Pesquisa Brasileira em Odontopediatria e Clínica Integrada 2023; 23:e220087
https://doi.org/10.1590/pboci.2023.001
ISSN 1519-0501 / eISSN 1983-4632

CRITICAL REVIEW

3D Bitemark Analysis in Forensic Odontology Utilizing a Smartphone Camera and Open-Source Monoscopic Photogrammetry Surface Scanning

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Academic Editor: Alessandro Leite Cavalcanti

Received: 24 May 2022 / **Review:** 21 June 2022 / **Accepted:** 04 July 2022

How to cite: Kurniawan A, Chusida A, Utomo H, Marini MI, Rizky BN, Prakoeswa BFW, et al. 3D bitemark analysis in forensic odontology utilizing a smartphone camera and open-source monoscopic photogrammetry surface scanning. Pesqui Bras Odontopediatria Clín Integr. 2023; 23:e220087. https://doi.org/10.1590/pboci.2023.001

ABSTRACT

Bitemark analysis is a challenging procedure in the field of criminal case investigation. The unique characteristics of dentition are used to find the best match between the existing patterned injury and the suspected perpetrator in bitemark identification. Bitemark analysis accuracy can be influenced by various factors, including biting pressure, tooth morphology, skin elasticity, dental cast duplication, timing, and image quality. This review article discusses the potential of a smartphone camera as an alternative method for 3D bitemark analysis. Bitemark evidence on human skin and food should be immediately recorded or duplicated to retrieve long-lasting proof, allowing for a sufficient examination period. Various studies utilizing two-dimensional (2D) and three-dimensional (3D) technologies have been developed to obtain an adequate bitemark analysis. 3D imaging technology provides accurate and precise analysis. However, the currently available method using an intraoral scanner (IOS) requires high-cost specialized equipment and a well-trained operator. The numerous advantages of monoscopic photogrammetry may lead to a novel method of 3D bitemark analysis in forensic odontology. Smartphone cameras and monoscopic photogrammetry methodology could lead to a novel method of 3D bitemark analysis with an efficient cost and readily available equipment.

Keywords: Photogrammetry; Smartphone; Dentition; Identity Recognition.

Introduction

Forensic odontology is a branch of dentistry that employs dentists' expertise for law enforcement and individual identification [1,2]. The main concerns of forensic odontology include individual identification, injury analysis, patterned injury analysis, dental age estimation, and expert witness in court [3,4]. Biting is a dynamic process influenced by several factors, such as the maxilla and mandibular arch relation and movements, morphological characteristics of teeth, masticatory muscle forces, and the reaction of the bitten person [5,6].

According to the American Board of Forensic Odontology (ABFO), a bitemark is defined as a physical alteration or representative pattern recorded in a medium caused by the contact of the teeth of a human or animal. It is characterized by teeth and dental arches' features, traits, and shapes [7]. Apart from its primary function for biting and mastication, teeth are used occasionally as a weapon to attack another person and as a defense mechanism from an attack. The manifestation of bite marks on the skin is often related to sexual assault, child abuse, and domestic violence. Non-sexual bitemarks may be left on the arms, legs, fingers, hands, chest, and ears. Sexual bitemarks are usually localized on the breast, genitalia, nose, neck, abdomen, and cheek. In many criminal cases, bitemarks are occasionally found on foodstuffs (fruit, pizza, cheese, among others) and other materials, such as plastic and wood [8]. A central bruising area can be frequently seen within bitemarks due to the pressure created by the teeth, and extravascular bleeding caused by the tongue and suction movement may accompany the bitemark wound [9].

Bitemark analysis is a challenging proceeding in forensic identification and criminal case investigation. A forensic odontologist's responsibility is to manage the bitemark evidence, starting with the proper preservation, documentation, examination, and presentation in a court [10]. The uniqueness of human dentition is the fundamental aspect of bitemark analysis since teeth form the bitemark pattern in combination with other oral structures. Identification of bitemark pattern is based on two assumptions: first, each human dentition has a unique characteristic, and second, these traits leave a unique impression on the bitten materials. The scientific basis of bitemark analysis is performed by matching the existing bitemark with the suspect's dentition characteristics [11]. Bite mark analysis requires extensive scientific investigation keeping in mind objective principles while carrying out all procedures. Previous research has demonstrated that bite mark evidence is affected by the substrate onto which the pattern is transferred [12]. The skin is a poor material for recording teeth patterns compared to other modern materials as it is visco-elastic. Due to its inherent visco-elasticity, indentations from the teeth often rebound, affecting the quality of the recorded pattern [12].

