Journal of Indopacific
Academy of Forensic Odontology (JINPAFO)

JINPAFO Vol.14, Issue 1, January - June 2025

ORIGINAL ARTICLE

Development and Validation of a Novel Device for Three-Dimensional Bite-Mark Analysis: An *In-vitro* Study

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Abstract

Background: Bite mark analysis is a pivotal tool in forensic odontology, founded on the uniqueness of dental configurations. However, traditional photographic methods are increasingly criticized for subjectivity, distortion, and inter-observer variability, challenging their forensic credibility. Recent technological advancements have emphasized the need for standardized, three-dimensional approaches to improve the reliability of bite mark evidence.

Aim: The present study aimed to develop and validate a novel three-dimensional bite mark analysis device and compare its diagnostic accuracy, reliability, and efficiency against conventional photographic methods.

Materials and Methods: An in-vitro study was conducted using 60 bite mark specimens created on dental impression materials. Measurements were independently performed by two blinded forensic dental examiners using both the novel device and the photographic method. The novel device employed a vertical screw mechanism with an optical rotary encoder and dual-direction Persistence of Vision sensors to capture x, y, and z coordinates. Measurement accuracy, time taken, inter-observer reliability, sensitivity, specificity, and diagnostic performance were assessed and statistically analyzed.

Results: The novel device achieved significantly higher measurement accuracy (92.3%) compared to the photographic method (76.4%) ($p < 0.001$). The mean analysis time was reduced by nearly half with the novel device (6.8 minutes vs. 12.4 minutes, $p < 0.001$). Inter-observer reliability was greater with the device (kappa = 0.82) compared to photography (kappa = 0.65). Sensitivity, specificity, and area under curve values were also superior for the novel device.

Conclusion: The novel bite mark analysis device demonstrated superior precision, efficiency, and reproducibility over conventional methods, offering a promising tool for enhancing the scientific and legal admissibility of bite mark evidence.

Keywords: Bite mark analysis; Forensic odontology; Measurement accuracy; Three-dimensional imaging

Introduction

Bite mark analysis has long served as a crucial tool in forensic odontology, founded on the premise that no two oral configurations are identical. Defined as "a mark caused by the teeth either alone or in combination with other mouth parts," bite marks offer potentially valuable evidence in criminal investigations when properly documented and interpreted.[1]

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How to cite: Sachdev SS, Joy T, Sardar MA, Kadam S, Sonawane S, Sachdev JB, Development and Validation of a Novel Device for Three-Dimensional Bite-Mark Analysis: An In-vitro Study. J Indo Pacific Acad Forensic Odontology. 2025 Jan-Jun 14 (1): 3-8
DOI: 10.53275/jinpafo.v14.i1.01

However, the reliability and admissibility of bite mark evidence have come under increasing scrutiny in recent years. Concerns regarding subjectivity, distortion from skin elasticity, and the lack of standardized analytical protocols have cast doubt on the forensic robustness of traditional methodologies, especially photographic analysis.[2,3]

Photographic documentation of bite marks has been a cornerstone of forensic evidence collection, relying heavily on correct angulation, scale placement, lighting conditions, and operator expertise.[4] Despite the use of standardized tools such as the ABFO No. 2 scale and advanced digital imaging, this method is not without its limitations. Issues such as distortion due to skin curvature, tissue elasticity, and variations in photographic conditions can lead to inaccuracies in measurements. Moreover, the process can be time-consuming, technically demanding, and prone to inter-observer variability.[4,5]

The growing skepticism surrounding bite mark evidence has catalyzed the need for more objective, standardized, and reproducible methods of analysis. In response, efforts have been made to incorporate digital technologies into forensic odontology. Recent innovations have explored three-dimensional (3D) scanning, coordinate mapping, and sensor-based measurement systems to enhance accuracy, reduce observer bias, and enable better documentation of bite mark depth, angulation, and orientation.[6,7]

The present study introduces and validates a novel device specifically developed for three-dimensional bite mark analysis. This device utilizes an integrated system comprising a vertical screw with an optical rotary encoder and a dual-direction Persistence of Vision (POV) sensor to capture precise spatial dimensions of bite marks. By directly measuring x, y, and z coordinates along with depth, this technology aims to minimize distortion and inter-observer discrepancy while enhancing the diagnostic utility of bite mark evidence. This study evaluates the reliability, efficiency, and diagnostic accuracy of the new device in comparison to conventional photographic methods, with the goal of bridging the gap between forensic accuracy and accessibility.

