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Credibility of bite mark analysis in forensic odontology: A diagnostic accuracy trail

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Abstract

Introduction: The study explores the credibility of bite mark analysis in forensic odontology, a field often scrutinized for its reliability. Bite marks serve as crucial forensic evidence, potentially linking perpetrators to crime scenes. However, concerns regarding its scientific validation and standardized protocols persist. This research aims to address this gap by conducting a diagnostic accuracy trial. **Methodology:** Ethical clearance was obtained, and informed consent was obtained from participants. A sample of 200 individuals with specific inclusion/exclusion criteria was selected. Full mouth impressions were made, and bite mark replicas were created using standardized procedures. Two experts in forensic odontology assessed the bite marks for matching, and gender identification was performed based on specific criteria.

Statistical Analysis: Data were analyzed using SPSS, measuring sensitivity, specificity, and inter / intra-examiner reliability using kappa statistics.

Results: Out of 200 triads, 189 were analyzed. Inter-examiner reliability for matched positive bite marks was 95.7%. Sensitivity, specificity, PPV, and NPV were also high. Gender identification accuracy ranged from 90.8% to 96.5%. These findings demonstrate the reliability of bite mark analysis in forensic odontology.

Discussion: The study's results indicate that bite mark analysis, when performed by experts and with standardized protocols, is a reliable tool for forensic investigations. The integration of advanced technologies and collaborative approaches may further enhance its credibility.

Conclusion: This research contributes valuable insights into the credibility of bite mark analysis in forensic odontology. It underscores its potential as a reliable forensic tool, provided that experts are involved and standardized protocols are followed. As forensic odontology evolves, embracing technological advancements and collaboration can further strengthen the field's credibility. Bite mark analysis remains essential in delivering justice in challenging cases within forensic science.

Keywords: Bite mark analysis, forensic odontology, credibility, diagnostic accuracy, intra examiner reliability, inter examiner reliability, gender identification

Introduction

Every individual has a unique and distinctive physical and biological makeup. This feature has led to the development of various forensic analyses methods that enable accurate identification. These methods play a significant role in identifying victims during disasters, establishing paternity, criminal investigations, insurance settlement, resolving legal disputes etc. [1-2]. The concept of identification using teeth and associated structures is not new. Literature extensively discusses the identification methods involving analysis of lip prints, dental implants, prostheses, dental restorations, bite marks and imaging techniques for teeth, jawbone, and surrounding structures [3-4]. Many a times bite marks left at the site of crime (on tissues of the victims or on food stuff) will remain as a sole available evidence for identification. Bite marks hold significant forensic value due to their potential to establish a link between a perpetrator and a crime scene [5]. Consequently, careful examination and documentation of bite marks are crucial steps in forensic investigations, helping to provide justice and closure in otherwise challenging cases [6].

A bite mark is an impression or pattern caused by the teeth of an animal or human biting onto a surface, object, or another person's skin. It is a visible mark that can vary in size, shape, and depth, depending on the force applied during the bites. These are either caused by teeth alone or in combination with oral tissues [7].

Human bite marks typically take the shape of an elliptical or circular wound and contain records of the teeth that form it. They range in diameter from 25 to 40 mm, with canines leaving triangular markings and incisors a rectangular mark^[8]. Size, shape, and pattern of the incisal or biting edges/surfaces of upper and lower anterior teeth are specific to an individual^[9]. It is reported that the mechanics of bite marks is not specifically defined; it is usually affected by time and force of the bite along with other physiologic and mechanical factors^[10].

