Reverse engineering in forensic investigations: a new approach to bite mark analysis

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ABSTRACT

The study of bite marks provides crucial elements that contribute towards identifying the biter. In many cases, it assumes importance when bite marks are detected on the body of a victim of violence, but it could also be relevant when the bite marks are seen on food substances at the crime scene. In both circumstances, comparing the bite marks with a suspect's dentition can be decisive in confirming or excluding the culpability.

In this case report, a bun (bread roll) with the sign of a bite was found at the crime scene.

We report a pilot study using 3D reproduction of the bite mark on the bun and dental models of the alleged biter and the victim. A reverse engineering process was used to obtain digital 3D models of the bitten bun and the dental models by taking numerous photographs and stitching them together using a software called Metashape by Agisoft.

The last step was to compare the bitemark to the two dental models, evaluating the spatial distance, the degree of overlap, and the degree of interpenetration. The results confirmed the usefulness of reverse engineering in forensic investigations showing the compatibility between the victim's teeth and the bite mark on the bun.

INTRODUCTION

Forensic odontology is invaluable in cases of unidentified bodies and human remains. [1,2] The uniqueness of the dental formula of each individual and the peculiarities of the dental treatments makes it possible to establish the odontobiography of the deceased that includes age, sex, race/ancestry, general and oral health, habits, profession, diet, and psychological and social status. [3-9]

The most challenging aspect of forensic odontology is investigating bite mark evidence, often seen in daycare centres, sports altercations, sexual assault, and sexual and elderly abuse. The bite marks on a victim's skin or inanimate objects, such as food substances present at the crime scene, are substantial evidence that can lead to the identification of the offender. [6,7]

As for other lesions, also for the bite marks, it is necessary to distinguish different phases of analysis: the first phase consists of the identification of human characteristics of bite marks [10], and then through the analysis of the pattern, it is possible to make a comparison of the bite mark to the dentition of persons of interests. [1,7,10]

Furthermore, the bite marks analysis requires the recording of the dental characteristics of any suspects to carry out the comparison with the lesion observed.
The bite mark and the suspect's dentition could be compared through 2D-3D comparison procedures, using software and experimental models to verify it. [10]
In the case of bites detected on different types of food, numerous comparative studies have been carried out based on the specific characteristics of the food itself. Specific software has also been used in some cases. [1,7]
Similarly, other studies have considered the variability of bite marks on different regions of the human body. [11]
In the comparison procedure between the bite marks and the suspect's dentition, the characteristics studied include the size, shape, and position of the dental elements and any morphological peculiarities useful for identification. [2]
The development of latest generation software allowed 3D acquisition of bite marks detected on food or skin and their comparison with the dental arches of a suspect, providing more precise and detailed information. [12-13]
This study aimed to test the use of a 3D scanning technique by comparing the bite marks found on a piece of bun (bread roll) at the crime scene to the suspect's and the victim's dentition. [14-19]

CASE

A 70-year-old woman was found lying on the floor of her home. At first glance, law enforcement assumed the victim died of natural causes; however, the doctors noticed a suspicious red spot on the deceased's dress in the abdominal region.
The intervention of the medical examiners was then requested, and at least eight stab and cut wounds were found all over the deceased's body. No weapon was found at the crime scene that may have caused the injuries.
During the inspection of the crime scene, the police officers and medical examiners realized that the kitchen table was set for a meal, but it was one element that attracted the attention of those present: on the table, there was a bun divided into two halves, and on one of them a bite mark was suspected (Figure 1).

Figure 1. The bun found on the crime scene with the half closer to the bottom, indicating a possible bite mark

The bun was immediately preserved as evidence to proceed with the subsequent forensic investigations.
The investigation led to a male, an acquaintance of the victim, who, according to circumstantial evidence, could have been the main suspect.
The bite marks on the bun were compared to the dentition of the victim and the suspect to investigate the possible presence of the man at the crime scene.

A forensic odontologist took dental impressions (negative) of the deceased and the suspect and then made dental models (positive) from the impressions.
Among the impressions detected, it was therefore chosen to use only the upper dental arches of the deceased and the suspect (Figure 2-3) as they are more involved in the act of biting and more visible.