Materials and Methods

Study Design

The present in-vitro study was designed to evaluate the validity, reliability, and operational efficiency of a newly developed three-dimensional bite mark analysis device. The study aimed to compare the performance of this novel device with that of conventional two-dimensional photographic bite mark analysis in terms of measurement accuracy, time efficiency, inter-observer agreement, and diagnostic performance.

Sample Size and Specimen Preparation

A total of 60 bite mark specimens were created using dental casts and prosthesis for the study. Dental impression materials, including putty, alginate, and modelling wax, were used to simulate bite mark substrates. These materials were selected to represent varying consistencies and responses to bite pressure, closely mimicking soft tissue in forensic contexts.

Standardized bite marks were created on these substrates using pre-fabricated dental casts with known measurements. The original dimensions of the biting surfaces (including depth, mesiodistal width, and inter-canine distance) were pre-recorded using a high-precision Vernier caliper by an independent investigator. These reference measurements served as the gold standard for evaluating the accuracy of both test methods.

A line was marked on the cast upto the desired depth of the bite mark. The material on which the bite mark was to be registered was then inverted on the cast upto the marked line and kept in position for five seconds to ensure that the static bite mark was adequately recorded. In this manner, the cast application pressure and contact time were standardized to avoid variability in bite depth or spread.

Investigators and Blinding

Two trained and calibrated forensic dental examiners participated in the study to perform the bite mark analysis using both the novel device and the photographic method. The investigators were blinded to the reference measurements obtained by Vernier calipers to eliminate bias. Each examiner independently performed and recorded measurements to allow assessment of inter-observer reliability.

The Novel Bite-Mark Analysis Device

The custom-designed bite mark analysis device (Figure 1) incorporated the following components:

Vertical Screw Mechanism with Optical Rotary Encoder

This component was used to assess the vertical depth (z-axis) of the bite mark. The encoder measured the degree of rotation of the screw, and as the screw pitch was known, the vertical displacement could be accurately calculated. This provided a precise means to quantify the depth of depressions or indentations caused by the bite.

Dual-Directional Persistence of Vision (POV) Sensor

Two POV sensors were aligned perpendicularly to each other to assess the horizontal (x and y axes) positioning of various bite mark elements. These sensors emitted electromagnetic waves and measured their interaction with reflective reference markers on the specimen surface to directly calculate horizontal distances, curvature, and orientation of the dental arch impressions. This allowed three-dimensional spatial mapping of bite mark parameters.

All measurements were taken with the specimen stabilized on a mounting platform to prevent any movement or tilt that could alter dimensional accuracy. Figure 2 summatively depicts various stages of simulation and analysis of bite marks using the novel device.

