"Biometric Dental Rosette" - Introduction into New Method of Dental Identification

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Abstract. The hypothesis of the study was that human dentition is unique. This study was performed to analyze whether biometric methods using measurements and proportions are suitable for dental identification. The use of 3D models with specialized systems for computer aided engineering (CAE) and Reverse Engineering (RE) allowed for a number of point surface and volume comparative analyses. "Mapping" was carried out next on the dentition models. This procedure results in a set of curves and points depicting the characteristic features of the teeth and their edges respectively. Based on the "mapping" the so-called "biometric dental rosette" was created for the dentition models. The "biometric dental rosette" was created for maxillary and mandibular dentition models. Every rosette was individual thus unique. The method allowed for positive identification of all the volunteers. The presented studies are of preliminary character, and the continuation is necessary.

Keywords: Bitemarks · Biometrics · Forensic odontology · 3D modeling · Reverse Engineering · CAME – Computer Aided Medical Engineering

1 Introduction

The bitemarks are not rare in practice of forensic odontologists [8]. Aside from bite mark analysis being the most challenging it is also the most controversial of all the tasks assigned to forensic odontologists. The literature concerning bitemark methodology is

"Biometric Dental Rosette" – a term invented by the authors and used in print for the first time.

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sorely lacking in rigorous scientific testing [5]. It is recognized that an urgent need for high quality studies on bitemarks analysis is required [11, 13, 14]. Although an ideal method probably does not exist, the classical pattern analysis has been continuously developing, as have new computer-aided methods [2–4, 10, 12, 15, 20, 22]. In spite of extensive work in the field of forensic odontology, bitemark analysis has come under increasing scrutiny because of wrongful convictions [11]. The introduction of new, scientifically proven methods could facilitate bite mark analysis, help forensic experts avoid erroneous opinions and thus take away the arguments of opponents.

Many characteristics of human anatomy and physiology (fingerprints, iris, hand geometry and facial appearance) are considered to be unique. Thus, they are suitable for biometric recognition [16]. Biometrics (Greek: *bios* = *life*, *metron* = *to measure*) deals with the use of measurable anatomical, physiological and behavioral features. It includes automated methods of measuring and comparing of anthropometric and behavioral characteristics. The aim of biometrics is personal identification or verification based on the analysis of unique and constant features.

The most commonly known is identification based on the facial appearance. Literally this is what a child does when it recognizes the face of its mother. A mother and father can recognize their child perfectly from a distance, even if they are one of a pair of identical twins. The reason is not just the facial appearance. Although single distances between the characteristic points may be similar in many people, four or five distances as well as the proportions between them are unlikely to be identical.

Pretty [13] is of the opinion, that the studies are not required to determine the uniqness of the human dentition, but how it is represented within the bitemark. However, the basis of this study was the assumption that human dentition is unique. There is no proof that it is, but also no proof, that it is not. The uniqueness in term of human dentition means characteristic shape, size, and pattern, and any individual features within the particular arch (i.e. broken crown, a developmental malformation, anomaly in eruption) [6]. The single distances between the teeth and their dimensions can be similar in many people, however the series of measurements and the proportions between them seem to be appropriate for biometrical methods. Nonetheless, every method has its limitations, thus to apply biometrics to bitemark analysis, it must guarantee certainty.

The Computer Aided Engineering (CAE) systems are very well known by designers in their every day practice and numerical analysis. Many of engineering technologies, especially CAD/CAM techniques, have an application in biomechanics, bioengineering, biometrics [17–19] presently known also as Computer Aided Medical Engineering (CAME).

The study was performed to analyze whether biometric methods using measurements and proportions are suitable for bitemark analysis.

The scope of work includes the following elements:

– maneuvering of the 3D models of the tooth geometry to compare with the bitemarks left in the cheese,
– three-dimensional "mapping" of the position of the characteristic points of the teeth "biometric dental rosette",
– comparison of the "bite-in" profile with the bite mark line of mandibular teeth.