One of the principal problems in bite mark analysis is the wide variety of techniques involving complex light sources, microscopes, and computer systems. Bite mark identification has significant value in investigations because biological and physical records are often subject to errors in recording. The use of bitemark photography has gained relevance in the forensic field, where film negatives were used to enlarge images to life-sized photos. Smartphone cameras these days can effortlessly capture high-resolution photos that can be used for various forensic studies. This review aims to analyze literature associated with the use of bite mark analysis and the benefits of using smartphones and monoscopic photogrammetry for forensic identification.

Basic Consideration of Bitemark Analysis

Bitemark is an injury in the skin caused by contacting teeth (with or without the lips or tongue), which shows the representational pattern of the oral structures. Bitemark evidence has played an essential role in the judicial system. In some criminal cases, bitemark is the only evidence to reveal the individual identity since the

bite pattern characterizes an individual. The appearance of bitemark on the human skin can be classified as partial bitemark, avulsive bitemark, multiple bite marks, and indistinct bitemark (also called *smoke-ring bitemark*") [13].

The scientific basis of bitemark identification is finding the best match between the bite pattern and the suspected dentition pattern [11]. According to the ABFO guideline for bitemark analysis, the evaluation of bitemark evidence includes examining the pattern, interpretation, comparison of the bitemark with the suspected dentition, and formation of opinion to conclude the analysis. Therefore, preliminary consideration is necessary when analyzing bitemark evidence, such as: was the injury being bitemark?; did human teeth cause it?; are there individual characteristics? [7].

Bitemark analysis is started by the appearance of the questioned pattern injury. First, it is necessary to determine whether humans or non-humans cause the injury. If the bitemark is caused by human dentition, the supporting evidence should be collected for an adequate examination.

A human bitemark is characterized by the mark that reflects the size, shape, arrangement, and distribution of the contacting surfaces of teeth. The contacting surfaces of human teeth include the incisal and occlusal surfaces and may also include the lingual surfaces of anterior teeth. The maxillary central and lateral incisors produced rectangular marks, with the characteristic of the central incisors being more prominent than those of the lateral incisors. The maxillary canines produce round or oval marks. The mandibular central and lateral incisors also produce rectangular-shaped marks with relatively similar sizes. The mandibular canines also create specific marks shaped as round or oval. In some cases, the suspect's bitemark might appear to have one or some missing teeth (unrecorded). This could happen due to shorter tooth size, or perhaps a clothing material prevents the teeth from coming into contact with the skin [9,14].

The most challenging stage of bitemark analysis is comparing bitemark evidence with the suspected dentition. Therefore, the decision of the bitemark analysis should be built based on the conclusion: dentition is excluded as having made the bitemark, dentition is not excluded as having made the bitemark, and inconclusive (Figure 1) [7].