Figure 2. Dental arch of the victim. A: Frontal view. B-C: Lateral views. D: Occlusal surface

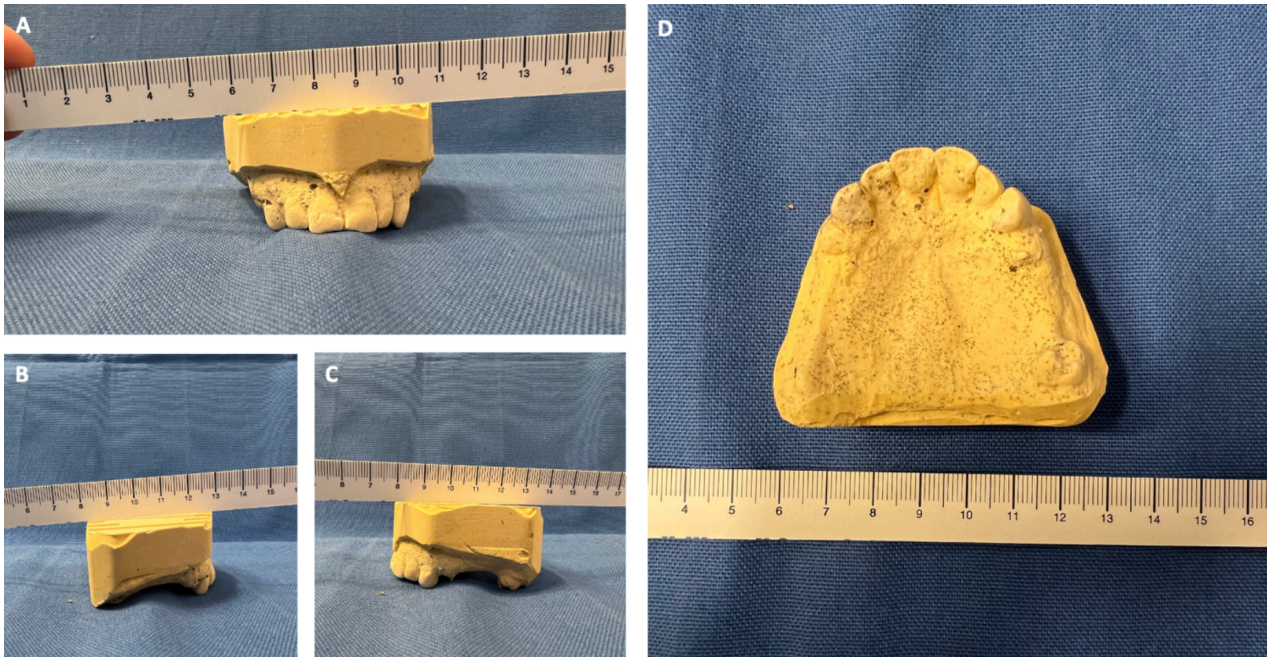
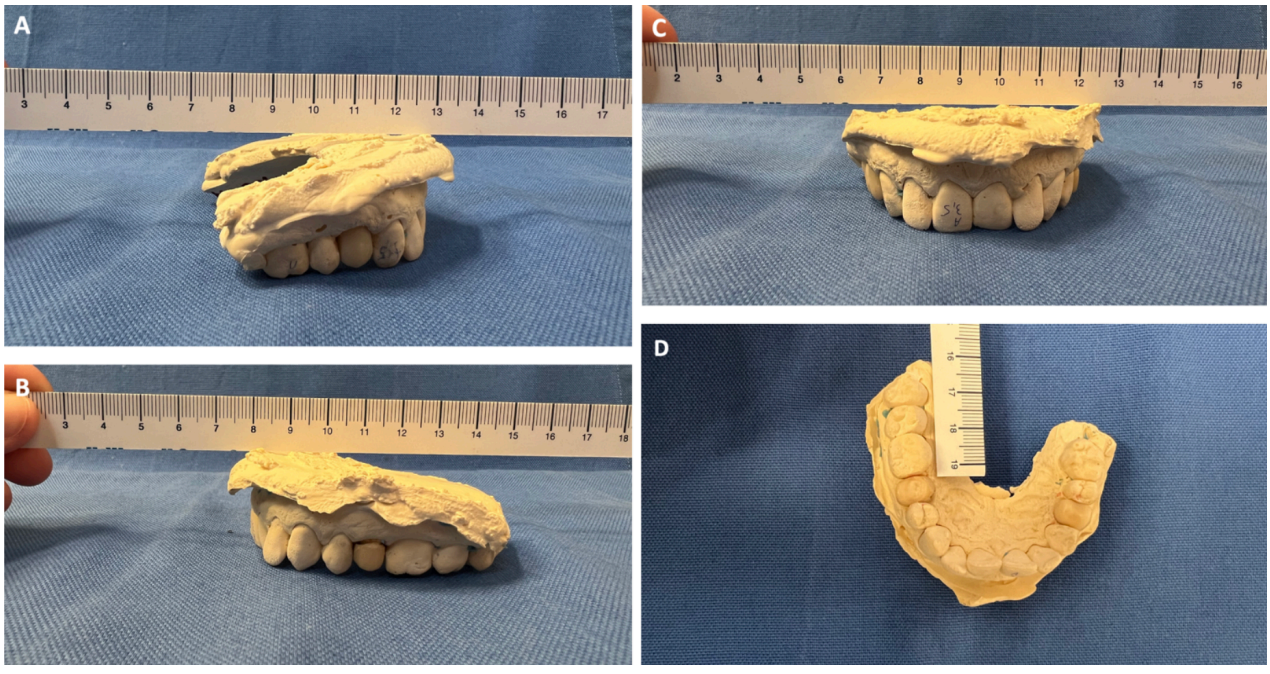