First reported case of bite mark analysis is attributed to Dr. Paul Jeserich, a German forensic scientist. However, it was not until 20th century that it gained more recognition and application in forensic science. Since then, bite mark analysis has become a major focus of research in forensic odontology^[11]. Common methods for inspecting bite marks are based on the interpretation of photographic evidence in which a suspect's bite is collated with models of their teeth^[12]. The general logic behind forensic identification through bite marks involves examining the distinctive patterns, spacing, and characteristics of dental impressions left on a victim's skin or other surfaces, and then comparing them to the dental records of potential suspects to establish a potential match or exclusion, aiding in the investigation and prosecution of criminal cases but lacks comprehensive scientific validation and standardized protocols due to limited research and inadequate support from existing literature^[13]. Over the past few decades, forensic odontologists have been testifying in courts claiming the ability to accurately identify the individuals who were the sources of bite marks^[14]. These claims have been questioned by various authors and experts who have pointed a lack of published literature assessing their accuracy.^[15] It is hence imperative to conduct field trials on diverse populations for establishing accuracy of bite marks in identification^[16]. Credibility of bite mark analysis in forensic odontology has also recently been questioned due to concerns regarding its reliability^[17]. It is thus critically important to continue research to assess the accuracy and reliability of bite marks, while also recognizing its potential limitations^[18]. This study is thus undertaken with an aim of assessing the credibility of bite mark analysis in forensic odontology.

Methodology

This diagnostic accuracy trial was conducted in Ethical clearance to conduct the study was obtained from Institutional Ethical Committee, KVG Dental college and hospital bearing the number IECKVGDCH/UG/01/2022-2023. Informed consent was obtained from the participants before the start of the study.

The sample size was calculated using the reported 72% accuracy rate of the ABFO system^[19]. Calculated sample size was 188, rounded off to 200 to compensate for sampling loss if any. Required sample was drawn from the participants reporting to outpatient department (OPD) of the institute, satisfying the inclusion/ exclusion criteria over a period of time (eight months). Apparently healthy adults, willing to participate in the study, with a minimum 20 permanent teeth in the anterior region were included in the study. Participants with various grades of teeth mobility/ jaw fractures and obvious oral lesions and/or cysts were excluded.

The investigators underwent training in the proper

documentation of bite marks and the creation of impressions, as outlined in the study. This training included the process of taking alginate impressions and with wax blocks as necessary protocol. Participants were trained and retrained to bite on softened wax blocks of uniform dimensions (4 cm×3 cm×1 cm) under optimum pressure. After satisfaction with the training, participants were included in the study. Basic demographic details were recorded and full mouth impressions were made with alginate impression material. Impressions were immediately sent to the lab. They were poured with type 3 Goldstone (Green) dental stone. Casts were removed after the final set, trimmed and coded with English alphabet codes (A, B, C.... AA,AB...) [Photograph No. 1]. After making of the impressions, participants were made to bite on a block of modelling wax [Photograph No. 2] of 4 cm×3 cm×1 cm under an optimum amount of pressure to obtain impressions of bite marks. Positive replicas of the bite surface were immediately obtained in the lab by gently injecting a light body addition silicone from a centre point to periphery using a plastic gun. It was then picked up with a heavy body silicone (Affins) [Photograph No.3]. And poured with Type 3 Goldstone dental stone and was correspondingly coded using three digits Indo-Arabic numerical system allotted using a random number table (001,002.....) [Photograph No.4]. Additionally, bite marks on the wax blocks were retrieved by gently pouring Goldstone (Yellow) dental stone upon the wax blocks and made to set for half an hour. Once set, Positive replicas of the bite marks were obtained and were correspondingly coded with Roman numerical system using random number tables (I, II, III....) [Photograph No.5]. A key pertaining to all codes was generated and maintained as a document for further reference. The procedure was repeated for 100 matched trios and 100 unmatched trios (Alginate casts, Positive replicas and negative replicas). Coded dental casts, positive bite marks along with their negative counterparts were jumbled and were provided to two experts in the field of Forensic Odontology for matching by manual docking method as per the ABFO criteria^[20]. Identification of gender was additionally performed by measuring arch length, width of central incisor, inter canine distance on positive replicas of bite marks as described in the literature^[21]. Matching and identification exercises were performed by two experts at two different points of time. Interpretations by the experts were recorded on a prepared pro-forma and were provided to the principal investigator for further analysis.

Statistical Analysis

Data were analysed using the SPSS version 27. Sensitivity and Specificity was measured for interpretation of two experts and inter examiner reliability and intra examiner reliability was analysed using kappa statistics. P-value <0.05 was considered statistically significant.

