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Assessment of Accuracy of Digitally Generated Overlays Compared to Conventional Overlays for Simulated Bitemark Analysis on Cheese Blocks

Sridhar Javangula[1*], Kannan Natarajan[2], Rakesh Kumar Manne[3], Venkata Sarath Prathi[4], Swapna Sridevi[4] and Sravya Reddy V.[5]

[1]Post-Graduate, Department of Oral Medicine and Radiology, Dr NTR University of Health Sciences, Narayana Dental College and Hospital, Nellore - 524002, Andhra Pradesh, India; drsridharj@gmail.com
[2]Professor and Head, Department of Oral Medicine and Radiology, Dr NTR University of Health Sciences, Narayana Dental College and Hospital, Nellore - 524002, Andhra Pradesh, India
[3]Professor, Department of Oral Medicine and Radiology, Dr NTR University of Health Sciences, Narayana Dental College and Hospital, Nellore - 524002, Andhra Pradesh, India
[4]Associate Professor, Department of Oral Medicine and Radiology, Dr NTR University of Health Sciences, Narayana Dental College and Hospital, Nellore - 524002, Andhra Pradesh, India
[5]Senior Lecturer, Department of Oral Medicine and Radiology, Dr NTR University of Health Sciences, Narayana Dental College and Hospital, Nellore - 524002, Andhra Pradesh, India

Abstract

Background: The bite injury or bite mark is examined as corroborative evidence in serious crimes such as rape, murder, robbery, and other forms of physical and sexual violence. The goal of this study was to comparatively evaluate the accuracy of overlays made with a digital, two-dimensional method compared to those made by directly tracing bite marks and using bite mark images obtained with a photocopier. **Materials and Methods:** A total of 61 participants were included in the study, of whom 31 were males with ages ranging between 18-65 years and 30 were females. The simulated bitemarks on the cheese block were used to prepare three sets of overlays, first by the way of hand-tracing, followed by a photocopying technique and a third set of overlays prepared using computer software called Adobe Photoshop version CS6 on a personal computer. Each pair of overlays and the study cast was then matched using 5-point criteria given by the ABFO guidelines, and a score between 0-3 was assigned to each observation. **Results:** The overall scores obtained in each group (A-hand-tracing, B-photocopy, C-digital method) were then compared amongst themselves for associations. By applying the Kruskal Wallis ANOVA test, the manual technique had a 29.5% positive matching rate, in photocopying method 32.8%, and the digital overlay 72.1%, which was significant. **Conclusion:** In conclusion, the digital overlay method outperformed the hand-tracing and photocopying methods in terms of minimizing the subjective errors and was found to be the most precise and dependable method.

Keywords: Adobe Photoshop, Analysis, Bitemark, Cheese Blocks, Digital, Overlay, Photocopying

Introduction

The bite injury or bitemark is examined as corroborative evidence in serious crimes such as rape, murder, robbery, and other forms of physical and sexual violence. Food, flesh, cigars, pipes, and musical instruments left at the crime scene may contain these marks[1]. The core philosophy of bitemark analysis, according to Pretty and Turnbull, is founded on two assumptions: first, that human teeth are unique, and second, that sufficient detail of the uniqueness is provided for the identification process of the suspect[2].

**Author for correspondence*

Bitemarks have now been discovered to provide detail comparable to the minute and exclusive detail provided by fingerprints[3]. Life-and-death decisions can hinge upon the accuracy with which such evidence is interpreted. One of the most remarkable, difficult, and sometimes troublesome challenges in forensic dentistry is the recovery, identification, and analysis of the bite marks in criminal cases with associated acts of violence.

Bitemark analysis can be done using a variety of methods, including dental stone impressions and hand-tracing from dental study casts, photography, photocopying, and computer-assisted overlay production. In reality, validating the methodologies used in the physical comparison between the biter's teeth and the physical injury is an important part of determining the validity of bitemark analysis[4].