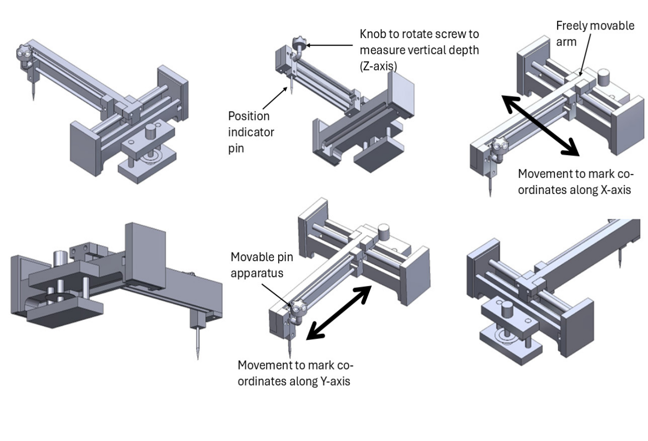

Figure 1: Schematic Diagrams of the novel bite mark device

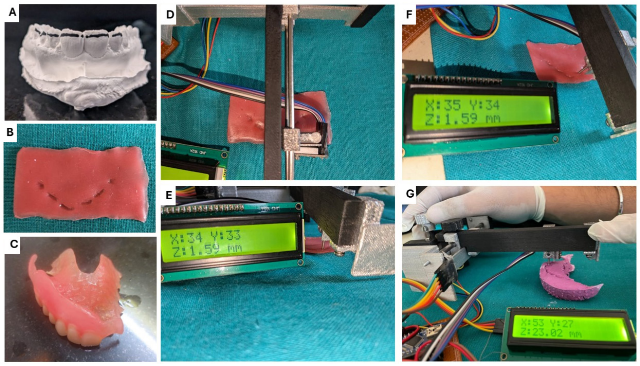

Figure 2 : A) Marking of the desired depth on the cast; B) Obtained bite mark on modelling wax; C) Sample removable prosthesis used to simulate a bite mark; D), E) and F) Positioning of the indicator pin on the desired position to measure the co-ordinates; G) Measuring co-ordinates on a putty impression

Conventional Photographic Method

For comparison, each specimen was also analyzed using standard 1:1 bite mark photography. Controlled lighting was used to minimize shadowing and glare. Instead of the standard ABFO No. 2 scale, a calibrated setup using graph paper with printed millimeter rulers and coin markers was used as a measurement reference, due to equipment constraints. The photographic images were then uploaded and analyzed using digital image processing software (Adobe Photoshop CS3) according to standard norms.[4,6]

Study Procedure

The sample bite marks were prepared as described in the above sections. Each examiner independently measured dimensions (depth, inter-canine distance, incisal width, and curvature) on each specimen using both methods. The time required to complete bite mark analysis using both the novel device and the photographic method was recorded using a digital stopwatch. All values were compared with the reference dimensions previously recorded using Vernier calipers. Both primary and secondary outcome parameters, as described below, were recorded systematically for each specimen and examiner. The workflow of bitemark analysis of the samples in the present study is depicted in Figure 3.

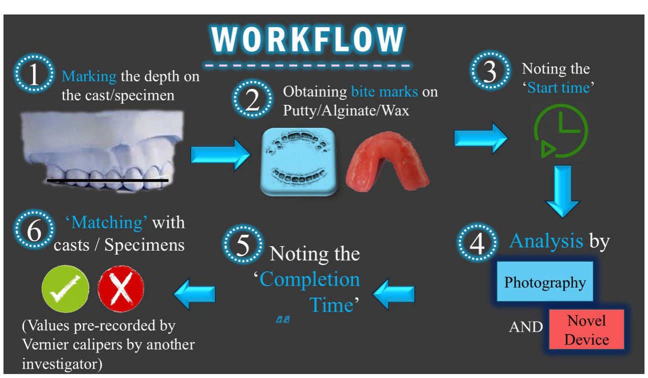

Figure 3: Workflow of bite mark analysis in the present study

Outcome Measures

Primary Outcomes

- Accuracy of Measurements: Accuracy was determined by comparing each method's measurements to the gold standard values obtained by Vernier calipers.
- Total Time Required: The time taken by each examiner to complete the analysis was documented for both methods.
- Inter-Observer Reliability: Measured using Cohen's kappa statistic and standard deviation of recorded values for each method.

Secondary Outcomes

- Sensitivity and Specificity: Ability of each method to correctly identify and replicate known dimensions.
- Positive and Negative Predictive Values: Assessed based on correct versus incorrect identification of reference points.
- Procedure-Specific Observations: Technical ease, portability, and subjective examiner feedback were also recorded.