Figure 3. Dental arch of the suspect. A-B: Lateral views. C: Frontal view. D: Occlusal surface



The bun and the dental models of the deceased and the suspect were then analyzed on Polishape 3D' Mechanical Engineering Laboratory to obtain a three-dimensional scan.

MATERIALS AND METHODS

During a murder-scene investigation, a bun with a very evident bite mark was detected (Figure 1). The bun was immediately produced as evidence to proceed with the subsequent forensic investigations.

The bite marks present on the bun were compared to the dentitions of the deceased and of the suspected bite mark perpetrator to confirm the possible presence of the man at the crime scene.

The autopsy of the woman was performed and a forensic odontologist proceeded with the acquisition of the dental impressions of both the deceased and the suspected biter using an alginate impression. The dental casts were made for both impressions (Figure 2-3).

The bun and the dental casts of the dental arches of the woman and the suspect were then analyzed by the "Polishape 3D" Mechanical Engineering Laboratory, Department of Mechanics, Mathematics, and Management, Polytechnic of Bari, Italy, to obtain a three-dimensional scan.

An experimental comparison between bun and bitemarks was attempted through 3D models' creation to avoid food degradation.

In this experimental technique, only the upper arch was used since it is more easily comparable with the bitemark on the bun.

3D reconstruction

Some 3D scanning and additive manufacturing were used to compare the dental models and the bite mark.

A 3D reconstruction of the bun was obtained to be compared with the scan of the woman and with the scan of the offender to verify the degree of overlap and therefore the possible geometric compatibility.

