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TECHNICAL NOTE

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Computer-Based Production of Comparison Overlays from 3D-Scanned Dental Casts for Bite Mark Analysis*

ABSTRACT: Bite mark analysis assumes the uniqueness of the dentition can be accurately recorded on skin or an object. However, biting is a dynamic procedure involving three moving systems, the maxilla, the mandible, and the victim's reaction. Moreover, bite marks can be distorted by the anatomic location of the injury or the elasticity of the skin tissue. Therefore, the same dentition can produce bite marks that exhibit variations in appearance. The complexity of this source of evidence emphasizes the need for new 3D imaging technologies in bite mark analysis. This article presents a new software package, DentalPrint® (2004, University of Granada, Department of Forensic Medicine and Forensic Odontology, Granada, Spain) that generates different comparison overlays from 3D dental cast images depending on the pressure of the bite or the distortion caused by victim-biter interaction. The procedure for generating comparison overlays is entirely automatic, thus avoiding observer bias. Moreover, the software presented here makes it impossible for third parties to manipulate or alter the 3D images, making DentalPrint suitable for bite mark analyses to be used in court proceedings.

KEYWORDS: forensic science, forensic odontology, human bite mark, comparison overlays, 3D images, computers

Bite mark evidence found on the skin of a living person or a corpse and on objects may be of great importance in criminal investigations (1). The scientific basis for bite mark identification is the assumption of uniqueness of an individual's dentition, which is used to match a bite mark to a suspected perpetrator. The procedure for comparing bite marks is well established (2,3) and includes measurement and analysis of the pattern, size, and shape of teeth against similar characteristics observed in an injury on skin or a mark left on an object.

Most common analysis methods are used to produce life-sized comparison overlays from suspect's teeth to detect similarities or differences with the bite mark. Several methods (4–9) exist to produce these overlays; in most of them the perimeter of the biting edges of the suspect's teeth are hand-traced directly from dental study casts or from wax bite exemplars, or indirectly from xerographic images produced with office photocopiers that are calibrated to produce life-sized final images. Other methods use X-ray film overlays created from radiopaque material applied to the suspect's wax bite. These methods cannot avoid the bias inherent in observer subjectivity, and significant errors incorporated to the overlays may make it difficult to reach conclusions with a high degree of confidence in court proceedings.

Recently, some authors have improved the methods for comparative analysis by using computer-based techniques to produce bite mark comparison overlays (10–13). In these methods, dental casts are scanned with a two-dimensional scanner and images are imported to Adobe® Photoshop® software (Mountain View, CA). The biting edges of the suspect's teeth are selected based on similarities between adjacent pixel values. However, there is still room for research and improvement in bite mark comparison and analysis.

Bite mark identification is also founded on the premise that unique features of the dentition are accurately recorded in the injury on skin or on an object. However, biting is a dynamic procedure involving three moving systems, the maxilla, the mandible and the victim's reaction. Bite marks are also influenced by the pressure of the bite, the anatomy of the body part or the shape of the object. These factors determine which teeth will be involved in the bite mark and the dental surface that is marked onto the skin or the object. Most recent research has focused on analyzing how these factors affect the bite mark with the application of 3D procedures (14).

In this article, we describe a new software package, DentalPrint (2004, University of Granada, Department of Forensic Medicine and Forensic Odontology, Granada, Spain), developed to generate comparison overlays from three-dimensional images of the suspect's dental casts. The software allows users to accurately and objectively select the biting edges of interest from the suspect's teeth. Moreover, DentalPrint can produce different comparison overlays with the selective use of tools that simulate different biting pressures or distortions caused by the dynamics of the action of biting.