Statistical Analysis

The collected data were compiled and subjected to descriptive and inferential statistical analysis. Mean values and standard deviations were calculated for measurement accuracy and analysis time. Paired t-tests or Wilcoxon signed-rank tests (depending on data normality) were used to compare the two methods. Cohen's kappa was applied to evaluate inter-examiner agreement. Receiver Operating Characteristic (ROC) curve analysis was conducted to compare the diagnostic performance of the two methods, with area under the curve (AUC) values interpreted to assess overall accuracy. A p-value less than 0.05 was considered statistically significant. All statistical analyses were performed using SPSS software version v23 (IBM Corp., Armonk, NY, USA).

Results

Accuracy of Measurements

The novel bite-mark analysis device demonstrated significantly higher accuracy in comparison to the conventional photographic method. Measurements obtained using the device showed a mean accuracy of 92.3%, closely aligning with the gold standard values previously recorded using a Vernier caliper (Figure 4). In contrast, the photographic method produced a lower mean accuracy of 76.4%. The difference between the two methods was statistically highly significant ($p < 0.001$) (Table 1). The enhanced accuracy of the novel device is attributed to its ability to measure three-dimensional coordinates (x, y, and z axes) directly from the specimen, thereby reducing errors caused by perspective distortion, angulation, and depth estimation inherent to two -dimensional photography.

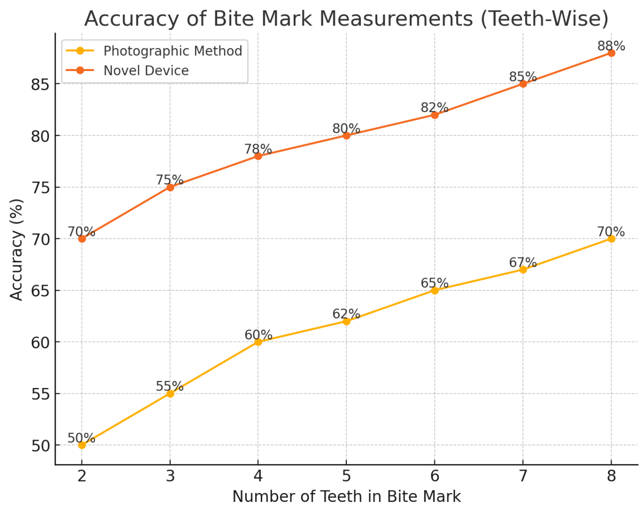

Figure 4 : Accuracy of both methods corresponding to the number of teeth included in the bite mark analysis

Time Required for Analysis

A comparative assessment of the time taken to perform bite-mark analysis revealed a substantial reduction when using the novel device. The average time required to complete one analysis was 6.8 ± 1.5 minutes with the novel device, compared to 12.4 ± 2.1 minutes for the photographic method (Table 2). This difference was found to be statistically significant ($p < 0.001$). The reduced time can be attributed to the device's integrated digital sensors and real-time measurement capabilities, which eliminate the need for additional post-capture processing and calibration steps that are typical of photographic analysis.

Inter-Examiner Reliability

Inter-observer consistency between the two examiners was assessed using standard deviation and Cohen's kappa statistic. The novel device demonstrated superior inter-examiner reliability with a standard deviation of 1.1 and a kappa value of 0.82, indicating substantial agreement. In contrast, the photographic method showed a higher variability, with a standard deviation of 2.3 and a kappa value of 0.65, signifying only moderate agreement (Table 3). These findings underscore the objectivity and reproducibility of the novel device, which reduces examiner-dependent variability.

Table 1 : Comparison of the Accuracy of Bite Mark Measurements

Method	*Mean accuracy (%)*	*Standard deviation*	*p-value*
Novel Device	92.3	±1.1	< 0.001
Photographic Method	76.4	±2.3	

Table 2: Time Required for Bite Mark Analysis

Method	*Mean time (minutes)*	*Standard deviation*	*p-value*
Novel Device	6.8	±1.5	< 0.001
Photographic Method	12.4	±2.1	

Table 3 : Inter-Observer Reliability

Method	*Standard deviation*	*Cohen's kappa*	*Interpretation*
Novel device	±1.1	0.82	Substantial agreement
Photographic method	±2.3	0.65	Moderate agreement

Diagnostic Performance

The diagnostic capability of both techniques was evaluated through sensitivity, specificity, and predictive value calculations. The photographic method showed a sensitivity of 60% and specificity of 75%, with a positive predictive value (PPV) of 65% and a negative predictive value (NPV) of 70%. In contrast, the novel device achieved a sensitivity of 85%, specificity of 90%, PPV of 88%, and NPV of 92% (Table 4). These results reflect the superior diagnostic precision of the novel device in correctly identifying and replicating bite mark dimensions with minimal error.