Results: A triad of 200 casts from participants with their respective positive replicas of bite marks and negative replicas of their bite marks were obtained. A total of 11 triads were eliminated from analysis as they were found to have abrasions, artefacts, damaged incisal ridges/edges and air bubbles. Thus, a total of 189 triads were available for forensic interpretation. The bite marks were interpreted by two technical experts and the data was recorded on an excel sheet.

Interpretation of both experts with regards to matched pairs of casts with positive bite marks revealed an inter-examiner reliability of 95.7%, and intra-examiner observations showed no statistically significant difference between both the expert [p= 0.857]. Further analysis of observations made by the experts I and II revealed a sensitivity of 99.1% vs. 98.7% at p =0.926, specificity of 98.5% vs 96.7% at p=0.783, positive predictive value [PPV] 98.2% vs. 94.5% at p= 0.653 and negative predictive value [NPV] 98.9% vs. 98.3% p=0.865 respectively [Table No.1].

Additional analysis of matched pairs of casts with negative bite marks were performed which revealed an inter examiner reliability of 93.7%. Intra examiner reliability was good with statistically non-significant differences among both the examiners [p= 0.784]. Further analyses revealed a sensitivity of 98.4% vs. 96.7% at p =0.853, specificity of 94.5% vs. 93.5% at p=0.897, PPV 97.1% vs. 96.9% at p=0.835 and NPV 98.7% vs. 97.5% at p=0.896 between Expert I and II respectively [Table No.2].

Gender identification was performed on the casts by measuring arch length, width of central incisor, inter-canine distance and inter canine ratio (maxillary and mandibular) according to the criteria described by Pagare N *et al.* [21] It revealed an accuracy of 96.5% for the first expert vs. 94.3% by the second expert with positive replicas and accuracy of 92.5% for the first expert vs. 90.8% by the second expert with negative replicas, disagreement between the experts

was statistically not significant [Table No.3].

Table 1: Credibility of matched pairs of casts with Positive bite marks between Expert No.1 and Expert No.2.

Parameters	Expert No.1	Expert No.2	p value
Inter Examiner Reliability	95.7%		
Intra Examiner Reliability	97.9%	96.8%	0.857
Sensitivity	99.1%	98.7%	0.926
Specificity	98.5%	96.7%	0.783
Positive Predictive value	98.2%	94.5%	0.653
Negative predictive value	98.9%	98.3%	0.865

Table 2: Credibility of matched pairs of casts with Negative bite marks between Expert No.1 and Expert No.2

Parameters	Expert No.1	Expert No.2	p value
Inter Examiner Reliability	93.7%		
Intra Examiner Reliability	95.9%	93.8%	0.784
Sensitivity	98.4%	96.7%	0.853
Specificity	94.5%	93.5%	0.897
Positive Predictive value	97.1%	96.9%	0.835
Negative predictive value	98.7%	97.5%	0.896

Table 3: Gender matching using casts by Expert No.1 and Expert No.2

Casts	Expert No.1	Expert No.2	p value
Positive Replicas	96.5%	92.3%	0.618
Negative Replicas	92.5%	90.8%	0.782

