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A Comparison Between Direct and Indirect Methods Available for Human Bite Mark Analysis*

ABSTRACT: Comparison techniques used in bite mark analysis are many and varied, the choice of technique depending largely on personal preference. Until recently, no one technique has been shown to be better than the others, and very little research has been carried out to compare different methods. This study evaluates and compares the accuracy of direct comparisons between suspects' models and bite marks with indirect comparisons in the form of conventional traced overlays of suspects' models or a new method using photocopier-generated overlays. Artificial bite marks in pigskin were made using standardized sets of models and recorded as photographs and fingerprint powder lifts on tape. The bite mark photographs and fingerprint lifts were coded and randomized so that a blind comparison could be made with the models, traced overlays, and photocopier-generated overlays using a modified version of the American Board of Forensic Odontology Scoring (ABFO) System for Bite Marks.

It was found that the photocopier-generated overlays were significantly more accurate at matching the correct bite mark to the correct models irrespective of whether the bite mark was recorded photographically or as a fingerprint lift. The photocopier-generated overlays were also found to be more sensitive at matching the correct bite marks to the correct models than the other two methods used. The modified ABFO scoring system was able to discriminate between a correct match and several incorrect matches by awarding a high score to the correct match.

KEYWORDS: forensic science, forensic odontology, bite marks, bite mark analysis, overlays

Direct and Indirect Comparisons

Bite mark analysis is usually carried out by comparison techniques, which can be either direct or indirect (1). Choice of technique is based largely on operator preference. Direct methods involve the use of a model of the suspect's teeth, which is then compared to life-size photographs of the bite mark.

Indirect techniques involve the use of transparent overlays, in one form or another, on which the biting edges of the suspect's teeth are recorded. Transparent overlays can be produced simply by placing a sheet of acetate over a cast of the suspect's teeth and then tracing the biting edges with an indelible marker pen; however, this method of freehand tracing can introduce bias and errors. The tracing method can be modified, and Dailey (2) used a photocopier to produce life-size copies of the model onto paper, which were then traced onto acetate. The photocopier can also be tested for accuracy at producing life-size copies using a technique also described by Dailey (2). This method makes it easier to produce a freehand tracing of the biting surfaces of the teeth, but it still may involve a certain amount of bias. Some operators have produced tracings from artificial bites made in skin (3).

Due to the problems of producing an accurate freehand tracing of the biting surfaces of the teeth, many forensic dentists have tried to develop methods that are more objective and reliable. To reduce the amount of interference or bias induced by an operator when making a traced overlay, some have used photographic overlays or transparencies, but others have sometimes found these not clear enough to see through to make an accurate comparison with the bite mark (4).

Overlays showing the bite mark itself, in negative format, have also been produced using photographic techniques and compared with a photograph of a model that has been painted black except for the biting surfaces of the teeth, but this may possibly be difficult for a jury to interpret (5). Another way of obtaining an overlay is to make some sort of print from the biting surfaces of the teeth. Sorup (cited in Ref 5) used a printing method where teeth on the model were inked, and, using several stages, a print was produced on transparent paper, but this was too complicated and involved too many stages, thus introducing the possibility of more errors.

Overlays have also been produced using radiographic film, where an artificial bite mark is produced in wax using the suspect's models and the subsequent indentations in the wax are filled with a radiopaque dust or solution and a radiograph taken. The problem with this method is that wax and skin are very different in consistency and require different amounts of pressure to produce a mark, and if too much force is used the wax bite mark will most likely produce an overlay that does not reflect the real situation.

Recently much interest has been focused on computer-based comparison techniques (6) that have been shown to be more accurate than many of the commonly used methods (7). Guidance on the digital analysis of bite mark evidence has been published (8) as has analysis of its effectiveness (9), and the future certainly lies in this direction. However, computer-based techniques may not always be available and may open the evidence to claims that the images can be manipulated by the software. It is important to remember that computer-generated overlays still retain an element of subjectivity, as the selection of the biting edge profiles is reliant on the operator placing the "magic wand" onto the areas to be highlighted within the digitized image. Computer-based techniques may also not be as well understood by a jury.

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Adjunctive Techniques

Several adjunctive techniques have been used in bite mark analysis, including computerized axial tomography (10), transillumination of excised skin (11), reflective utraviolet photography (12), scanning electron microscopy (13), and xeroradiography (14). Finally, Rao and Souviron (15) developed a method of recording bite marks that was based on the powder and brush method used when lifting fingerprints. These authors claimed that the prints lifted can highlight some important features in a bitemark and remove the problems of photographic distortion.