Receiver Operating Characteristic Curve Analysis

ROC curve analysis was conducted to further assess the discriminative power of both techniques. The Area Under the Curve (AUC) for the novel device was 0.92, indicating excellent diagnostic accuracy. The photographic method showed a lower AUC of 0.78, suggesting moderate performance (Table 5). These results confirm the superior capability of the novel device to distinguish between accurate and inaccurate measurements, reinforcing its forensic applicability.

Success Rate and Procedural Observations

The overall success rate for complete and accurate bite mark analysis was 96.7% with the novel device and 78.3% with the photographic method (Table 6). Investigator feedback noted that although the novel device required initial training and familiarization, it was easier to use and produced more reliable results once calibrated. Additionally, the device reduced dependency on external variables such as lighting conditions, image scaling, and operator skill. One observed limitation was its inapplicability in cases involving actively bleeding tissue

Table 4: Diagnostic Performance of the Two Methods

Parameter	Novel Device (%)	Photographic method (%)
Sensitivity	85	60
Specificity	90	75
Positive predictive value	88	65
Negative predictive value	92	70

Table 5: Receiver operating characteristic curve analysis

Method	*Area under curve (AUC)*	*Interpretation*
Novel device	0.92	Excellent accuracy
Photographic method	0.78	Moderate accuracy

Table 6 : Success rate of bite mark analysis

Method	*Total successful analyses (n=60)*	*Success rate (%)*
Novel Device	58/60	96.7
Photographic Method	47/60	78.3

or mobile anatomical areas, which may restrict its use in live forensic examinations. Despite this, the device proved feasible and effective for in-vitro analysis and controlled post-mortem forensic applications.

Discussion

The present study was conducted to evaluate the diagnostic utility, precision, and operational efficiency of a newly developed three-dimensional bite mark analysis device and compare its performance with the conventional photographic method. The findings of this study demonstrate a clear superiority of the novel device across multiple parameters, including measurement accuracy, inter-observer reliability, diagnostic sensitivity and specificity, as well as overall time efficiency. These results highlight the potential of the device to address several long-standing challenges associated with traditional bite mark analysis techniques in forensic odontology.

One of the key outcomes of this study was the significant improvement in the accuracy of measurements using the novel device. With a mean accuracy of 92.3%, the device closely replicated reference values recorded by Vernier calipers, unlike the photographic method, which showed a lower accuracy of 76.4%. This difference can be primarily attributed to the device's ability to measure not just the horizontal (x and y) dimensions, but also the depth (z-axis), which is typically neglected or estimated in conventional 2D photographic analysis.[8] Previous literature has noted that distortion introduced by angulation, tissue curvature, or photographic artifacts can compromise measurement accuracy and reproducibility when using 2D photographs, even when standardized scales such as ABFO No. 2 are used.[9] The novel device eliminates these variables by allowing real-time direct contact measurements, thereby offering an objective and distortion-free analysis.

Time efficiency is another important factor in forensic workflows, particularly in scenarios involving multiple specimens or urgent investigations.[10] The bite marks undergo distortion whether on human tissues or simulated on materials, and therefore, warrant rapid investigation.[11] In this study, the novel device significantly reduced the average analysis time from 12.4 minutes (photographic method) to just 6.8 minutes. The streamlined workflow, integration of electronic measurement sensors, and reduced need for post-processing contributed to this efficiency. This time advantage becomes especially relevant in mass disaster scenarios or legal investigations requiring rapid evidence analysis. In the context of efficiency, the novel device lagged behind the conventional photographic method.