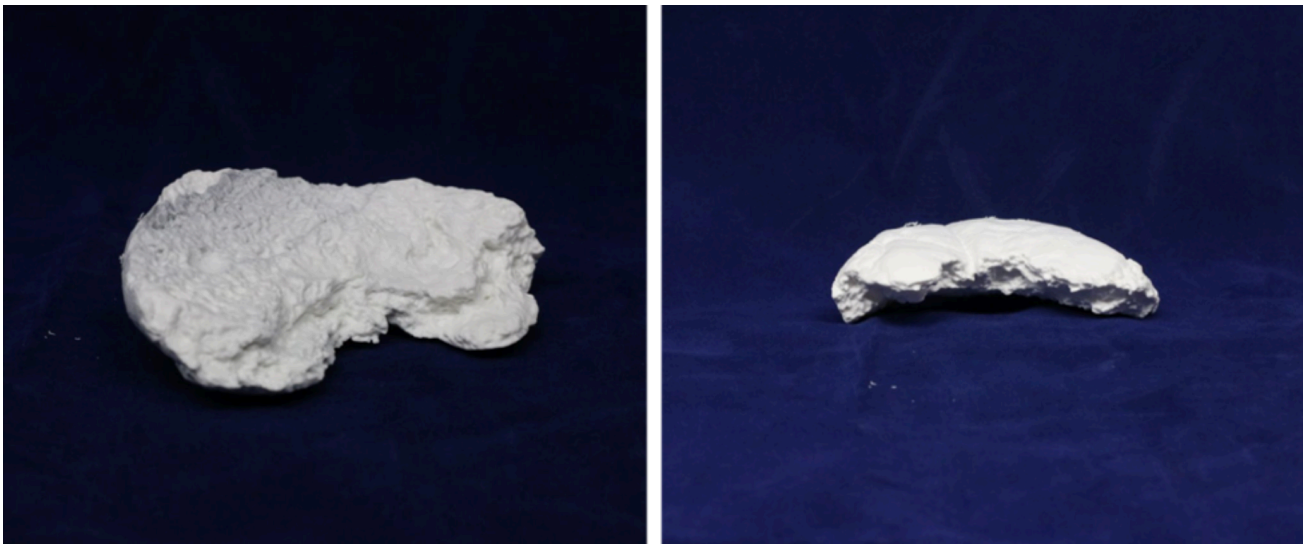
The technique used to obtain the 3D reconstruction is reverse engineering [20] which allows obtaining a 3D model of a physical object starting by taking photographs.

A technique called close-range photogrammetry [21] that consists of two phases: (i) taking multiple overlapping photographs of the object at varying angles and (ii) using software to stitch the photographs together to create a 3D model of the object was employed.

A Canon (EOS 760D) DSLR (Digital Single Lens Reflex) camera with an EF 50mm f/1.8 II lens and a 12mm extension tube was used for photographing the subjects. This optical configuration was selected to allow a sufficient level of magnification and resolution for a detailed and accurate reconstruction of the object. A total of 72 photographs of the piece of bun with the suspected bite mark were uploaded onto Agisoft Metashape (photogrammetry software) for creating the 3D model.

The resulting model was of 0.01 mm in-plane resolution and 0.03 mm in depth resolution. This resolution made it possible to obtain a sufficiently detailed reconstruction of the bun (Figure 4).

Figure 4. 3D reconstruction of the bun. Views from different planes of spaces



Next was the Additive Manufacturing phase, where the digital 3D reconstructed model of the bun was printed using a 3D printer allowing continuous investigations and comparisons using the 3D model of the bun, even after the degradation of the original evidence.
The 3D printing of the bun was executed with Fused Filament Fabrication (FFF). This process uses a filament of polymeric material extruded through a heated nozzle and deposited on a working platform. The model to be made is thus printed, layer by layer, until it is complete. Here are the technical details of the machine and the material used.

- Printer: Delta WASP 40 70, nozzle diameter 0.4 mm.
- Printing material – White Polylactic Acid (PLA).
- Print layer height (single deposited layer): 0.2 mm.

The same reverse engineering was used to obtain 3D scans of the dentition of the deceased and the offender. For 3D printing the dental models, Digital Light Processing (DLP) was used. This additive manufacturing technique uses a photosensitive resin that photopolymerizes when exposed to ultraviolet radiation. Here are the technical details of the machine and the material used.