2 Materials and Methods

Registration of Volunteers' Dentition. Twelve adult volunteers of different gender and age were involved in the study. A standard dental examination was performed and dental records were created for every person. According to standard dental procedures the impressions of maxillary and mandibular teeth were made in order to prepare the gypsum models of the volunteers' dentitions.

Experimental Bitemarks. Experimental bitemarks were collected from every person involved in the study. The bitemarks were left on the previously prepared rectangular piece of medium-hard cheese (approx. 2 cm thick). The volunteers were asked to bite-in and bite-off a piece of cheese.

3D Scanning of Dental Casts and Bitemarks. Both, the gypsum models of the dentition and the bitemarks registered on the cheese were immediately scanned. The 3D scanning was performed using an optical scanner GOM Atos II Rev.01 with a measuring volume of 120 × 96 × 80 mm. The resolution of the camera was 1.4 megapixels. Distance between points during scanning was 0.18 mm.

The reference data for computational analyses were 3D models of the dentition and fragments of cheese with bitemarks (Fig. 1).

The 3D Analysis of Dentition Models and Bitemarks. The 3D analysis was performed with the use of specialized CAE programs (Computer Aided Engineering) as well as Rhinoceros 4.0 and Reverse Engineering software, as Geomagic Studio (a specialized program for processing and analysis of the models obtained from 3D scanners).

Creation of "Biometric Dental Rosette". The method comprises the following steps:

(1) development of a computer model of the dental arch - based either on data from a three-dimensional scanner (dental cast scanning) or on direct scanning within the patient's oral cavity;
(2) identification of the characteristic features (points) on the crowns of the teeth;

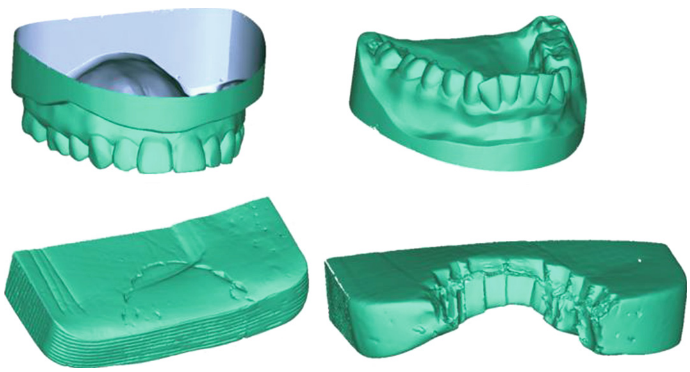

Fig. 1. 3D models of the dentition and fragments of cheese with bitemarks

(3) determination of a system of axes and reference planes - based on the characteristic points;
(4) determination of quantities characterizing the dental arch features.

As the result of the above steps is three-dimensional “Biometric Dental Rosette”.

3 Results

The use of 3D models, and specialized programs for computer aided engineering (CAE), allowed for a number of point surface and volume comparative analyses. Models obtained from 3D scanning are fully parametric, retaining all essential geometric parameters of their originals.

Implementation of individual analysis of 3D models is presented in the following sections.

3.1 Geometric Matching of 3D Models of Dentition with Bitemarks Left in the Cheese

Matching the 3D models of dentition with bitemarks left in the cheese was performed first. Matching was done separately for “bite-in” (Fig. 2) and “bite-off” marks (Fig. 3).

The ability to manoevre the dentition models and bitemarks in 3D space aided analysis of the indentations of the teeth into the cheese.

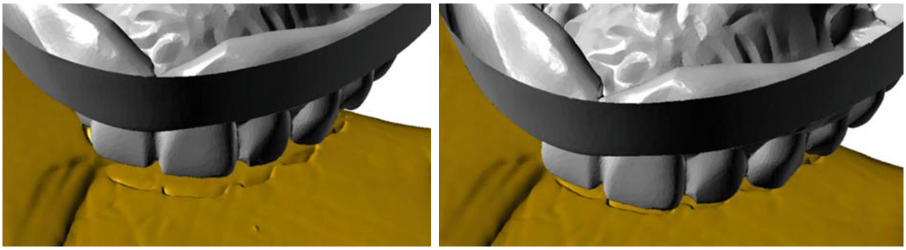

Fig. 2. Three dimensional matching of dentition with bitemarks for “bite-in” marks