Inter-observer agreement is critical in forensic methodologies, including bite mark analysis, to ensure that evidence interpretation does not vary significantly between examiners.[12] The findings of this study showed that the novel device had a higher inter-examiner reliability, with a Cohen's kappa of 0.82 compared to 0.65 for the photographic method. The reduced variability in measurements obtained using the device suggests that it minimizes examiner subjectivity. This contrasts with the photographic method, where variations in angle of capture, lighting, scaling, and landmark identification can contribute to inconsistent results between investigators.[13] This improvement is particularly important in legal settings, where the admissibility and credibility of forensic evidence often hinge on reproducibility and examiner consensus.

The diagnostic sensitivity and specificity of the novel device were also notably higher than those of the photographic method. With a sensitivity of 85% and specificity of 90%, the novel device demonstrated an enhanced ability to correctly identify true positive and true negative measurements. This has practical implications for forensic bite mark comparisons, especially in criminal investigations where misidentification can have serious legal consequences. The higher area under the ROC curve (AUC = 0.92) further validates the diagnostic robustness of the novel device, highlighting its discriminatory power in distinguishing between correct and erroneous measurements. In contrast, the photographic method demonstrated only moderate performance with an AUC of 0.78.

The success rate of the analysis was also higher for the novel device, with 96.7% of cases successfully analyzed, compared to 78.3% for the photographic technique. The device was found to be technically user-friendly after initial training and did not rely on sophisticated software or expensive image-processing tools. Investigators reported that the novel device simplified the process by directly collecting dimensional data through physical interaction with the specimen, thereby bypassing several intermediate steps involved in photographic analysis, such as image calibration, landmark annotation, and digital measurement.[4,14] Moreover, the device showed high adaptability to various substrate materials including wax, alginate, and putty, reinforcing its versatility in different forensic contexts.

Despite these promising outcomes, the study does recognize certain limitations associated with the device. Firstly, its use is currently limited to dry or non-bleeding specimens, making it less applicable in real-time clinical or fresh post-traumatic forensic scenarios where tissue fluids are present. Secondly, while the device is relatively more efficient than traditional methods, it still involves hardware components that require stabilization, calibration, and operator familiarization. Although its cost is comparable to a few high-quality ABFO scales, the need for training may initially limit its adoption in less-equipped forensic settings.

Nevertheless, the development of this novel bite mark analysis device represents a significant step forward in improving the scientific rigor of bite mark evidence, a domain that has historically faced criticism for lack of reliability and objectivity. Several authors, including Souviron and Haller, have emphasized the need to differentiate between bite mark analysis and bite mark identification, cautioning against overreliance on subjective interpretations.[3] Similarly, the Innocence Project and other advocacy groups have raised concerns about wrongful convictions linked to poorly supported bite mark evidence.[15] In this context, a device that introduces quantitative, reproducible, and three-dimensional data holds the potential to bridge the gap between forensic utility and evidentiary credibility.

Looking ahead, the future scope of this device is considerable. Further validation studies involving dynamic tissue models, animal bites, and in vivo simulation could broaden its applicability. Integration of automated software with coordinate mapping and artificial intelligence-based recognition may also enhance its functionality for bite mark comparison and suspect profiling. Additionally, the current prototype can be miniaturized and adapted for portable field use in disaster victim identification and other field forensic applications. Continued development and refinement, including the incorporation of Acharya and Taylor's conclusive scale,[16] may enable the device to contribute toward more standardized, scientific, and legally defensible bite mark analysis protocols.

Conclusion

The novel bite mark analysis device developed in this study demonstrated superior performance over the conventional photographic method in terms of measurement accuracy, time efficiency, inter-observer reliability, and diagnostic sensitivity and specificity. By enabling three-dimensional assessment of bite marks and minimizing examiner-dependent variability, the device addresses many of the longstanding limitations associated with traditional 2D analysis techniques. Although certain practical constraints exist, such as limited use in bleeding or dynamic tissue environments, the device offers a reliable and reproducible approach for forensic bite mark evaluation. With further validation in clinical and field settings, this innovation holds strong potential to enhance the scientific credibility and legal admissibility of bite mark evidence in forensic odontology.