Quantitation

Recognizing a need to quantify comparisons, the American Board of Forensic Odontology (ABFO) published a scoring guide (16) to systematize bite marks so that a score given to a comparison could be understood by other examiners. Unfortunately, in practice, a great variance of scores was found between examiners and accordingly the scheme was withdrawn (17,18). For the present study, a method of quantifying the results was needed, and as the ABFO system is the only genuine previous attempt at quantitation we decided to use a modified version of this scoring system.

Aim of This Study

This study aims to evaluate different comparison techniques used in bite mark analysis. Two commonly used techniques are to be compared with each other and to a third new method that utilizes a photocopier to generate overlays from prepared models. For the purposes of this experiment, artificial bite marks are to be produced in porcine skin to represent the nearest approximation to human skin. A modified version of the American Board of Forensic Odontology (ABFO) scoring system (16) is used to provide a quantitative aspect to the comparisons.

Materials and Method

Experimental Bite Marks

Eight dentate adults exhibiting variations in the presence, status, and arrangement of their upper and/or lower anterior teeth were selected for participation in the study. The variations included missing teeth, fractured, rotated, and displaced teeth, diastemas, and degrees of tooth wear. Cases chosen included relatively mild departures from the norm as well more distinctive dentitions. Addition-cured silicone impressions were cast in stone. Each set of models was given a different code number. The eight sets of stone models were then used to produce experimental bite marks in pigskin. Squares of thawed frozen pigskin (90 by 90 by 6 mm) were pinned out onto 65-mm-diameter foam pipe cladding (Climaflex, UK), the latter chosen to simulate, roughly, the shape, curvature, and consistency of an arm. To record the bites, the models had the biting edges of the premolar and anterior teeth lightly covered with a layer of "Occlude" indicator spray (Pascal Company, Inc.). The biting edges on each model were then pressed into the skin on the tube using firm manual pressure for 40 s to leave an imprint (Fig. 1).

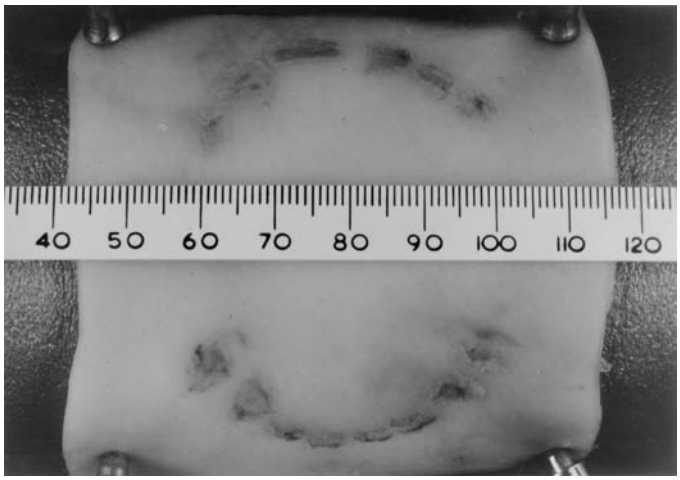

FIG. 1—*Experimental bite mark in porcine skin pinned to foam pipe cladding (centimetre scale).*

Recording of Bite Marks

Photographs—The resulting bite mark was then photographed alongside a scale (see Fig. 1). For the purposes of this study, each individual bite from the upper and lower model in a set was photographed separately even though they were classed as a single bite mark for the comparisons. Each pair or set of photographs was coded with a randomly selected letter that corresponded to the number of a given model set so that the eventual comparisons would be carried out in a blind manner. The "photo letter–model number" combinations (e.g., M-1) were placed in a sealed envelope that remained unopened until the comparisons were completed. The models were rinsed with water to remove the "Occlude" spray after the bites had been produced.

Fingerprint Powder Lifts—A further eight sets of bite marks were produced in eight further pieces of pigskin but without the use of "Occlude" on the biting edges/surfaces of the teeth. In these cases the bitten skin was dusted lightly with black fingerprint powder using a soft sable hair brush according to the method described by Rao and Souviron (15).