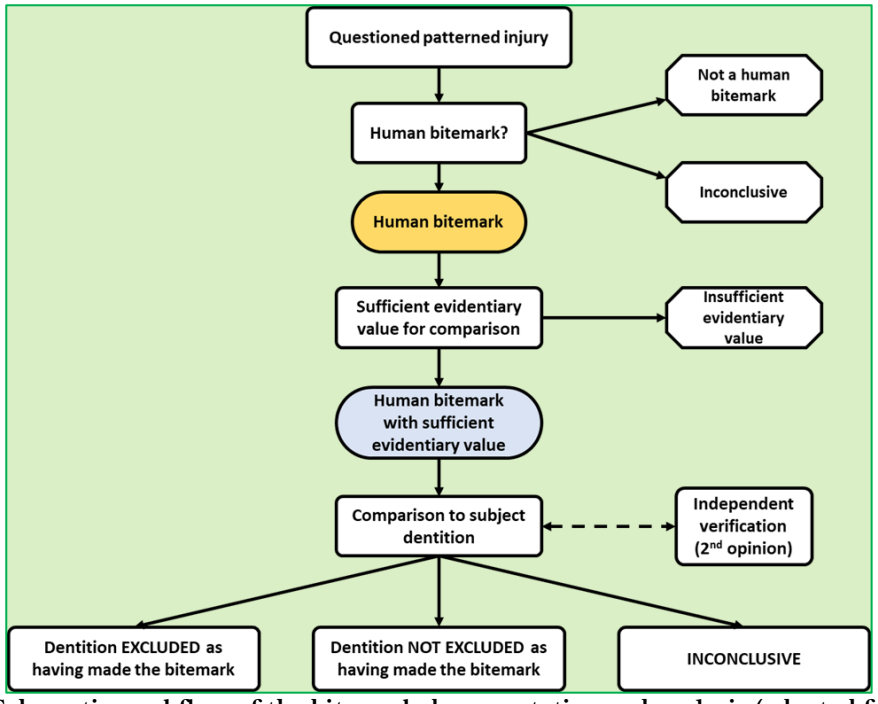

Figure 1. Schematic workflow of the bitemark documentation and analysis (adapted from ABFO Guideline) [7].

Bitemark Documentation

Bitemark evidence is impermanent traces left on some medium, such as food and human skin; food may decompose over time, and cutaneous wounds may recover. Therefore, forensic investigators should immediately record or duplicate the bitemark's impression. Several studies have been developed to obtain a quick and accurate method for recording, analyzing, and interpreting bitemark evidence.

In the study of bitemark analysis, ABFO suggests several materials to reproduce the bite impression, such as dental modeling wax, base plate wax, Styrofoam, and clay. Dental wax was selected as an impression material for bitemark analysis because of its ability to record bitemarks accountably similar to human skin [15]. Daniel and Pazhani [16] proved that the bitemark pattern was more accurately analyzed in chocolate and cheese than in apples. Kanaparthi et al. [17] also conducted a bitemark analysis on food and found that the use of food medium for bitemark study has several susceptibilities due to the shrinkage of food, food decomposition, and the influence of temperature.

There have been many significant improvements in the IT development in dentistry, including the dental imaging technique. The two-dimensional (2D) imaging technique was the most used in dentistry for radiographic examination and photographs. However, nowadays, the use of three-dimensional (3D) imaging techniques has gradually succeeded the use of 2D imaging techniques. 3D imaging technique offers an accurate, precise, and reliable analysis for treatment planning [18,19]. 3D technology in dentistry, such as intraoral scanners, is used to produce 3D data for multiple purposes like prosthodontics, orthodontics, and surgical treatment planning. In the forensic field, the intraoral scanner offers a possibility for individual identification, including bitemark analysis [15,17,20].

Imaging Technique for Bitemark Analysis

Dental imaging techniques are required to diagnose, plan, and implement dental treatment. However, dental imaging is also essential to assist the investigation and identification process in the forensic field. Various studies involving 2D and 3D imaging technology have been developed to obtain accurate and precise results of bitemark analysis [18,21]. An intraoral scanner (IOS) is a medical scanning device that can be employed for bitemark analysis. IOS offers a precise record of the 3D geomatics of an object with STL (Standard Tessellation Language) file format as one of the most commonly used digital format data [22]. The sensor captures the dental-gingival tissue image and then is processed in the 3D software to generate the 3D point clouds, resulting in a 3D model [23].

Most non-contact digital 3D scanners offer an accurate and precise image analysis; however, it requires a well-trained operator and cost high to be used in daily dental treatment and forensic identification [24,25]. Therefore, an alternative method should be suggested to overcome the expensive cost of the 3D scanner. Technological developments in recent years have led to the emergence of a new method of photogrammetry called structure from motion (SfM). The 3D photogrammetry technique may become an efficient and effective method of generating 3D models from 2D images using a daily camera, such as a smartphone camera [26]. In addition, this method provides fast and simple image capture and processing without radiation exposure to the subjects. A study by Utomo et al. [27] found that using a smartphone and its application, such as CAD Assistant, Exocade, and Adobe Photoshop Mix, is a suitable method for superimposing 3D models.