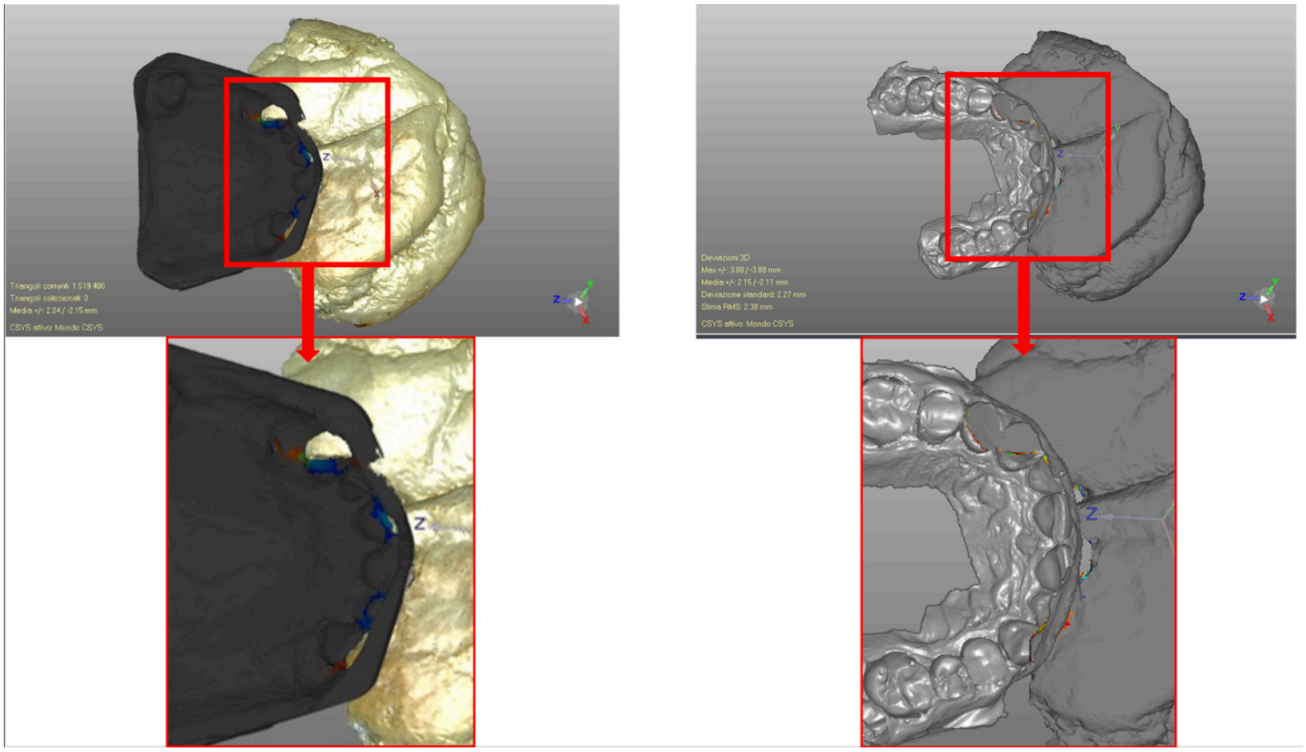
- Anycubic Photon Mono Resin LCD printer.
- Printing material: White Photocentric Hard resin.
- Print layer height (single deposited layer): 0.05 mm.

The bun and the casts of the dental arches of the victim and the suspect were scanned to obtain the virtual model of the pieces of evidence and, therefore, a direct comparison.

Digital comparison

The comparison between the scans of the bun and the dental arches was carried out in two phases: (i) alignment of the scans in correspondence with the bite mark and (ii) comparison of the 3D scans, with the calculation of spatial distances and colourimetric reproduction, to verify the degree of overlap.
The reproductions of the models scanned through additive manufacturing techniques, therefore, allowed a direct comparison between the bun and the dental arches avoiding the use of the original finds (Figure 5).

Figure 5. On the left: a direct comparison between the bun and dental arch of the victim. On the right: a direct comparison between the bun and dental arch of the suspect



RESULTS AND DISCUSSION

From the comparison by overlapping the dental model of the deceased and the 3D model of the bun with the bite mark, it was possible to deduce an objective morphological and dimensional compatibility between the two pieces of evidence, more evident in the medial portion of the evidence and the dental model.

From the comparison with the dental model of the suspect, poor compatibility was found in the medial part, but an excessive interpenetration of the cast on the lateral areas of the bite mark (Figure 6-7).