The dusted bite marks were then lifted from the pigskin using fingerprint tape (50-mm wide) and transferred onto sheets of acetate (Fig. 2). Each fingerprint powder lift included both the upper and lower bite marks for a given set of models. Care was taken not to use too much powder when dusting the bite mark, with excess powder being tapped away from the brush before beginning. Two lifts were performed after each brushing, the first lift usually being discarded owing to the powder density obscuring detail. Only the bite arch area was dusted to reduce the amount of surplus powder that could obscure details. Each bite mark lift was coded with a randomly selected letter that corresponded to the number of a given model set so that the eventual comparisons would be carried out in a blind manner. The "fingerprint powder lift–model" combinations were placed in a sealed envelope that remained unopened until the comparisons were completed. The bite marks used to produce the lifts were not photographed for use in the comparisons with overlays or models. The lifts themselves were used as an alternative method of recording the experimental bite marks as opposed to photographs.

Production of Overlays

Three methods of bite mark comparison were investigated: a direct comparison of dental models to photographs and powder lifts; an indirect comparison of traced overlays to photographs and powder lifts; and an indirect comparison of photocopier-generated overlays to photographs and powder lifts.

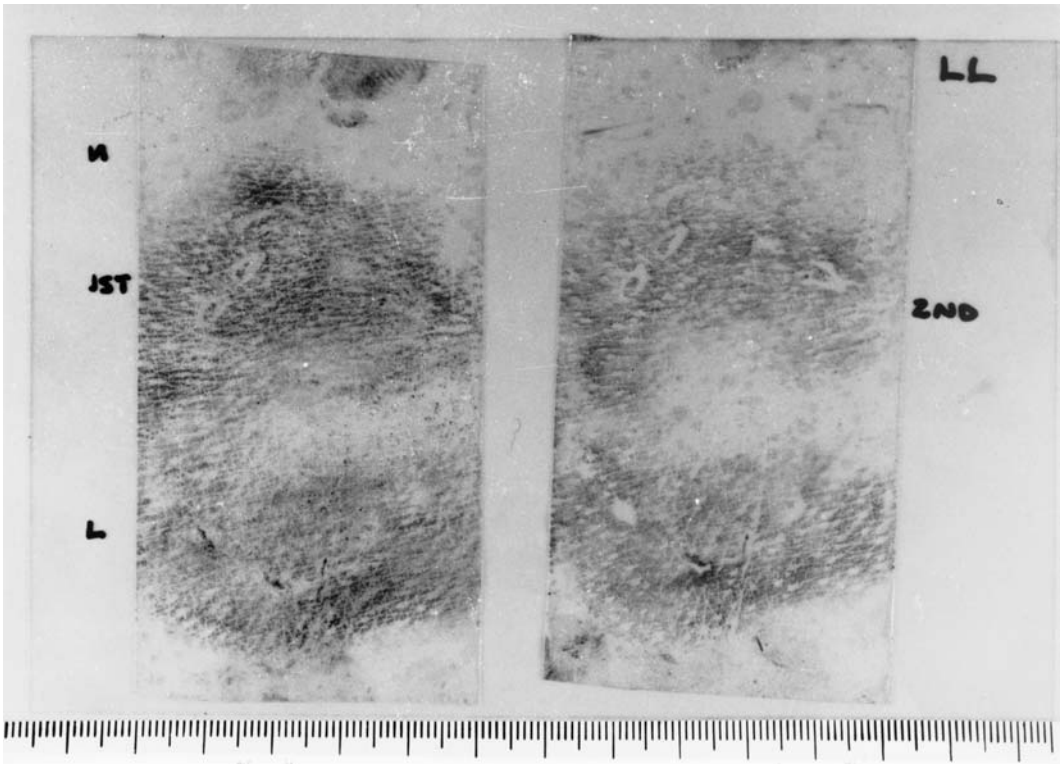

FIG. 2—*Consecutive fingerprint powder lifts from an experimental bite mark (centimetre scale).*

Traced Overlays—Traced overlays were produced using acetate sheets that were placed over the occlusal surfaces of the models; the acetate was held in place over the model using "Blu tack" adhesive (Bostik Ltd) so that the acetate did not slip out of position. The outlines of the biting edges of the teeth present from second premolar to second premolar in each dental arch were then traced using a fine permanent marker pen. Each traced overlay was coded with a randomly selected number that corresponded to the number of a given model set so that the eventual comparisons would be carried out in a blind manner. The "traced overlay–model number" combinations were placed in a sealed envelope that remained unopened until the comparisons were completed.