SfM is a technique that utilizes a series of 2D images to reconstruct the 3D structure of an object. SfM software will recognize and match standard features in numerous photos and generate a computerized, true-scale

3D model. Subsequently, this method gives a permanent, quantifiable 3D record of an object with a consumer-grade computerized camera and basic training to guarantee the overlap of photographs (Figure 2) [28,29].

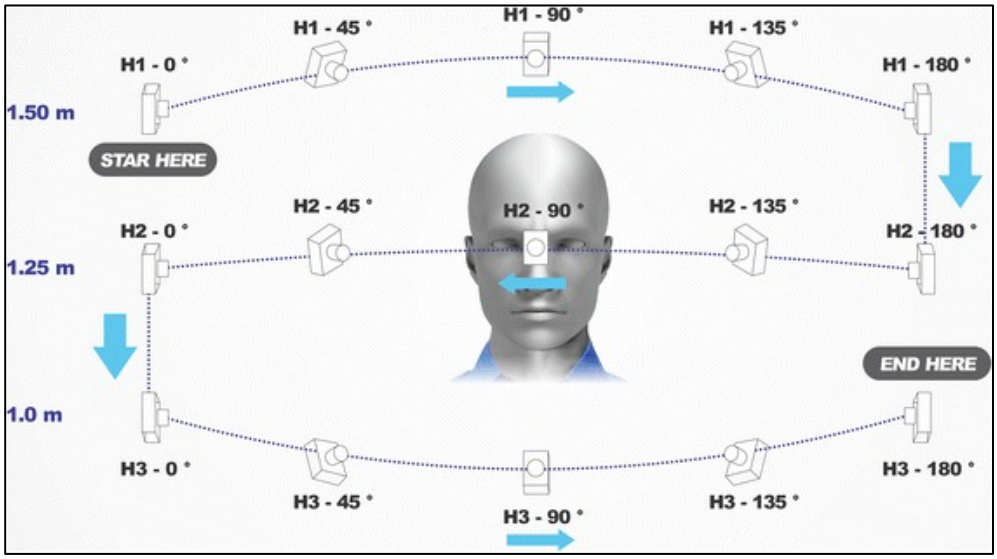

Figure 2. Illustration of the complete sequence of photo capture protocol for monoscopic photogrammetry [29].

The monoscopic photogrammetry technique can generate 3D models without extensive expertise or expensive equipment than the stereophotogrammetry techniques (Figure 2). The stereophotogrammetry techniques require simultaneous photo capture using multiple cameras with different objects' heights and angles. The monoscopic photogrammetry technique can only use one camera to capture the photo from different heights and angles. The photos are then processed in open-source software that is freely available and user-friendly [29,30]. Besides its advantages, monoscopic photogrammetry requires numerous well-captured photos with the best possible lighting source to build a 3D model. Monoscopic photogrammetry has been applied in a medical study to rehabilitate facial defects; however, it has not been attempted yet in the forensic field. The application of monoscopic photogrammetry could lead to a novel method of 3D bitemark analysis with simple and efficient resources [31]. Further studies in 3D bitemark analysis are necessary to examine the accuracy of the monoscopic photogrammetry compared to the intraoral scanner devices.

Conclusion

Monoscopic photogrammetry proposes a simple method to generate a 3D model using user-friendly 2D cameras, such as smartphone cameras. Researchers worldwide have been using this technique to create surgical planning prosthetic devices; however, it has not been attempted in the forensic field. Numerous advantages of monoscopic photogrammetry could lead to a novel method of 3D bitemark analysis in forensic odontology. Further studies are required to explore the accuracy and applicability of monoscopic photogrammetry in the forensic field.

Authors' Contributions

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All authors declare that they contributed to critical review of intellectual content and approval of the final version to be published.

Financial Support

None.

Conflict of Interest

The authors declare no conflicts of interest.

Data Availability

The data used to support the findings of this study can be made available upon request to the corresponding author.

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