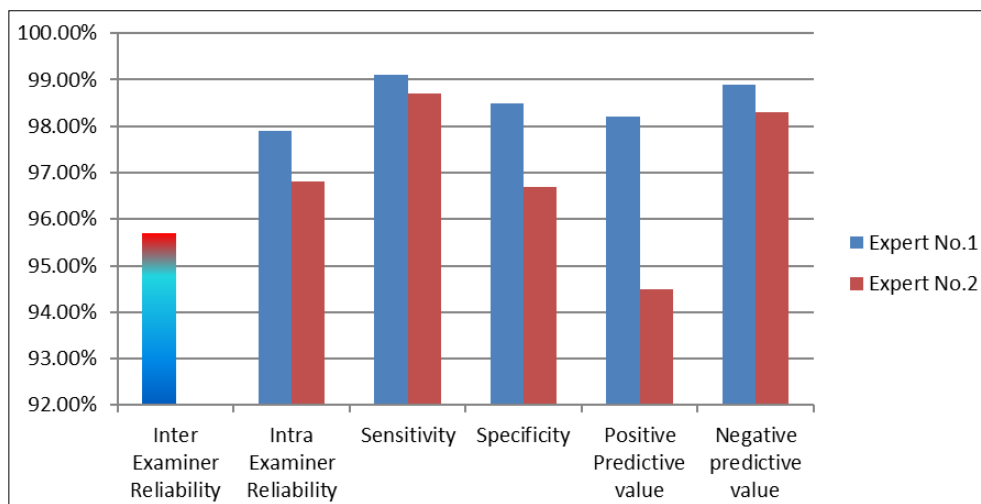


Fig 1: Credibility of matched pairs of casts with Positive bite marks between Expert No.1 and Expert No.2.

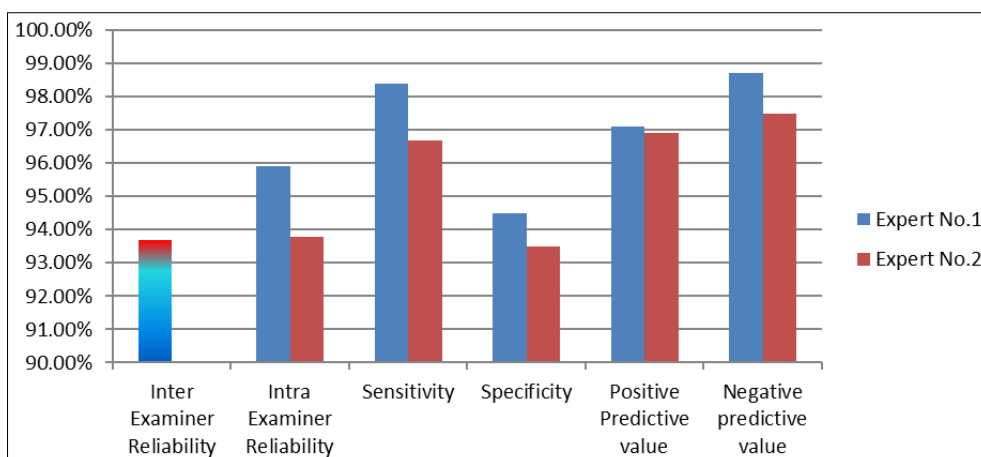


Fig 2: Credibility of matched pairs of casts with Negative bite marks between Expert No.1 and Expert No.2