The goal of this study was to comparatively evaluate the accuracy of overlays made with a digital, two-dimensional method compared to those made by directly tracing bitemarks and using bitemark images obtained with a photocopier. The aim was to see how accurately the computer-generated overlays matched the dentition models with the bitemarks on the cheese blocks, and these findings were compared to the other conventional methods namely, the hand-tracing and photocopying methods.

Materials and Methods

Study Design

The study participants were recruited from out-patient section of oral medicine and radiology at the Narayana Dental College and Hospital, Nellore, Andhra Pradesh. After a thorough scientific evaluation, the Institutional Ethics Committee (IEC) granted ethical approval for the research project before the subjects were recruited. IEC/NDCH/2019/P-26, dated November 21, 2019, is the approved IEC registration number. This study was registered in the Central Trials Registry - India. (REF/2021/11/049133).

Inclusion Criteria

Patients with a full set of natural upper and lower anterior teeth who expressed a willingness to participate in the study were recruited.

Exclusion Criteria

Patients with orthodontic appliances, intra-oral prosthesis, impaired mouth opening, loss of anterior teeth, gingival and periodontal diseases, developmental tooth anomalies, severe wasting diseases of the teeth (i.e., attrition and abrasion), allergies to cheese and milk products, finally those not willing to participate.

Preparation of Overlays Using Manual Method

A transparent acetate sheet was placed on the cheese block with the simulated bitemarks, and the incisal/biting edges from canine to canine of the upper jaw were traced using a Felt-tip black pen, as clearly as possible. This is labelled and stored for further matching.

Preparation of Overlays Using Photocopying Method

The cheese blocks with simulated bitemarks are placed facing the scanner on a flat-bed scanner, and the image quality is adjusted to 300 dpi and best contrast. Using an ABFO No. 2 scale as a reference, each image is scanned. The enhanced image is then printed directly onto transparent sheets, and these overlays are used for matching with the study casts.

Preparation of the Digital Overlays From Simulated Bite Marks and the Cast (Using Adobe® Photoshop® CS6 Software)

The upper casts were pressed against the ink pad so that the edges of all teeth from canine to canine are marked. A digital image of each cast with the ABFO No. 2 scale as reference is then captured and stored directly in the computer for further steps. The image of the simulated bite marks on the cheese blocks is taken and transferred directly to the computer. Both the images of casts and simulated bitemarks on cheese blocks were opened in Adobe Photoshop CS6 software. Then, a gradual selection of the biting edges of the teeth on the study cast and the simulated bite marks on the cheese blocks

was done using the 'Lasso' selection tool to obtain outlines of the biting edges from the cheese blocks and the study casts.

Grouping Overlays with Study Casts

The obtained Overlays using these three methods were grouped as under: Group A – The overlay degenerated by hand-tracing method, Group B – The overlay generated by the photocopying method and Group C – The overlay generated by the digital method using Adobe Photoshop® CS6.

Scoring Criteria

The following 5 criteria were followed to choose the most appropriate match. Criteria 1 (Inter-canine (ICD) distance), Criteria 2 (Labiolingual thickness, medial-lateral width and spacing of the incisal edges of the anterior teeth), Criteria 3 (Rotations of teeth from their position in the arch), Criteria 4 (Alignment of each tooth in the arch form) and Criteria 5 (Biting edge curves of the incisors).

Matching Criteria

The scores were then assigned as follows: '0' = 'No Match' (none of the criteria match), '1' = 'Slight Match' (at least one criterion matches), '2' = 'Moderate Match' (two to four criteria match), '3' = 'Excellent Match' (all five criteria match). A score between 0-3 is assigned for each sample matched. According to a modified version of the American Board of Forensic Odontology (ABFO) bite mark grading methodology, the accurate match received the highest score[5].

The Procedure to Compare and Match Pairs

The overlays obtained by the manual method are first placed on the incisal edges of the study cast, the matching criteria are followed and a score is given at the end of each matching. The study cast is then placed on the transparent acetate sheets with the scanned bitemarks from the cheese blocks in procedure 2, and the same matching criterion is repeated and a score of 0-3 is allotted for the match. While matching the digital overlays, first, using the Adobe® Photoshop CS6 software, a transparent layer was created over the original bite mark image from the photograph of the imprint on the cheese blocks (Figure 1). Another layer was created using the scanned images of the ink-marked biting edges of the study casts and saved as a separate binary image (Figure 2). These two images could be placed over each other on a single screen to be compared for matching using the criteria (Figure 3). Part of the ABFO No. 2 scale was made visible to accommodate the placement of the image over the original photograph with 100% exactitude. A score between 0-3 is assigned for each sample matched.

