specificity, a true positive rate of 100% and a false positive rate of 0%.

The results obtained in this study are expressed in Table 1 and Table 2. The sensitivity ranged respectively from 84% to 100% and from 63% to 100%; and the specificity ranged from 99.7% to 100% in both tables. The significant lower result (true positive of 63%) was found in comparisons of mandibular models. However, when both arches (maxillary and mandibular) were considered the accuracy was increased remarkably; the false positive rates were 0%.

A threshold was applied in all the comparisons of models and models.

The software was also able to recognize the two models from the same individual taken two years apart modified by anterior restorations and to associate both with the correct bitemark. Furthermore, the results for the models scanned with the G2LX MicroScribe® were not significantly different from the results for those scanned with the G2X device.

DISCUSSION

The features of the incisal and occlusal surfaces from the dental casts were transferred to the wet cowhide leather. Also, the three-dimensional information from the depressions on the leather and the dental casts were successfully recorded with the MicroScribe® 3D.

In this study, white stone models were utilized instead of yellow stone models, light pressure was applied to all tooth surfaces coronal to the gingiva with the stylus of the Microscribe® device, and some dental models were slightly damaged after using sharp metal tip from the device. For that reason, the protocol was to create the depressions in the leather first then subsequently scan the casts and the bitemarks.

Table 1 – Bitemark arches compared with models arches.

Bitemark Arches Compared with Models Arches			
	Maxillary Arch	Mandibular Arch	Maxillary + Mandibular Arches
*p** (True Positive)	59/67 (0.88)	56/67 (0.84)	67/67 (1)
p (False Positive)	8/67 (0.12)	11/67 (0.16)	4067/4067 (1)
p (False Negative)	8/4067 (0.002)	11/4067 (0.003)	0
p (True Negative)	4059/4067 (0.998)	4056/4067 (0.997)	0
Sensitivity	*p* (0.88) = 88%	*p* (0.84) = 84%	*p* (1) = 100%
Specificity	*p* (0.998) = 99.8%	*p* (0.997) = 99.7%	*p* (1) = 100%

p = Probability

Table 2 – Model arches compared with models arches.

Model Arches Compared with Models Arches			
	Maxillary Arch	Mandibular Arch	Maxillary + Mandibular Arches
*p** (True Positive)	16/16 (1)	10/16 (0.63)	16/16 (1)
p (False Positive)	0/16 (0)	6/16 (0.37)	5990/5990 (1)
p (False Negative)	8/5990 (0.001)	15/5990 (0.003)	0
p (True Negative)	5982/5990 (0.999)	5975/5990 (0.997)	0
Sensitivity	*p* (1) = 100%	*p* (0.63) = 63%	*p* (1) = 100%
Specificity	*p* (0.999) = 99.9%	*p* (0.997) = 99.7%	*p* (1) = 100%

p = Probability

Generally, the approximate time required to digitize one arch of the dental cast with the Microscribe® device was between 15 to 20 minutes. Laser scanners are capable of capturing more points per unit area and are faster, with the scan times ranging between 10 seconds to 2 minutes.

False Positive and False Negative rates were higher in the lower arch results likely because of the higher degree of similarity among the mandibular dentitions. This also reduced the sensitivity values for those arches.

CONCLUSION

The results of this study indicate that when comparing the incisal surfaces, the position of the teeth and the arch shape of the anterior dentition of both maxillary and mandibular arches, the dentitions are in fact unique. Furthermore, the uniqueness of the dentitions was transferred to the impression media (cowhide leather).

The Grantos Bitemark Software is an efficient, rapid, and helpful tool, comparing two or more sets of metrics data. However, a forensic odontologist should scan the dental models and bitemark depression and interpret the results.

To evaluate the reliability of the software developed for this pilot study, larger sample tests must be performed. A large database may be created to further investigate the uniqueness of the human dentition or provide large datasets for analysis of frequency of occurrence of specific dental profiles. A laser scanner would improve the speed and ease of digitizing and the software can be configured to recognize the three-dimensional information from laser devices.

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RESUMO

Um sistema foi proposto para digitalizar modelos dentais para registrar características tridimensionais visualizadas nos dentes anteriores para criar um banco de dados de perfis dentais. Modelos dentais foram selecionados aleatoriamente para criar indentações em couro bovino. O *Reid Bite Reader* foi usado para medir as forças de mordida geradas pelo *Reynolds Controlled Bite Force Generator* para fazer as impressões dos dentes. Usando o Immersion MicroScribe® 3D, as informações das 53 depressões da marca de mordida e 62 conjuntos de modelos de gesso foram transferidas para uma planilha do Excel. O software foi desenvolvido para realizar a comparação 3D usando análise métrica e padrão. A análise estatística mostrou 100% de sucesso ao comparar os dois arcos dentais dos modelos de gesso com as marcas de mordida ou diferentes modelos de gesso.

PALAVRAS-CHAVE

Odontologia legal; Marcas de mordida; Análise tridimensional.

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