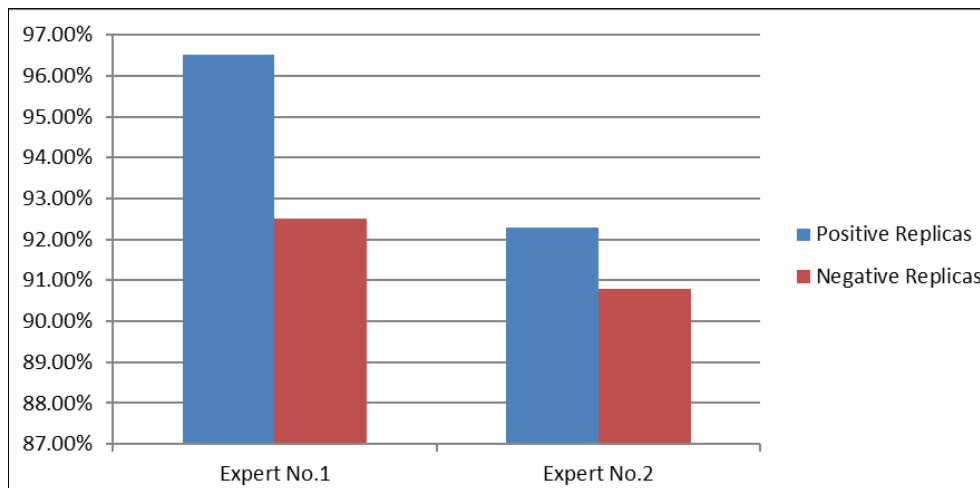


Fig 3: Gender matching using casts by Expert No.1 and Expert No.2

Discussion

Bite mark analysis has been widely used as a forensic tool in criminal investigations and judicial proceedings [1]. However, there have been debates and controversies related to their reliability, credibility and accuracy [2]. It is critically important to establish the scientific validity and diagnostic accuracy of bite mark analysis to ensure its credibility in the field of Forensic Odontology [5]. This study was thus undertaken with a name of assessing the credibility of bite marks in forensic identification. We have analysed credibility of bite marks by assessing inter and intra examiner reliability in interpreting bite marks, as well as assessing four important parameters *viz.* sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) [14]. The findings of this study have to be interpreted with caution as no studies of such kind have been reported in literature. Our study mainly focuses on the credibility of the bite marks (positive and negative) using the manual docking method.

Studies on bite mark analysis have traditionally been concentrating upon preservation of bite marks on various food items *viz.* a study by Rakesh K G *et al.* on comparison and analysis of bite marks on the cheese and bananas reported that, in banana, there was an accuracy of 82.33% whereas in Paneer (Cottage cheese) accuracy was 28.5%, suggesting that different food materials have different rates of accuracy in accurate determination through bite marks [22]. Fernando Rivera-Mendoza *et al.* reported that Bite mark analysis in inanimate objects and foodstuffs seems to offer more reliability than that on the body or skin [14]. Published literature, technical notes and case reports have addressed different procedures which can be direct or indirect procedures *viz.* computer based, hand traced, photographic, xerographic, radiographic analyses to identify perpetrator in the forensic arenas [6, 8, 14, 15, 18]. This study is first of its kind and intends to assess the accuracy of bite mark analysis in forensic odontology. We have compared 189 casts, positive bite mark replicas, and negative bite mark replicas, by two technical experts and it demonstrated high intra (97.9% for Expert No. 1 and 96.8% for Expert No. 2) and inter examiner reliability (95.7%). There were no statistically significant differences between the experts in terms of sensitivity, specificity, positive predictive value and negative predictive value for positive bite marks replicas. Similarly the analysis demonstrated substantial intra- and inter-examiner reliability for negative bite marks replicas

indicating the credibility in identifying positive and negative bite marks.

Gender interpretation yielded an accuracy rate of 96.5% for Expert No. 1 and 94.3% for Expert No. 2. The inter-examiner gender interpretation results were not statistically significant, suggesting that both experts performed gender matching comparably. Overall, the findings demonstrated a high level of agreement and reliability between the two experts in interpreting both positive and negative bite marks. Their sensitivity, specificity, PPV, and NPV values indicate the credibility in bite mark analysis. Similarly, their accuracy in gender interpretation further underscores the use of bite marks in forensic investigations. These results contribute to the existing knowledge in the field and emphasize the importance of skilled experts in obtaining accurate and reliable forensic outcomes [23].

Understanding the strengths and limitations of bite mark analysis can contribute to the development of standardized protocols, enhance the accuracy of forensic investigations, and support the legal system in making informed decisions based on scientific evidence [24]. Furthermore, the assessment of gender interpretation through bite mark analysis adds another dimension to this research, as it explores the potential application of this method beyond individual identification [19]. By investigating the accuracy of gender identification based on bite mark analysis, this research addresses a relevant and practical aspect of forensic analysis [25].

Overall, this research aims to contribute to the ongoing discourse on the credibility of bite mark analysis and its potential role in forensic investigations. By examining the diagnostic accuracy and reliability of experts, this study provides valuable insights that can inform forensic practitioners, legal professionals, and the scientific community regarding the use and interpretation of bite mark evidence in forensic odontology.

In the evolving field of forensic odontology, future advancements are likely to leverage cutting-edge technologies and collaborative approaches to further enhance the credibility and accuracy of bite mark analysis. The utilization of computer-based tools and algorithms for bite mark analysis has the potential to revolutionize the field. Computer docking techniques can provide a standardized and objective method for comparing bite marks, reducing the subjectivity associated with manual assessments. These technologies can analyze a vast array of

parameters, such as tooth morphology and alignment, to generate more precise and reliable results. By automating certain aspects of the analysis, forensic experts can focus on interpreting the data and providing their expertise in a complementary manner.