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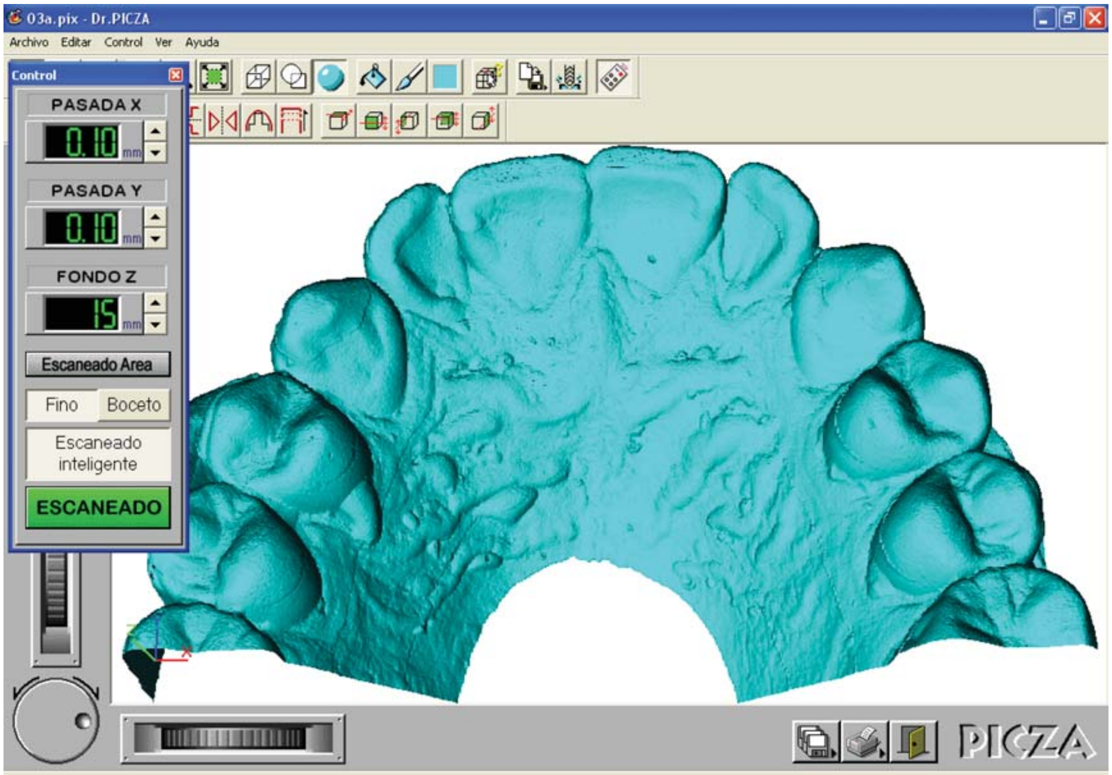

FIG. 1—*Original 3D image of an upper dental cast obtained with a Picza 3D Scanner® (0.1 mm scanning pitch).*