Figure 6. On the left: colourimetric comparison-intersection between bitemark on the bun and dental arch of the victim, occlusal surface. On the right: colourimetric comparison-intersection between bitemark on the bun and dental arch of the suspect, occlusal surface

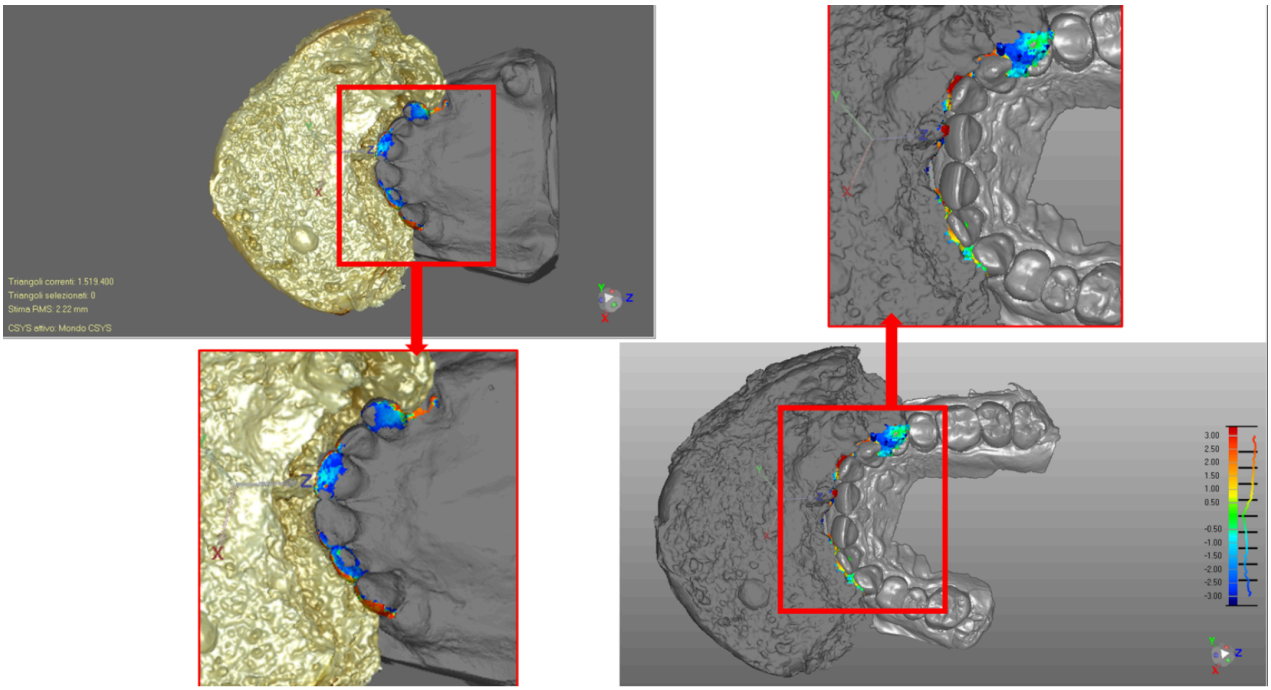
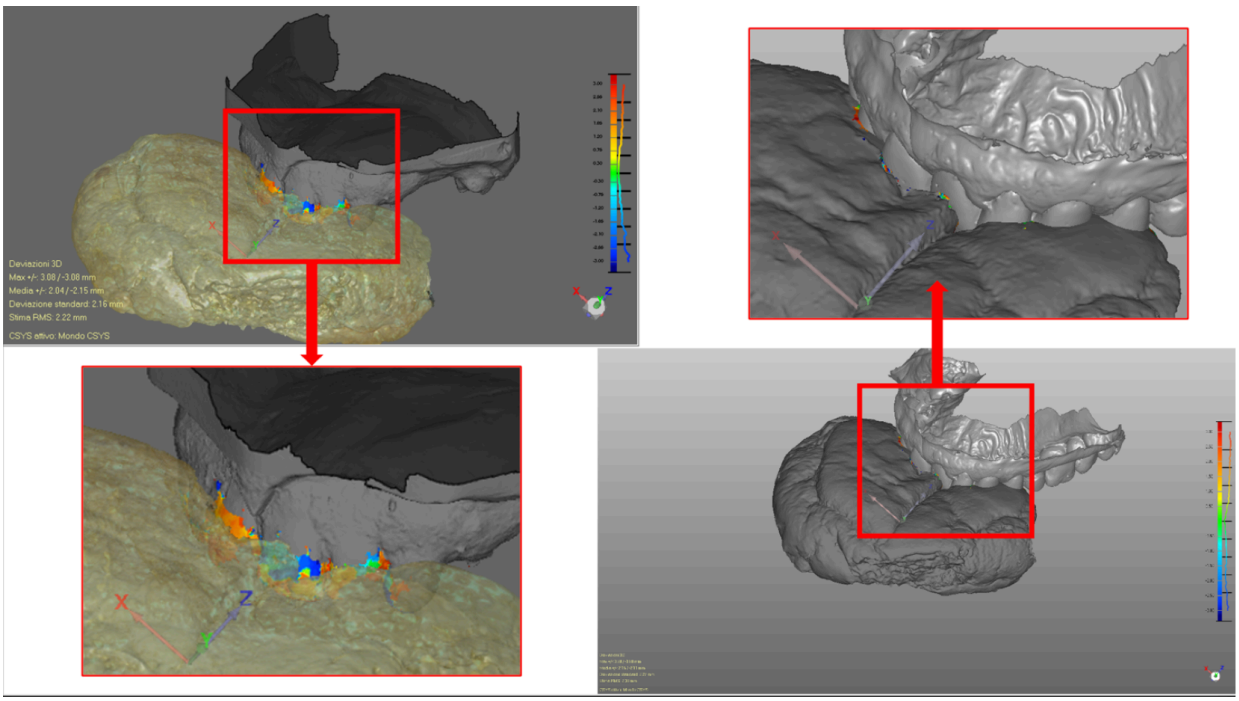