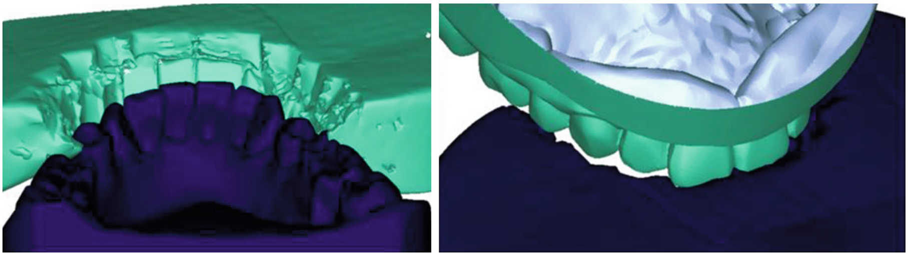

Fig. 3. Three dimensional matching of dentition with bitemarks for “bite-off marks”

Using 3D methods, 864 blind trials of matching the dentition models to the bitemarks were made. Every model of maxillary dentition was matched sequentially to every “bite-in” mark (to its superior and inferior surface-144 matches each) and to the superior surface of “bite-off” mark (144 matches). The models of inferior dentition were matched in the same way: every model was matched sequentially to every “bite-in” mark (to its superior and inferior surface-144 matches each) and to the inferior surface of “bite-off” mark (144 matches). Adjusting was conditioned by the type of the bitemark. The “bite-in” mark represents the edges of the maxillary (on the superior surface of the bitemark) and mandibular teeth (on the inferior surface of the bitemark). Because it is not always clear which surface of the bitemark is superior or inferior, both dentition models, the maxillary and mandibular, were matched to both surfaces of the “bite-in” mark. The superior surface of the “bite-off” mark represents the edges of maxillary teeth (an anchor), while on its inferior surface the profiles of mandibular teeth are visible. The inferior teeth penetrate deep into the material when the jaws are closed leaving behind marks on the material’s vertical surfaces along its entire thickness.

The edges of the maxilla and the mandible were transformed into the corresponding positions of the bitemark and the edges of the maxillary and mandibular incisors and canines as well as cusps of premolars were adjusted to the bitemarks in 1:1 scale.

In this 3D pattern comparison, the structure of several teeth, as well as the relationship to the surrounding teeth was compared. The width and shape of the maxillary and mandibular arches, width and shape of the projection of the incisive edges and cusps of the teeth, and other characteristics of the teeth (position, rotations and restorations) were analysed. This allowed conclusive results regarding the correspondence between the dentition and the bitemark to be made. Finally, every dentition model (maxillary and mandibular) was matched to corresponding “bite-in” and “bite-off” marks. This allowed for a positive identification to be made of all the 12 volunteers based on the bitemarks they left. Any comparison of the dentition characteristics of one person to the bitemark left by another person participating in the experiment was negative.

3.2 Three Dimensional “Mapping” of the Position of the Characteristic Features (Points) of the Teeth

“Mapping” was carried out next on both the dentition models and the bitemarks. This procedure results in a set of curves and points depicting the characteristic features (points) of the teeth and their edges respectively (Fig. 4). Based on the “mapping” the so-called “Biometric Dental Rosette” was created for the dentition models.

The “Biometric Dental Rosette” is initiated by the determination of the closing line (a straight line connecting the first characteristic point to the last one). Afterwards, the straight lines between points are plotted and extra lines between the centre of the closing line and the various characteristic points are spanned. An established “rosette” functions similarly to the so-called “Golden Triangle”, known for biometric systems used in face recognition. Similarly, the “rosette”, was created for bitemarks (Fig. 5).