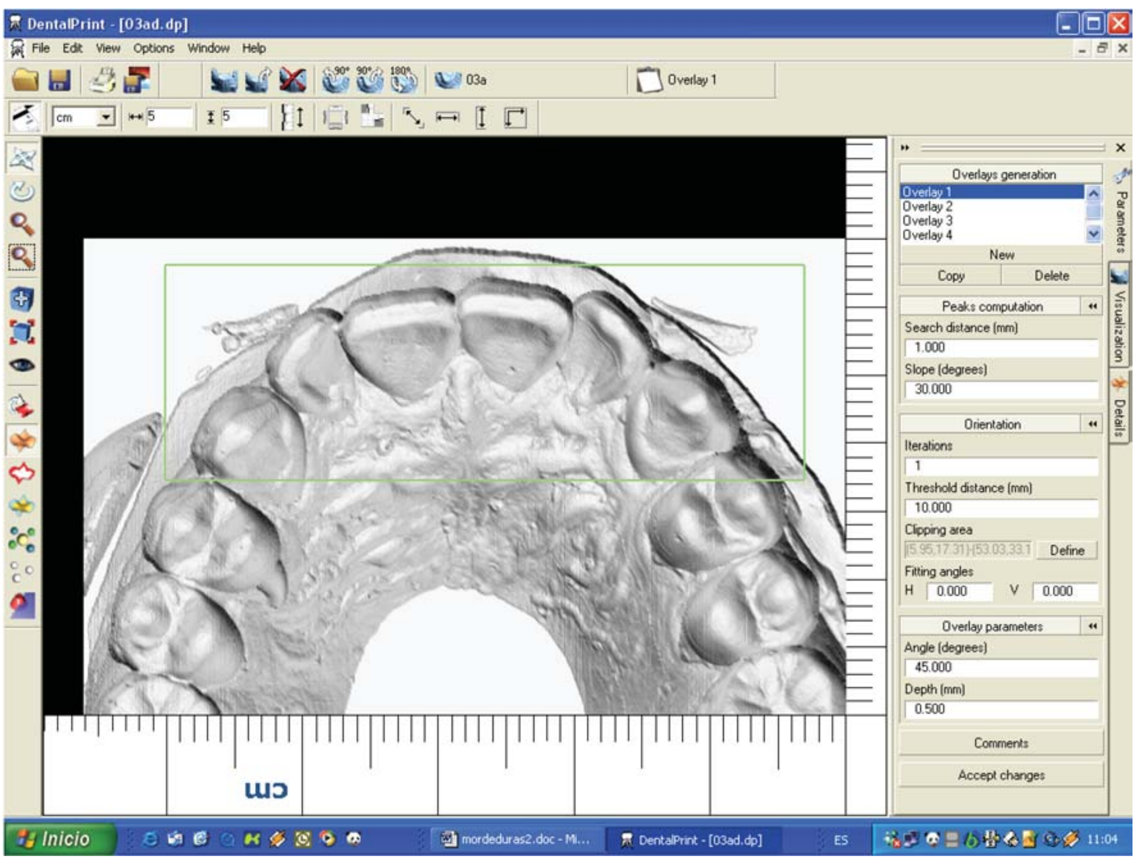

FIG. 2—*Data model of the dental cast imported to DentalPrint software. The teeth selected for further analysis are framed inside the clipping area.*