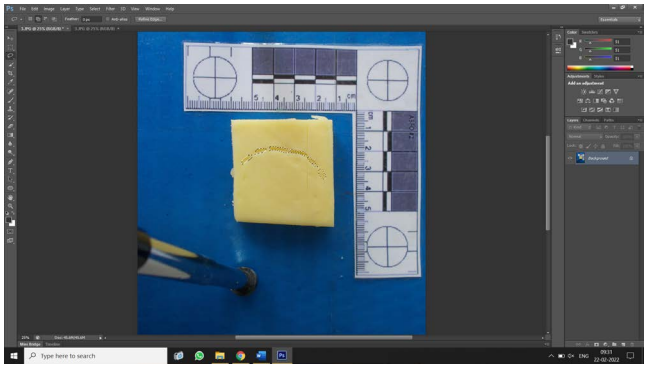

Figure 1. Tracing by 'Lasso' tool in photoshop software on simulated bitemarks made on the cheese block.

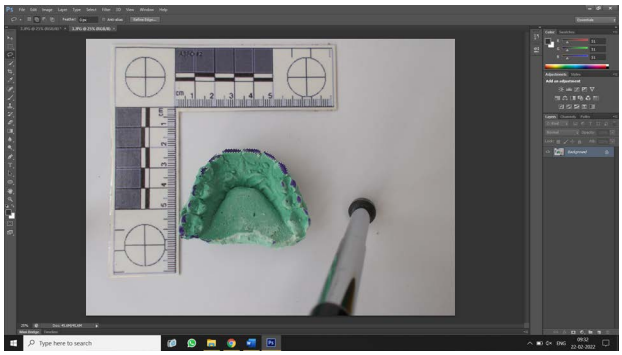

Figure 2. Tracing by 'Lasso' tool in photoshop software on study casts with incisal edges marked with ink.

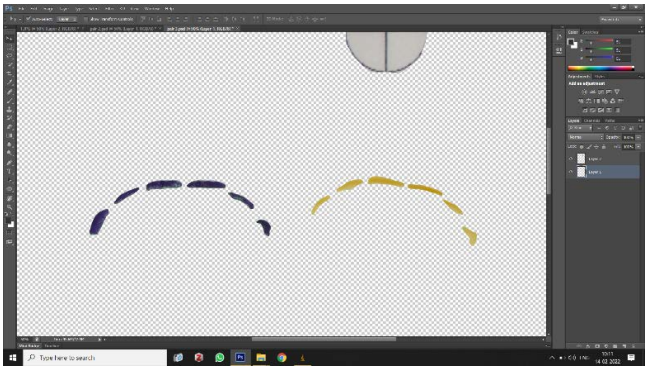

Figure 3. Comparing with superimposition of the two digital overlays in a single layer and final scoring.

Results

Study Sample

A total of 61 participants were included in the study, of whom 31 were males with ages ranging between 18-65 years (mean ages: 31.6±13.2 years) and 30 were females (mean ages: 32.4±12.1 years). For each pair that was compared using the three techniques, a score of 3 was assigned for a more than 4-point match, a score of 2 for 2-3 criteria matching, a score of 1 for just one point matching, and a score of 0 for no criteria match at all. The Kruskal Wallis ANOVA test was used to compare the three methods of matching the criteria: manual, photocopying, and digital overlay methods. The manual technique had a 29.5% positive matching rate, the photocopying method had a 32.8% positive matching rate, and the digital overlay approach had a 72.1 percent positive matching rate, which was judged to be significant ($\chi^2 = 32.9$, $P < 0.001$). (Figure 4 and Table 1).