Photocopier-Generated Overlays—Photocopier-generated overlays were developed to remove any operator bias or error that can be introduced during tracing what the operator determines as the biting edges. The technique is based on a method that uses photocopies of models to produce tracings (2) but does not involve a stage where any tracing is undertaken. To produce these photocopies, the eight sets of models used to produce the bite marks were duplicated in white plaster of paris and each set was given a three-number code different from the original models but which corresponded to the number of a given model set so that the eventual comparisons using photocopier-generated overlays would be carried out in a blind manner. The "duplicated model number–original model number" combinations were placed in a sealed envelope that remained unopened until the comparisons were completed. Each set of coded white plaster models had the biting surfaces of the teeth pressed into a stamp ink pad to accentuate the biting surfaces with black ink. These inked models were then placed with the teeth down onto a photocopier and copied onto acetate sheet (Fig. 3) at life-size with a scale included. The photocopier was set at the lightest setting to reduce the darkness of the copy. The triple-number code from the duplicated model was marked on each acetate photocopy.

Comparisons

After all the bite marks were photographed, the powder lifted, and all the overlays produced, the models and overlays were compared with the photographs and powder lifts.

All eight sets (upper and lower) of models, eight sets of traced overlays and eight sets of photocopier-generated overlays ($8 + 8 + 8 = 24$), were compared with the photographs for the eight experimental bite marks, so that 192 ($24 \times 8 = 192$) comparisons were made in total. The comparisons were repeated, with the powder lifts being used in place of the photographs so that another 192 comparisons were made based on the lifts. Each comparison was made by allocating a score using a modified and simplified version of the American Board of Forensic Odontology scoring system (16). In view of the large number of comparisons involved in this study, it was decided to modify the original ABFO system to simplify each assessment. Figure 4 shows the modified scoring system together with guidelines used for allocating different scores for each variable. For example, the size and shape of the arches were assessed together rather than separately, as were variations in individual tooth position and tooth shape. In contrast, spacing between teeth was treated as a separate variable and scored accordingly.

The different groups of comparisons were all carried out separately from each other in a randomized, blind manner to avoid any bias. As this study comprised RFK's supervised undergraduate degree research project, the comparisons could only be carried out by one examiner (RFK). Although no formal intra-examiner testing was performed, 25 randomly selected replicate comparisons were undertaken three months after the intial comparisons to assess reproducibility of the scoring method. There were no significant differences between the scores allocated on the two occasions.

For each set of comparisons, the top score obtained was assumed to be the model or overlay most likely to be the correct match. The arithmetic difference between the top and next highest score in

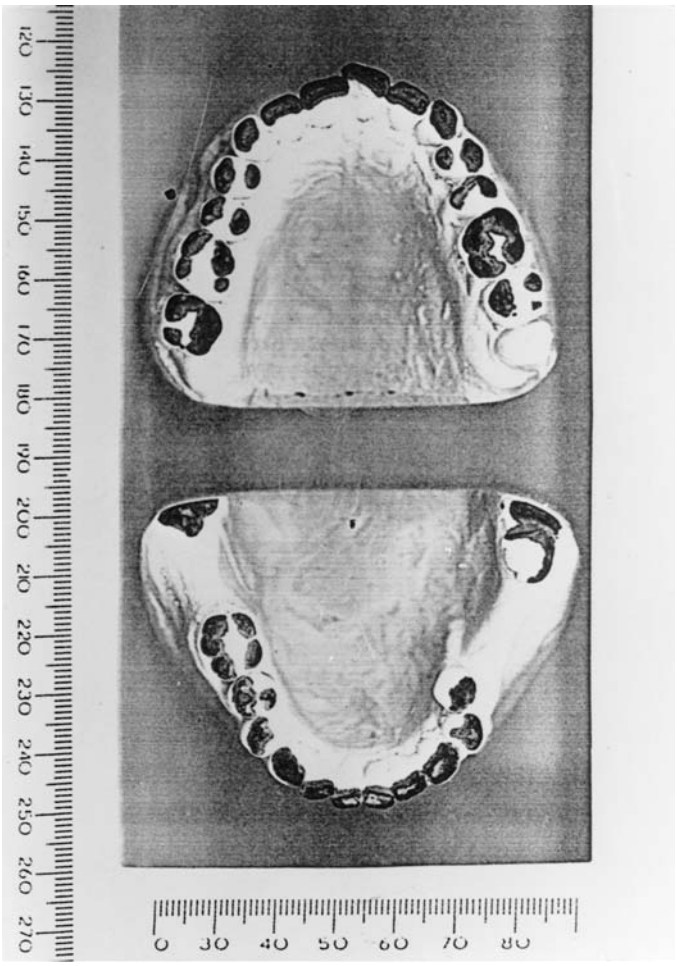

FIG. 3—*Photocopier-generated overlays prepared from models on which teeth biting edges/surfaces have been accentuated with ink (centimetre scales).*

each set of comparisons was calculated and the average difference for each of the eight sets of comparisons in a group and for each of the six groups of analyses were compared against one another statistically.