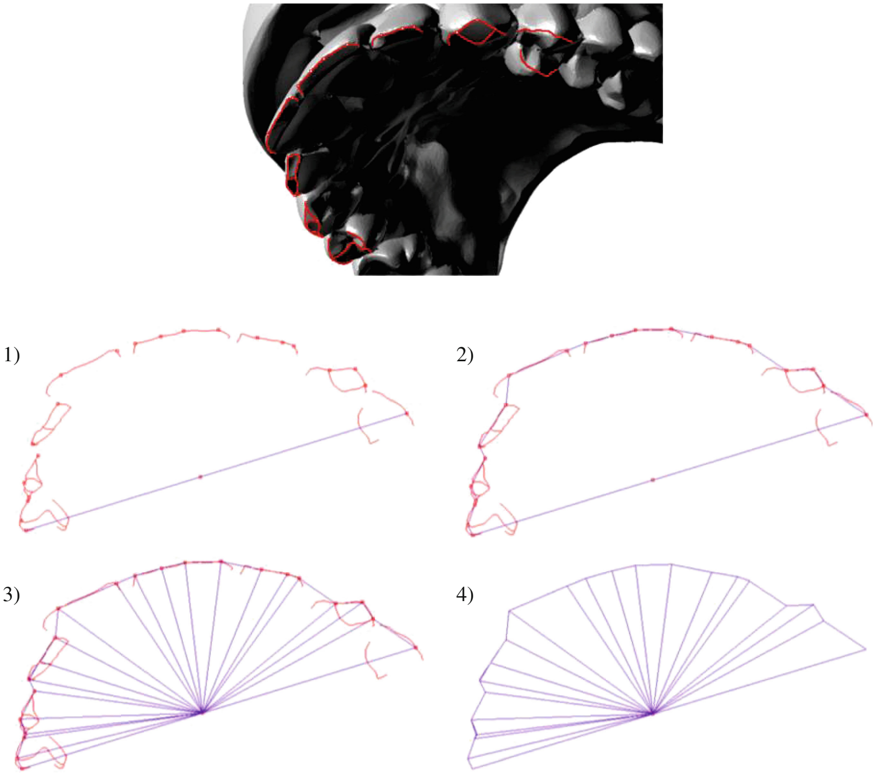

Fig. 4. "Mapping" the position of characteristic features (points and curves) of the teeth and stages of creating the three-dimensional "Biometric Dental Rosette": (1) characteristic features (points and curves) of tooth, (2) curve connecting characteristic points and closing straight line, (3) setting of rosette arms, (4) final "Biometric Dental Rosette".

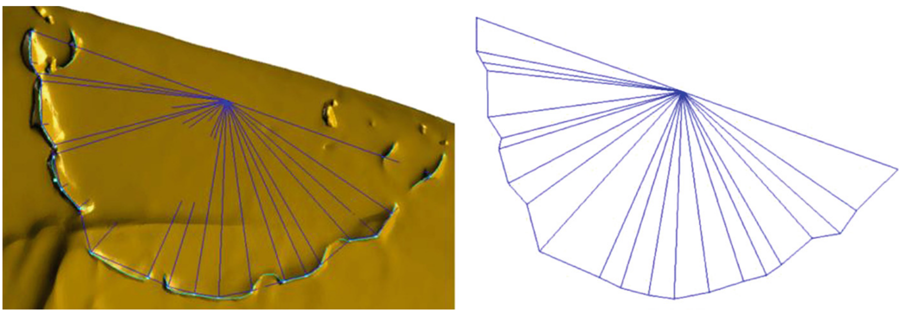

Fig. 5. "Mapping" the position of characteristic features (points and curves) of the bitemark and three-dimensional "Biometric Dental Rosette".

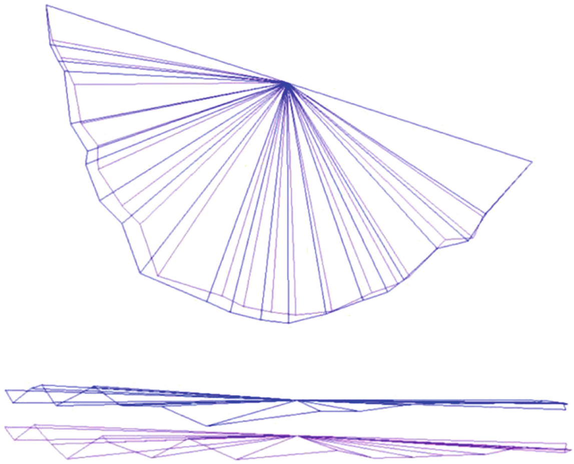

Fig. 6. The “Biometric Dental Rosette’s” comparison of the dentition and bitemarks

Finally, the “Biometric Dental Rosette” of the dentition was compared to the “Biometric Dental Rosette” of the bitemark (Fig. 6).