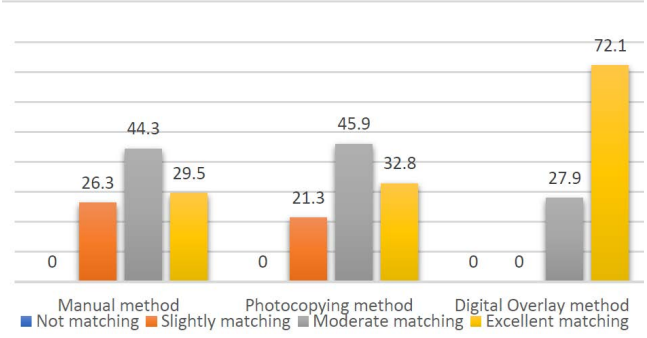

Figure 4. Grading scores in each group.

Table 1. Comparing manual, photocopying, and digital-overlay methods

Group	N	χ^2 value	P value
A	61	32.9	< 0.001*
B	61		
C	61		

Kruskal Wallis test $p < 0.05$ *(significant)

Discussion

The hand-traced manual method was the only way to generate overlays in the past (around 1966). Predisposing factors include the morphology of the dental arch, inter-canine distance, buccolingual version, mesial or distal drifting of teeth, spacing between teeth, rotation of teeth, the curvature of biting edges, missing teeth, developmental defects, restorations, and wear patterns. These traits add to each tooth's individuality, making it distinct from the others. These characteristics, along with other features like malalignment, developmental abnormalities, and restored teeth, were taken into account in the current study's exclusion criteria[6].

For the past 60 years, numerous studies utilising various bite mark analysis methodologies have been conducted. Although manual methods have been used since 1966, Dailey (1991) was the first to use office photocopy machines to create transparent overlays[7]. Sweet and Bowers assessed five approaches in use in 1998 and concluded that computer-generated overlay methods were superior to the others, citing improved accuracy and objectivity as reasons[8].

Anne, *et al.,* compared the reliability of two methods for producing computer-generated bite mark overlays with Adobe Photoshop in 2005[9]. Using a magical wand selection tool was one technique, while flipping the glowing edges was another. Both procedures were found to be reliable for producing bitemark overlays in the assessment of teeth.

Various writers have used Manual, Radiographic, and Computer-Assisted bite mark analysis approaches in the literature. Indirect approaches for bite mark analysis were utilised by Van der Velden, *et al.,*[10] Patil, *et al.,*[11] Rathore, *et al.,*[12] Osman, *et al.,*[13] and Gopal and Anusha,[14] who established that computer-assisted methods were preferable. The Computer-Assisted overlay generation method for bite mark examinations was later presented by Naru and Dykes[15].

Bite marks can be examined using a variety of methods, including direct and indirect methods. The direct method employs a model of the suspect's teeth, which is then compared to life-sized images of the bitemark, whereas the indirect method employs translucent overlays on which the suspect's biting edges are recorded. Place a piece of acetate over the dental cast of the suspect's teeth and trace the biting edges with a Felt-tip marker pen to create transparent overlays. The photocopier-generated overlay was found to be more precise than hand-tracing by Kouble, *et al.*,[16] and Maloth, *et al*[17]. In their study, Sweet and Bowers concluded that the subjective technique of hand tracing directly on the casts should be avoided[8].

Rai, *et al.,*[18] evaluated bite mark analysis on cheese and clay using the direct (docking analysis) and indirect (overlay method) methods, concluding that when the indirect method comparison is unclear, the direct method comparison is likely to match. McKenna, *et al.,*[19] reported a case of bitemarks on chocolates recovered from a chocolate factory theft scene, where it was discovered that direct and photomicrographic comparisons of the chocolate casts and the suspect's dentition revealed correspondence between their unique characteristics, leading to the conviction of chocolate thieves. Aboshi, *et al.,* described a fire at a snack bar in Mount Gambier, South Australia, in which the culprit was identified by matching computer-generated images of the victim's biting surfaces with bite marks on cakes recovered from the crime scene[20]. Bernitz, *et al.,* and Pretty, *et al.,* even documented a murder case in which bitemarks on a slice of cheese were recorded. Bite marks left on pliable things like cheese have a higher chance of being accurately identified[21,22].