Statistical Analysis

Statistical analysis was carried out using the Mann-Whitney U test between groups for the comparisons with photographs and the comparisons with powder lifts, the Null hypothesis stating that the score differences for the six groups were not significantly different from each other.

Results

The models and overlays each produced eight scores for every comparison made. Of the eight scores obtained for each comparison with a photograph or powder lift, for a given bite mark, the top score was assumed to be the correct match, and the difference between the top and next highest scores was used to estimate the relative sensitivity of the comparison techniques.

Tables 1 to 6 show the results obtained from the comparisons and include the code of the photograph, the top two scores for each comparison (from each set of eight scores), whether the match was correct, and the difference between the top and next highest

TABLE 1—*Comparisons between photographs and models.*

Photograph	Model	Score	Correct Match	Difference Between Top and Next Highest Scores
Ph M	*M2*	23	Y	
	M4	13		10
Ph C	*M8*	20	Y	
	M2	10		10
Ph A	*M6*	19	Y	
	M5	16		3
Ph P	*M5*	23	Y	
	M3	17		6
Ph L	*M1*	25	Y	
	M6	6		19
Ph N	*M3*	29	Y	
	M6	23		6
Ph B	*M7*	29	Y	
	M6	18		11
Ph O	*M4*	23	Y	
	M2	11		12

NOTE: Ph = photograph; *Mx* = model set number; Y = yes.

TABLE 2—*Comparisons between photographs and traced overlays.*

Photograph	Traced Overlay	Score	Correct Match	Difference Between Top and Next Highest Scores
Ph M	*T14*	30	Y	
	T12	22		8
Ph C	*T11*	27	Y	
	T16	18		9
Ph A	*T16*	29	Y	
	T13	21		8
Ph P	*T15*	20	Y	
	T13	14		6
Ph L	*T10*	23	Y	
	T17	14		9
Ph N	*T13*	27	Y	
	T16	15		12
Ph B	*T17*	30	Y	
	T13	16		14
Ph O	*T12*	21	Y	
	T14	17		4

NOTE: Ph = photograph; *Tx* = traced overlay number; Y = yes.

TABLE 3—*Comparisons between photographs and photocopy overlays.*

Photograph	Photocopy Overlay	Score	Correct Match	Difference Between Top and Next Highest Scores
Ph M	*C004*	24	Y	
	C003	8		16
Ph C	*C009*	29	Y	
	C007	8		21
Ph A	*C012*	30	Y	
	C010	13		17
Ph P	*C003*	27	Y	
	C004	6		21
Ph L	*C006*	29	Y	
	C010	3		26
Ph N	*C010*	26	Y	
	C083	12		14
Ph B	*C083*	33	Y	
	C010	10		23
Ph O	*C007*	24	Y	
	C009	10		14

NOTE: Ph = photograph; *Cx* = photocopy overlay number; Y = yes.

Modified ABFO Scoring Guidelines

1. **Size and shape of arches (each arch scored separately):**
   The overall arch shape and width in the bite mark is assessed and compared with the model/overlay. The degree of correspondence is scored from 0-3 for each arch (max score based on two arches per case = 6)

2. **All teeth represented in the mark are present in the suspect's mouth (1 point/arch):**
   1 point is awarded per arch if all the tooth marks in the bite are present as corresponding teeth on the model or overlay (max score = 2).

3. **Tooth marks in the bite correlate with tooth position in the suspect (each arch scored separately):**
   A score of 0-3 is awarded for each arch according to the degree of correspondence of the labiolingual / rotational / vertical tooth positions on the overlays or models (max score based on two arches per case = 6)

4. **Spacing of marks in the bite compared to the spacing of the suspect's teeth:**
   1 point is allocated for each corresponding space in the maxilla and mandible
   eg. if teeth 14 to 24 are present and spaced the score would be 7 points and if teeth 34 to 44 were also spaced then a further 7 points would be awarded (max score = 14).

5. **Individual tooth marks in the bite correspond with the suspect's teeth in shape/size:**
   The width, curvature and shape of the individual tooth marks in the bite are compared to the suspect's teeth and a score of 0-3 is given for each arch (max score based on two arches per case = 6).