Figure 7. On the left: colourimetric comparison-intersection between bitemark on the bun and dental arch of the victim, axonometric view. On the right: colourimetric comparison-intersection between bitemark on the bun and dental arch of the suspect, axonometric view



However, in the case presented by the authors, reverse engineering techniques adapted to the study of the bitemark detected on the sandwich did not help identify the murderer, since the bitemark belonged to the victim. Furthermore, in this specific murder case, the main suspect confessed after a few days to killing the elderly woman in her home.

However, thanks to the results obtained, we can also consider reverse engineering techniques could be very useful and satisfactory for bit-mark analysis in forensics. The analyses performed seems to be highly sensitive and specific, nevertheless further studies wild broad sample could be performed to validate the technique.

For these reasons, it is helpful to continue the analyses in this field by carrying out multiple comparisons between different foods and bitemarks of different people, to analyze the results.

Our study can therefore be considered a pilot study, which demonstrates that the 3D scanning technique could represent valid support in forensic investigations and personal identification. The high specificity, the objectivity of the analysis and comparison performed using software, and the reproducibility make this technique usable in different areas of personal identification, overcoming the limits of an outdated manual comparison, often conditioned by subjectivity and the operator's expertise.

This technique's most significant advantage is preserving perishable evidence or evidence that may change over time. The 3D reconstruction allows the recreation of a model faithful to the original, kept almost indefinitely in time for any subsequent forensic investigations.