Data developed in this way include not only the coordinates of the characteristic points, but also the mutual distances between them as well as a whole range of proportions between the different parts of triangles. It is the entire complex of 3D data, as rosettes do not lie in one plane, but are absolutely 3D (three-dimensional) structures.

A total of 144 trials of matching were performed for the maxillary dentition and the superior surface of “bite-in” marks and another 144 trials were made for the mandibular dentition and the inferior surface of “bite-in” marks. All the individuals were positively identified as the biters. Any comparison of the dentition of one person to the bitemark left by another person was negative.

3.3 Comparison of the Profile of “Bite-in” Mark and the Profile of Mandibular Dentition

In this part of the experiment the models of mandibular dentition and corresponding “bite-off marks” (from the first step of the study) were used.

The 3D analysis was based on the reconstruction of both the bitemarks left in the cheese and the shape of teeth edges. For this part of study we were inspired by ballistic analysis. An analogy to cases comparing bullets fired from rifles and pistols seemed obvious. The analysis was based on an assumption that the trait left of the barrel on the surface of the bullet is unique in the same way that a bitemark is left by teeth on the surface of the cheese.

Transversely to the course of the bite line the plane was appointed and the curve of bitemark was plotted. Then, based on the curve, the projection (prolongation) of the bitten surface was made and its representation in 3D space was created (Fig. 7). The analogical procedure was made of the mandibular dentition (Fig. 8). The image

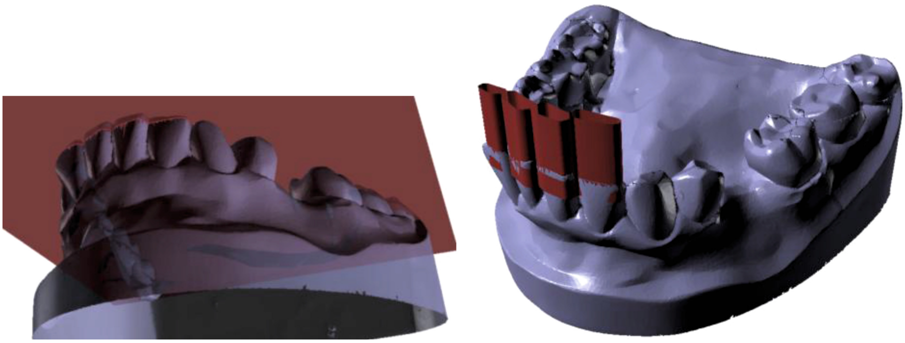

Fig. 7. Projection of the profile of mandibular dentition and their 3D representation

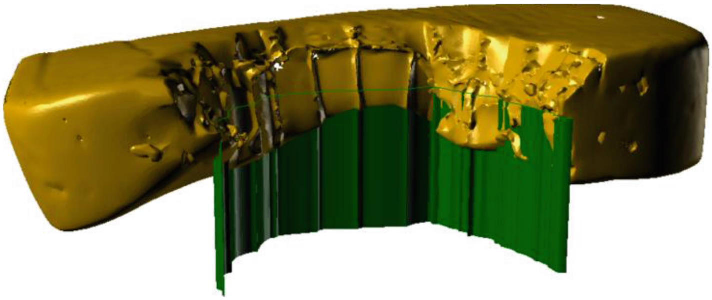

Fig. 8. Projection of the surface profile of "bite-in" mark on cheese

obtained in the space corresponds to the surface, theoretically left by the teeth if they had moved vertically from top to bottom.

Finally, both surfaces were superprojected and their concordance was analyzed (Fig. 9). In all investigated cases the correlation was observed, the more accurate the marks left by mandibular teeth, the higher the correlation.