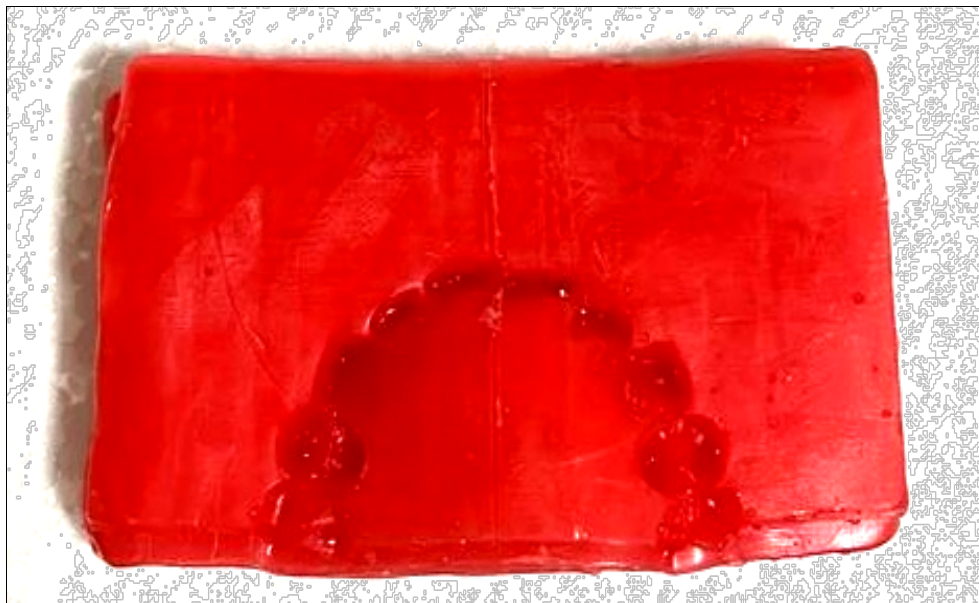
Additionally, the inclusion of multiple investigators in bite mark analysis can bring diverse perspectives and skills to the table. Collaborative efforts among experts from various backgrounds can enhance the reliability of bite mark identifications. Each investigator may bring unique insights and experiences, leading to more comprehensive and accurate assessments. Moreover, the validation and cross-verification of results by multiple investigators can further bolster the credibility of bite mark analysis in forensic investigations.

In future research we recommend to develop standardized protocols that incorporate computer docking techniques and

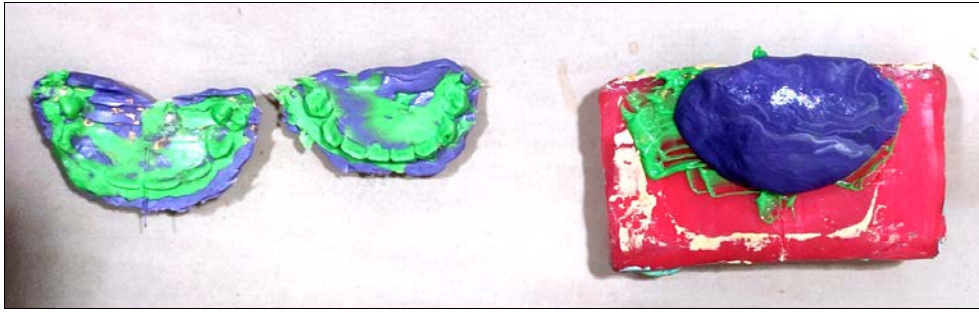
establish guidelines for collaboration among forensic experts. By combining technological advancements with the collective expertise of multiple investigators, the field of forensic odontology can continue to evolve, ensuring that bite mark analysis remains a valuable tool in criminal investigations and judicial proceedings. In addition to the standardization of protocols and collaboration among forensic experts, future research in the field of forensic odontology should also focus on advancements in simulating mouth-like environments for more accurate bite mark analysis. Developing highly realistic synthetic models of the oral cavity complete with soft tissue properties, tooth structure, and dynamic elements like saliva, could significantly improve the reliability and precision of bite mark analysis. These advancements will contribute to the ongoing efforts to strengthen the scientific validity and diagnostic accuracy of bite mark analysis, ultimately enhancing its credibility in the realm of forensic science.