References

1. Acharya, A. B., & Taylor, J. A. (2003). Are a minimum number of concordant matches needed to establish identity in forensic odontology? Journal of Forensic Odontostomatology, 21(1), 6–13.
2. Berketa, J. W., James, H., & Lake, A. W. (2012). Forensic odontology involvement in disaster victim identification. Forensic Science, Medicine and Pathology, 8, 148–156. https://doi.org/10.1007/s12024-011-9279-6
3. Bowers, C. M. (2010). Photography and forensic dental evidence. In Forensic dental evidence: An investigator's handbook (pp. 287–306). CRC Press.
4. Cardoza, A. (2023). Forensic odontology and bite mark analysis: Understanding the debate. Journal of the California Dental Association, 51(1), 2210332.
5. Dama, N., Forgie, A., Mânica, S., & Revie, G. (2020). Exploring the degrees of distortion in simulated human bite marks. International Journal of Legal Medicine, 134, 1043–1049. https://doi.org/10.1007/s00414-019-02058-1
6. Fournier, G., Savall, F., Galibourg, A., Gély, L., Telmon, N., & Maret, D. (2020). Three-dimensional analysis of bitemarks: A validation study using an intraoral scanner. Forensic Science International, 309, 110198. https://doi.org/10.1016/j.forsciint.2020.110198
7. Golden, G. S. (2011). Standards and practices for bite mark photography. Journal of Forensic Odonto-Stomatology, 29(2), 29–36.
8. Innocence Project. (2025, April 27). Bite mark evidence deemed unreliable. Innocence Project. https://innocenceproject.org/news/bite-mark-evidence-deemed-unreliable/
9. Kavitha, B., Einstein, A., Sivapathasundharam, B., & Saraswathi, T. R. (2009). Limitations in forensic odontology. Journal of Forensic Dental Sciences, 1(1), 8–10. https://doi.org/10.4103/0974-2948.50885
10. Rajshekar, M., Kruger, E., & Tennant, M. (2012). Photographic imaging distortion and its effects on forensic bite mark analysis. Journal of Advanced Oral Research, 3(3), 1–6. https://doi.org/10.1177/2229411220120301
11. Ramos, B., Torres, J. C., Molina, A., & Martin-de-las-Heras, S. (2019). A new method to geometrically represent bite marks in human skin for comparison with the suspected dentition. Australian Journal of Forensic Sciences, 51(2), 220–230. https://doi.org/10.1080/00450618.2018.1453717
12. Rizwal, A. A., Azahar, N., Reduwan, N. H., & Yusof, M. Y. (2021). Superimposed polygonal approximation analysis comparing 2D photography and 3D scanned images of bite marks on human skin. Egyptian Journal of Forensic Sciences, 11, 1–5. https://doi.org/10.1186/s41935-021-00226-4
13. Sheasby, D. R., & MacDonald, D. G. (2001). A forensic classification of distortion in human bite marks. Forensic Science International, 122(1), 75–78. https://doi.org/10.1016/S0379-0738(01)00437-0
14. Souviron, R., & Haller, L. (2017). Bite mark evidence: Bite mark analysis is not the same as bite mark comparison or matching or identification. Journal of Law and the Biosciences, 4(3), 617–622. https://doi.org/10.1093/jlb/lsx030
15. Tarvadi, P., Kishore, N., Manipady, S., & Shetty, M. (2021). Inter-observer variations in bite marks analysis. International Journal of Medical Toxicology and Legal Medicine, 24(1–2), 178–180. https://doi.org/10.5958/0974-4614.2021.00042.2
16. Verma, A. K., Kumar, S., & Bhattacharya, S. (2013). Identification of a person with the help of bite mark analysis. Journal of Oral Biology and Craniofacial Research, 3(2), 88–91. https://doi.org/10.1016/j.jobcr.2013.04.001