6. **Other distinctive features in the mark are compared to the suspect's teeth (3 points per distinctive feature)**
   eg. fractured teeth - missing teeth - peg-shaped lateral incisor - unusual or distinctive occlusal patterns - distinctive tooth crowding / overlapping incisors / proclined lateral incisors (max score variable).

Scoring for numbers 1,3 and 5 is carried out according to the degree of correspondence between features that have been reproduced within the bite mark and those evident in the suspect's teeth. The score is assigned to each arch subjectively using the following guide;

Score
- 0-Excluded/no match
- 1-Possible match/some similar features
- 2-Probable match/several similar features
- 3-Definite match

FIG. 4—*Modified ABFO scoring guidelines.*

scores. Tables 1 to 3 show that all the comparisons using the photographs were correctly matched to the correct models with all three techniques. For the comparisons with the powder lifts, only the photocopier-produced overlays matched all eight bite marks with the correct models (Table 6), whereas only six were matched correctly when comparing powder lifts with models (Table 4), and only four were correctly matched when traced overlays were compared with powder lifts (Table 5). In one case, the comparisons between powder lifts and traced overlays generated two equal top scores, one of which represented the correct match (see Y/N in Table 5).

The three methods of comparison with the photographs (Tables 1 to 3) all matched the correct photograph to the correct model or overlay. The average of the differences between the top and next highest scores for the photograph comparisons did vary between the groups, with the photocopier-generated overlays showing an average difference of 19.5, while the models showed only a difference of 9.6 and the traced overlays 8.8 (Table 7). This pattern was repeated in the comparisons with the powder lifts where the photocopier-generated overlays showed an average difference of 17.1, the models showed an average difference of 6, and the traced overlays again showing the smallest average difference at 4.8 (Table 7). Using either the photograph or the powder lift comparisons with the photocopier overlays resulted in much higher top scores and correspondingly greater individual and average differences between the top and next highest scores for each group.

For photographs, the differences between the top and next highest scores in each group when compared statistically showed that a model comparison and a traced overlay comparison were not significantly different with p values >0.05 (Table 8). However, the average differences between the top and next highest scores for the photocopier-generated overlays were significantly different from the average differences for models and traced overlay comparisons (Table 8). Again, a similar pattern is repeated for the comparisons with the powder lifts, as also shown in Table 8.

TABLE 4—*Comparisons between powder lifts and models.*

Powder Lift	Model	Score	Correct Match	Difference Between Top and Next Highest Scores
PL T	*M4*	23	Y	
	M2	21		2
PL X	*M3*	19	N	
	M2	17		2
PL V	*M8*	23	Y	
	M5	9		14
PL Z	*M2*	23	Y	
	M8	20		3
PL W	*M3*	10	N	
	M4	7		3
PL S	*M3*	23	Y	
	M6	18		5
PL Q	*M1*	23	Y	
	M2	12		11
PL R	*M7*	26	Y	
	M3	18		8

NOTE: PL = powder lift; *Mx* = model set number; Y = yes; N = no.

TABLE 5—*Comparisons between powder lifts and traced overlays.*

Powder Lift	Traced Overlay	Score	Correct Match	Difference Between Top and Next Highest Scores
PL T	*T12*	23	Y	
	T11	13		10
PL X	*T16*	7	Y	
	T14	2		5
PL V	*T11*	23	Y	
	T17	17		6
PL Z	*T14*	23	Y/N	
	T12	23		0
PL W	*T10*	20	N	
	T15	17		3
PL S	*T11*	17	N	
	T13	16		1
PL Q	*T10*	25	Y	
	T17	5		20
PL R	*T13*	17	N	
	T17	16		1

NOTE: PL = powder lift; *Tx* = traced overlay number; Y = yes; N = no.

TABLE 6—*Comparisons between powder lifts and photocopy overlays.*

Powder Lift	Photocopy Overlay	Score	Correct Match	Difference Between Top and Next Highest Scores
PL T	*C007*	25	Y	
	C009	11		14
PL X	*C012*	23	Y	
	C004	6		17
PL V	*C009*	23	Y	
	C007	6		17
PL Z	*C004*	24	Y	
	C010	7		17
PL W	*C003*	21	Y	
	C004	10		11
PL S	*C010*	26	Y	
	C003	9		17
PL Q	*C006*	25	Y	
	C083	8		17
PL R	*C083*	29	Y	
	C009	5		24

NOTE: PL = powder lift; *Cx* = photocopy overlay number; Y = yes.