In bite mark analysis, the results of the computer-assisted overlay creation approach are found to be more accurate than the Xerographic method. There is no subjective bias from the operator because the software Adobe Photoshop-CS6 does all of the biting edge selection. The software's pixel-based selection, on the other hand, is entirely dependent on the image's quality and the surrounding light during scanning. The sharper the image scanned must be, the more precise the biting edge selection can be. The first pixel must be chosen carefully because it will serve as a reference for the software when determining other pixels with similar values.

The computer-assisted overlay generation (indirect) methodology was easier to use and took less time than the other methods. However, because this technique is the result of an objective study, it was found to be more accurate when applied to bite marks formed by a dentition with some distinctive traits such as rotation, spacing, crowding, and so on. Sweet and Bowers compared computer-generated overlay to different overlay generation techniques, concluding that computer-generated overlay is the most accurate and gold standard technique for bite mark analysis[8].

When bitemark analysis was done using life-size images of dental casts and the bitemark pattern on the three foodstuffs, and photographs with good quality and angulation, and in situations where teeth revealed some distinctive features, the computer-assisted overlay technique had a higher accuracy. Our findings were in accordance with those of Stavrianos, *et al.,* who found that the computer-assisted overlay generation methodology for bite mark analysis was as accurate as of the manual docking method in situations of a bite mark on an apple and that it could be used on a variety of substrates[23].

The purpose of this study was to compare the accuracy of digitally created overlays to other traditional methods such as hand-tracing and overlays printed on transparent sheets using a photocopier. The accuracy of recreated aspects of the teeth in the bite marks, such as shape, size, and rotations, was compared between the three overlay procedures, which could be checked and documented for subsequent examination. The 2-D computer-generated method used digital photographs of dental study casts to create overlays, which were found to be quite accurate.

The inter-canine distance, labiolingual thickness, medial-lateral width and spacing of the incisal edges of the anterior teeth, rotations of the teeth from their position in the arch, alignment of each tooth in the arch form, and the biting edge curves of the anterior teeth were the main comparison points while trying to assign a matching score for each of the "pairs" in the study model. Previous bite mark modelling research has employed human and nonhuman skin, as well as chocolate, apple and Styrofoam, clay, and other materials, however, cheese has not been used as frequently in these investigations. The simulated bite marks on cheese blocks were collected, and a comparison was made using the aforementioned criteria. A final score was assigned to each pair, and statistical analysis was performed using the Kruskal Wallis ANOVA test to compare the results. The Mann-Whitney U test was used to determine the significance of association between each of the traditional methods and the digital method, as well as between them.

Statistical analysis revealed that the computer-generated overlay method was the most accurate of the three methods for all of the study's criteria. The results showed that the matching scores based on the incisal margins and biting areas vary significantly between the three overlay fabrication processes. The use of the magic-wand in Adobe Photoshop CS6 to map the incisal and bite edges on the digital images of the cheese blocks was an indispensable tool to improve the accuracy of the overlay so produced and the feasibility with which the digital overlays of the bitemarks and the dental study casts were prepared using transparent layers of images and the easy manoeuvrability of these layers, allowing them to move over one another for studying the criteria of matching.

Conclusion

In this study, the matching done with dental study casts and computer-generated overlays using Adobe Photoshop CS6 had the highest percentage of "excellent" matches (72.1%), followed by photocopying (32.8%) closely followed by the hand-tracing method with 29.5% ('excellent' matching score). Hence, the findings of this study imply that, out of the three overlay preparation methods evaluated, the computer-generated or the digital overlay technique may produce more consistent outcomes that are easier to replicate and need less money and time to complete. However, like with any forensic analysis study, more research is needed to develop a technique that has more specificity and reduces the percentage of erroneous criminal implications that may be generated by subjective errors while processing bitemark data.

To summarize and conclude, digital-overlay method outperforms the hand-tracing and photocopying methods in terms of minimizing subjective errors. In our study, the digital overlay preparation method was found to be the most precise and dependable.

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