4 Discussion

Any biological or behavioral characteristics could be used to identify individuals if it meets the following requirements:

(1) Collectability = accessibility (the element can be measured or easily acquired);
(2) Universality = availability (the element exists in entire population);
(3) Unicity = distinctiveness (the element must be distinctive to each person, the biometric characteristic should show great variation over the population);
(4) Permanence = robustness (the property of the element should be stable and remain constant over time) [7].

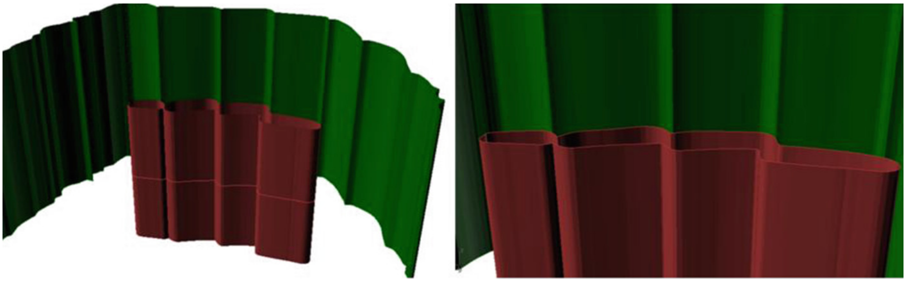

Fig. 9. Superprojection of the profile of “bite-in” mark and the profile of mandibular dentition

Contextually, the human dentition meets all the above requirements with a little controversion on its permanence. Considering the fact, that behavioral characteristics can change over time and it is not a precluding factor for biometric analysis, it can be concluded, that biometric methods applied for bitemark analysis have to accept some degree of variability.

What we consider advantageous is that all the presented analyses may proceed the standard bitemark analysis.

The “biometric dental rosette” may be created for maxillary and mandibular dentition models as well as for the bitemarks and appropriate number of matches can be performed.

The pairs of rosettes showing the highest concordance will show the dentition model and corresponding bitemark, making the identification of the biter possible. Likewise, the reconstruction of the bitten surface and the creation of the hypothetical surface left by the mandibular teeth, followed by the appropriate number of matches, will enable the mandibular dentition model to be matched to the corresponding bitemark. The maintenance of size and proportions of the original, both dentition model and the bitemark is an absolute condition for comparative analysis [21]. The first step in computer analysis of biological/medical objects is to obtain the correct and high accurate 3D model [17–19]. Models obtained from 3D scanning are fully parametric, retaining all essential geometric parameters of their originals.

The 3D models of scanned cheese reproduce the bitemarks with high resolution and are highly accurate. The bitemarks preserved by scanning were clear and legible.

The ability to maneuver the models in 3D space significantly facilitates bitemark analysis by allowing the assessment of bitemarks and the maxillary and mandibular arches from different angles. It also allows the depressions of the teeth in the material to be observed.

However, biometrics is not a perfect method [1, 9] and some limitations of our analysis should be discussed. Some inaccuracies in the implementation of computer models, as well as relations arising from the nature of food as well as the chewing process have to be emphasized. We also found the following elements affected the results:

- inaccuracy of mapping the geometry of the teeth caused by food elasticity;
- shortages of food elements caused by rupture of food by the action of shear forces between the teeth and food;

– inaccuracies in the reconstruction of the 3D model due to its recreation based on bitemarks and scanning of the gypsum model. The intermediate elements can be eliminated when the teeth directly, not their model are scanned.

It has to be emphasized that the presented studies are of preliminary character, and the continuation is necessary. The increase of the sample number and the trial to eliminante the imperfections of the methods are the most required.

Nevertheless, we believe that the introduction of "biometric dental rosette" is both legitimate and can of great benefit in the analysis of bitemarks.

5 Conclusions

All the above methods can be successfully used in the identification of the biter. The introduction of "biometric dental rosette" into bitemark analysis seems to be a scientifically reasonable idea. Further development of methods and their adoption in practice can be advantageous.

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