TABLE 7—*Summary of results.*

Type of Comparison	Correct Matches	Average of Differences Between Top and Next Highest Scores
Ph v M	8 out of 8	9.6
Ph v T	8 out of 8	8.8
Ph v C	8 out of 8	19.5
PL v M	6 out of 8	6.0
PL v T	4 out of 8	5.7
PL v C	8 out of 8	16.7

NOTE: Ph = photograph; PL = powder lift; M = model; T = traced overlay; C = photocopy overlay.

TABLE 8—*Statistical results.*

Comparisons Between Averages of Differences for Top and Next Highest Score			Probability Values
Ph to M	V	Ph to T	$p > 0.05$ ($p = 0.7513$)
Ph to M	V	Ph to C	$p < 0.005$ ($p = 0.0027$)
Ph to T	V	Ph to C	$p < 0.005$ ($p = 0.0013$)
PL to M	V	PL to T	$p > 0.05$ ($p = 0.3152$)
PL to M	V	PL to C	$p < 0.005$ ($p = 0.0016$)
PL to T	V	PL to C	$p < 0.01$ ($p = 0.0088$)

NOTE: Ph = photograph; PL = powder lift; *M* = model; *T* = traced overlay; *C* = photocopy overlay.

Discussion

Although the experimental bite marks in the porcine skin seemed highly reproducible, the method could have been improved by using upper and lower models articulated with plaster instead of a free hand technique. A plasterless articulator was used during the initial pilot experiment, but the joints worked loose when pressure was applied to produce a mark. The amount of pressure used to produce the marks could have been standardized by the use of a G-clamp on an articulator as in an experiment performed by Rawson et al. (19). Porcine skin was chosen as a substitute for human skin in this study because it is similar histologically and has been used by other operators (20). It must be remembered that a bite mark in porcine skin will not be the same as a bite mark in vital human skin, which is produced differently and behaves in a dynamically different way.

The comparisons made with the photographs matched every bite mark to the correct set of models, irrespective of comparison method, but this did not happen when lifts were used instead of photographs. Using lifts as a record of the bite mark, the photocopier-generated overlays were the only technique to match all eight bite marks correctly, with model comparisons coming second at six out of eight correct matches and traced overlay comparisons matching only four out of eight correctly. The fact that all the photographic comparisons were matched correctly may be due to the clarity of the artificial bite marks made using the "Occlude" in contrast to the bite marks represented within the lifts showing that good photographs are important in bite mark analysis. Green "Occlude" was used because it would contrast better with the skin in a black and white photograph. A criticism of the comparisons carried out here could be that bias may be introduced because only one examiner was used, and, although this is the case, in a real-life situation there would generally be only a single examiner carrying out a comparison. One may question whether this practice needs to be looked at further in a field such as bite mark analysis. The original ABFO scoring system was criticized because of a lack of reproducibility among different investigators. Future studies could look at methods

of calibrating examiners as is done in screening programs for child dental health in the United Kingdom. It would be interesting to see whether the modified scoring system used here achieves greater reproducibility among different examiners.

The lifts, however, did not suffer from the potential distortion present in a photograph. However, both lifts and photographs suffer from the disadvantage that they are two-dimensional representations of a bite mark on a three-dimensional surface. It is also worth remembering that in actual criminal cases the bite marks are rarely as clearly depicted as the artificial bite marks seen here. The lifts did prove useful in identifying occasional distinctive features that could also be seen on the models and the two types of overlays, and so may collect information additional to a photograph, but further testing of this needs to be carried out.

Within the limits of this study it can be said that the photocopier-generated overlays were more accurate at matching the correct bite mark to the correct set of models. This may be because there was no hand tracing involved, which might have introduced errors from incorrectly defining the biting surfaces/edges involved in the bite, and that the biting surfaces were accentuated with a printer's ink pad, which was not done on the models that were traced. Tracing errors have even been attributed to the thickness of the pen mark used (21). Traced overlays were found to be the least accurate technique for bite mark comparison, presumably due to tracing errors or inaccuracies.

The inking of the models used for the photocopier-generated overlays was seen to make easier the identification of the biting edges when compared with the photographs or prints, therefore making the analysis easier. Sweet and Bowers (7) found that the overlays produced by Dailey's photocopy technique were inaccurate because they were slightly larger than the original due to the photocopier. However, their study involved a two-stage photocopying procedure that included hand tracing of biting-edge profiles, factors that could account for the error reported. The photocopier-generated overlays described here were produced by a single calibrated photocopy procedure and magnification errors were not detected.