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REFERENCES

1. van der Velden A, Spiessens M, Willems G. Bite mark analysis and comparison using image perception technology. *J Forensic Odontostomatol*. 2006;24(1):14-17.
2. Nagare SP, Chaudhari RS, Birangane RS, Parkarwar PC. Sex determination in forensic identification, a review. *J Forensic Dent Sci*. 2018;10(2):61-66. doi:10.4103/jfo.jfds_55_17
3. Divakar KP. Forensic Odontology: The New Dimension in Dental Analysis. *Int J Biomed Sci*. 2017;13(1):1-5.
4. Krishan K, Kanchan T, Garg AK. Dental Evidence in Forensic Identification - An Overview, Methodology and Present Status. *Open Dent J*. 2015;9:250-256. Published 2015 Jul 31. doi:10.2174/1874210601509010250
5. Freeman AJ, Senn DR, Arendt DM. Seven hundred seventy eight bite marks: analysis by anatomic location, victim and biter demographics, type of crime, and legal disposition. *J Forensic Sci*. 2005;50(6):1436-1443.
6. Wagner GN. Bitemark identification in child abuse cases. *Pediatr Dent*. 1986;8(1 Spec No):96-100.
7. Daniel MJ, Pazhani A. Accuracy of bite mark analysis from food substances: A comparative study. *J Forensic Dent Sci*. 2015;7(3):222-226. doi:10.4103/0975-1475.172442
8. Santoro V, Mele F, Introna F, De Donno A. Personal identification through digital photo superimposition of dental profile: a pilot study. *J Forensic Odontostomatol*. 2019;37(3):21-26. Published 2019 Dec 30.
9. Scorca A, Santoro V, De Donno A, Grattagliano I, Tafuri S, Introna F. Early childhood caries (ECC) and neglect in child care: analysis of an Italian sample. *Clin Ter*. 2013;164(5):e365-e371. doi:10.7417/CT.2013.1614
10. Santoro V, Lozito P, De Donno A, Introna F. Experimental study of bite mark injuries by digital analysis. *J Forensic Sci*. 2011;56(1):224-228. doi:10.1111/j.1556-4029.2010.01519.x
11. Radford G, Kieser JA, Bernal V, Waddell JN, Forrest A. Biomechanical approach to human bitemark reconstruction. *J Forensic Odontostomatol*. 2009;27(1):33-36. Published 2009 Jun 1.
12. Naether S, Buck U, Campana L, Breitbeck R, Thali M. The examination and identification of bite marks in foods using 3D scanning and 3D comparison methods. *Int J Legal Med*. 2012;126(1):89-95. doi:10.1007/s00414-011-0580-7
13. Bush MA, Bush PJ, Sheets HD. Similarity and match rates of the human dentition in three dimensions: relevance to bitemark analysis. *Int J Legal Med*. 2011;125(6):779-784. doi:10.1007/s00414-010-0507-8
14. Thali MJ, Braun M, Markwalder TH, et al. Bite mark documentation and analysis: the forensic 3D/CAD supported photogrammetry approach. *Forensic Sci Int*. 2003;135(2):115-121. doi:10.1016/s0379-0738(03)00205-6
15. Martin-de las Heras S, Valenzuela A, Javier Valverde A, Torres JC, Luna-del-Castillo JD. Effectiveness of comparison overlays generated with DentalPrint software in bite mark analysis. *J Forensic Sci*. 2007;52(1):151-156. doi:10.1111/j.1556-4029.2006.00321.x
16. Evans S T, Jones C, Plassmann P. 3D imaging for bite mark analysis, *The Imaging Science Journal*. 2013; 61:4, 351-360, doi: 10.1179/1743131X11Y.0000000054
17. Naether S, Buck U, Campana L, Breitbeck R, Thali M. The examination and identification of bite marks in foods using 3D scanning and 3D comparison methods. *Int J Legal Med*. 2012;126(1):89-95. doi:10.1007/s00414-011-0580-7
18. Fournier G, Savall F, Nasr K, Telmon N, Maret D. Three-dimensional analysis of bitemarks using an intraoral scanner. *Forensic Sci Int*. 2019;301:1-5. doi:10.1016/j.forsciint.2019.05.006
19. Daniel MJ, Pazhani A. Accuracy of bite mark analysis from food substances: A comparative study. *J Forensic Dent Sci*. 2015;7(3):222-226. doi:10.4103/0975-1475.172442
20. Barszcz M, Montusiewicz J, Dziedzic K Methodology of teaching reverse engineering in biomedical engineering studies. EDULEARN18 Proceedings 2018;pp. 3808-3817.
21. Luhmann T, Robson S, Kyle S, Harley I. Close Range Photogrammetry. Principles, Techniques and Applications. Scotland, UK, 2006. ISBN 1-870325-50-8.