Photograph 1: Stone casts of the participants obtained through alginate impressions coded with English alphabets.



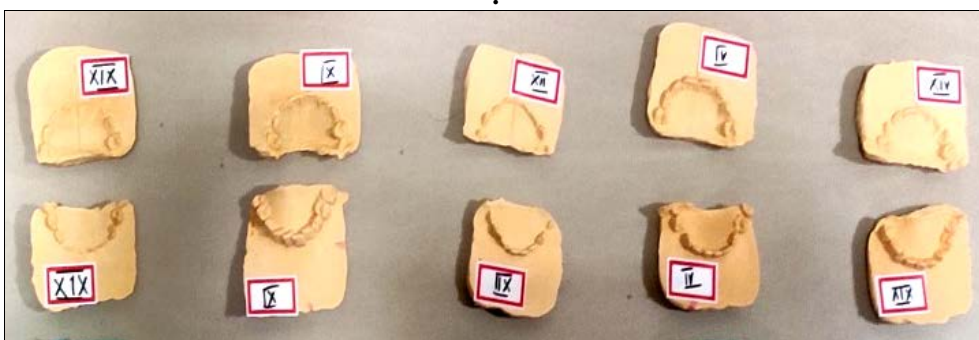
Photograph 2: Participants' bite mark obtained on a block of modelling wax.



Photograph 3: Positive replicas of bite marks obtained using heavy body silicone (Affins)



Photograph 4: Negative replicas of bite marks obtained using positive silicone bite marks on type III goldstone



Photograph 5: Positive replicas of the bite marks obtained from the modelling wax blocks and correspondingly coded with Roman numerals (I, II, III....)

Conclusion

This pioneering study on the credibility of bite mark analysis in forensic odontology has yielded promising results, showcasing a high level of inter and intra-examiner reliability, sensitivity, specificity, and predictive values in the interpretation of both positive and negative bite marks. Moreover, the successful application of bite mark analysis in gender identification adds a valuable dimension to its forensic utility. These findings underscore the potential of

bite mark analysis as a reliable tool in criminal investigations and judicial proceedings, provided it is performed by skilled experts and standardized protocols are established. Furthermore, the integration of cutting-edge technologies and collaborative approaches holds the promise of further enhancing the accuracy and credibility of bite mark analysis in the evolving field of forensic odontology. As we continue to refine our methodologies and embrace technological advancements, bite mark analysis

can play a vital role in delivering justice and closure in challenging cases, reaffirming its importance in the realm of forensic science.

Funding Declaration

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Ethical Clearance

Ethical clearance for our research study was obtained from the Institutional Ethics Committee (IEC) K.V.G Dental College and Hospital, Sullia, DK. The IEC plays a crucial role in ensuring that research involving human participants adheres to the highest ethical standards and safeguards the rights and well-being of those involved. The ethical clearance provided by the IEC, with CDSCO Registration Number ECR/1119/Inst/KA/2018, signifies that my research study has undergone a rigorous ethical review process and has been deemed ethically sound and compliant with established ethical principles and regulations.

Author's contribution

Anujna B M, Suman B and Nusrath Fareed conceptualized the study. Suman B and Anujna B M were the principal investigators. Anujna B M, Suman B, Nusrath Fareed, Medha Babashet and Srikanth supported the data collection in the field. Suman B and Nusrath Farred performed the statistical data analysis and contributed to writing the paper. Suman B, Anujna B M, Nusrath Fareed, Medha Babashet and Srikanth H S contributed to the critical interpretation of the data. Suman B drafted the first version of the paper and was involved in conceptualizing the study and data interpretation. All authors gave their final approval and agree to be accountable for all aspects of the work.

Competing Interest declaration: None

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