Analysis using both types of overlays did have the advantage that the bite mark on the photograph or lift could be visualized through the acetate during comparison, while direct comparison with a model does obscure the bite mark. The bite mark was easier to visualize with the traced overlays than with the photocopier-generated overlays because the latter relicated the full model.

When the average of the differences between the top two scores for each set of comparisons was calculated, a pattern emerged between the photograph and lift groups. This pattern showed that the greatest difference between the top two scores was seen with the photocopier-generated comparisons, suggesting that they were more accurate at discriminating which models were a correct match with which bite marks. The average of the differences between the top two scores for the photocopier-generated overlays was shown to be statistically significantly larger when compared against the top score average differences for the models and traced overlays (Table 8). The average of the differences between the model comparisons and the traced overlay comparisons also followed a pattern where the model comparisons showed a greater average difference between the top two scores than the traced overlay comparisons, but this was not as statistically significant (Table 8). The statistical evidence suggests that the photocopier-generated overlays are more sensitive at discriminating between a bite mark that matches a set of models and one that does not match.

One further advantage of the photocopier-generated overlays was that other details within the model were represented on the overlay, such as fractured teeth that may not be accurately represented on a traced overlay. These features may not neccesarily be marked with the black ink but give additional information that would not be seen on a traced overlay. It would be interesting to repeat the experiment with sets of models that are more similar in respect of tooth arrangement, etc., to see how the three methods cope with detecting points of correspondence and discriminating between the top scoring comparisons.

As originally reported, the ABFO scoring system (16) was shown to have a high degree of reliability and allowed discrimination between degrees of match (22). However, these authors conceded subsequently that much more work was needed before a stable and accurate index could be developed for wider applications (17). Because of these problems, we simplified and modified the ABFO system to utilize it for quantification of our results in order to provide a common denominator when comparing the different methods of analysis.

As originally devised, the American Board of Forensic Odontology Scoring System incorporates a number of variables relating to arch and tooth form/size/position that are to be evaluated and scored separately. Unfortunately, the original ABFO system did not include precise descriptors for allocating scores. The lack of precise descriptors perhaps serves to reflect the essentially subjective nature of bite mark analysis. In the present study it was felt that to consider some of the features separately, for example arch shape and size, was to ignore potentially important interrelationships and possibly attribute undue significance to individual features considered in isolation. Other examples where individual features have been combined include comparisons between tooth mark in the bite to tooth position on the models/overlays. In this context, labiolingual, rotational, and vertical positions were combined and scored as a single variable. Furthermore, it was decided to consider comparisons involving tooth size and shape together rather than separately as advocated in the original ABFO system. In contrast, it was felt that when certain distinctive features within a bite mark (see No. 6 in Fig. 4) were present also in a potential suspect's models/overlays, these should be scored individually. Accordingly, the modifications used in this study aimed to both simplify and increase the sensitivity of the comparison process and to more accurately reflect real life situations. The modified ABFO scoring guide (Fig. 4) used in the analysis of each comparison proved to be very sensitive when comparing a given bite mark to more than one set of models because the resulting scores could be compared with each other and the highest score was considered likely to be a match. Few bite mark cases involve several sets of models, and it is more common to have to compare just one set of models with a mark.

Though the system developed for this project allowed more account to be taken of the subjective nature of bite mark analysis, it remains essentially similar to the original. The modified ABFO system appeared to work very well in practise and was shown to be able to discriminate between possible matches. Although the models selected included some examples in which the arrangement of teeth did not differ widely, it would be interesting to compare a larger number of very similar sets of models to further test the sensitivity of the new overlay technique and the modified ABFO system. However, it would be important to calibrate investigators in use of the system and to formally evaluate intra- and inter-observer variation.

The new photocopier-generated technique does not aim to replace more sophisticated techniques that involve computer-generated overlays but provides a fast, effective method for comparisons that a lay jury can easily comprehend and that can be made without the use of expensive equipment. Indeed, the simplicity and speed of the

present method suggest that it could prove useful for preliminary screening purposes. When we commenced this study, digital-based comparisons had not been described in publications so we chose methods that were in common use at that time. However, we recognize that the future lies in digital technology (8,9) though there remains a need for these newer approaches to be fully validated for use in court.

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