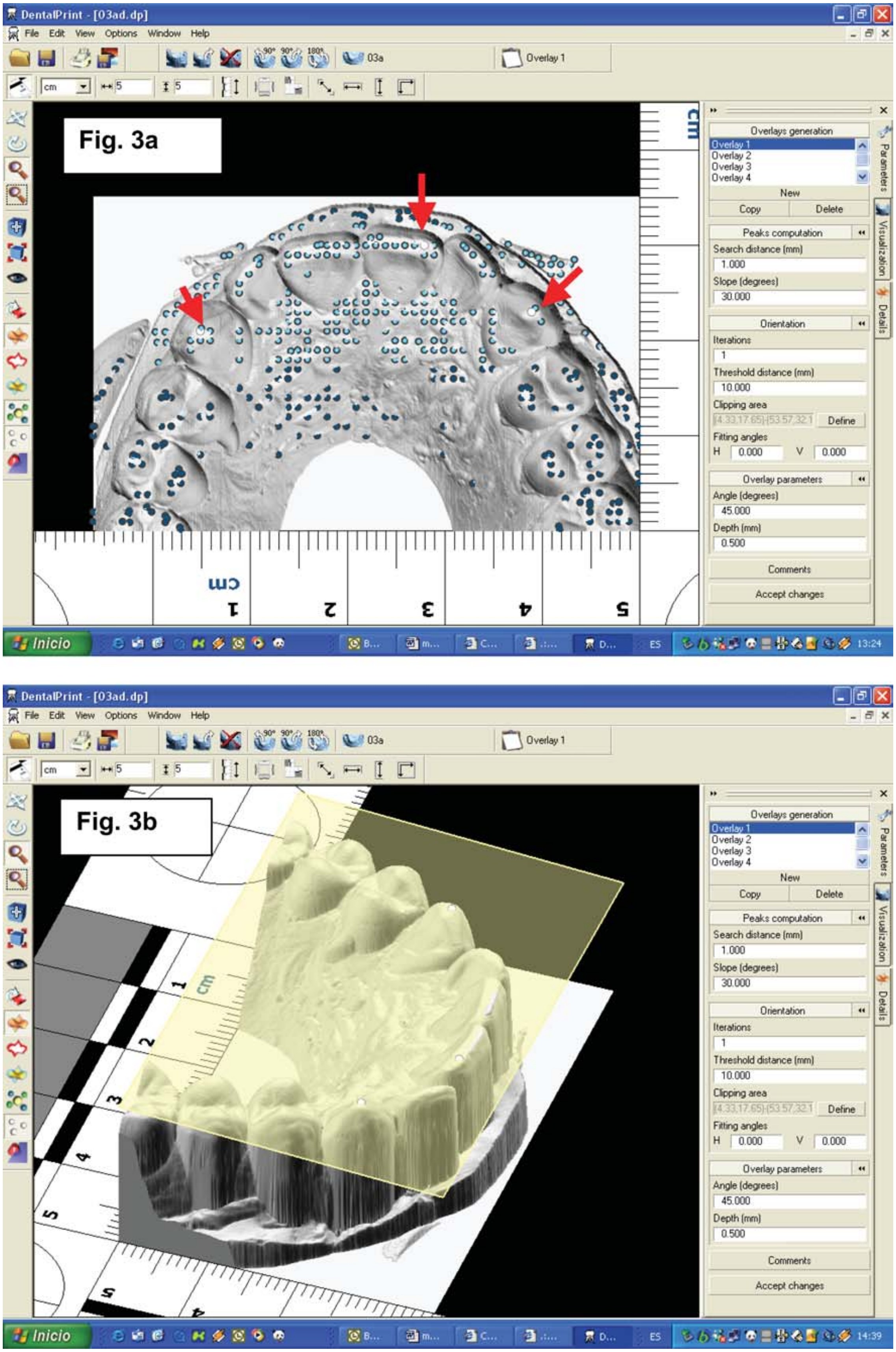

FIG. 3—*To create the contact plane, the highest points were detected from defined small areas of the dental cast (panel a). The three highest points were used to define the contact plane (arrows, panel a). Panel b shows a lateral view of the contact plane.*

Materials and Methods

The computer hardware used with this technique includes a Intel® Pentium 4 CPU PC running at 1.50 GHz, with 524 mB RAM, a Elsa Gloria II Quadro graphics accelerator card (Elsa Technology Inc., Taiwan, Republic of China), the Windows Millenium operating system (Microsoft Corp., Redmond, WA), 17-in. color monitor (Trinitron® Color Computer Display, Sony Corp., Tokio, Japan), a Hewlett-Packard Photo Smart 7350 printer (Hewlett-Packard Comp., CA), and a three-dimensional contact type scanner (Picza 3D Scanner® model PIX-3, Roland DG Corp., Japan).

Study casts were fabricated from accurate upper and lower dental impressions of the suspects. These casts were placed on the 3D scanner with the biting edges facing up. Upper and lower dental casts were scanned separately. The PIX-3 can scan objects as large as 152.4 mm (width, X axis) × 101.6 mm (depth, Y axis) × 40.65 mm (height, Z axis). Picza's high performance enables a scanning pitch of 0.025 mm (Z axis) and 0.05 mm to 1 mm (X axis and Y axis). The Picza 3D Scanner comes with its own scanning software, Dr. Picza®. The basic settings for scanning are the scanning pitches of the X and Y axes and the scanning range. To obtain accurate images of the dental models, different values of scanning pitch were carried out. Excellent 3D images were obtained with a scanning pitch of at least 0.1 mm for the X and Y axes (see Fig. 1).

These 3D images were imported to a new software named DentalPrint and then processed (see Fig. 2). Additional information regarding DentalPrint and a demonstration version of the software are available at their website (http://www.ugr.es/local/stella/dentalprint).

DentalPrint Procedure and Utilities

DentalPrint makes it possible to obtain biting edges from 3D images of the dental cast and to generate comparison overlays as follows:

1. Selection of teeth from 3D-scanned dental cast—The suspect's biting edges can be obtained from all scanned teeth. As an alternative, a selection of teeth (clipping area) can be used (Fig. 2). When this procedure is used, the entire process is based on the teeth included in the clipping area.
2. Create the contact plane—Firstly, DentalPrint selects the highest points detected in areas defined in the 3D images of dental casts. The software allows users to select the highest points for different searching distances (mm) and angulations (degrees) (Fig. 3*a*). Finally, a contact plane (Fig. 3*b*) is created from the three highest points selected from among all points detected. When the three highest points which define the contact plane seem to be too close (e.g., when an extruded tooth is present), a minimum distance between points can be specified.
3. Obtain biting edges from the data model of the dental casts—To obtain biting edges from 3D images of the dental cast, DentalPrint allows the contact plane to extend deep into the teeth (Fig. 4). Different biting edges can be obtained depending on selected depth (mm) and angulation (degrees). An additional adjustment is possible to rotate the contact plane on the dental model horizontally and vertically (fitting angles). Therefore, a variety of comparison overlays of a single dental cast can be generated with the different tools this software incorporates.

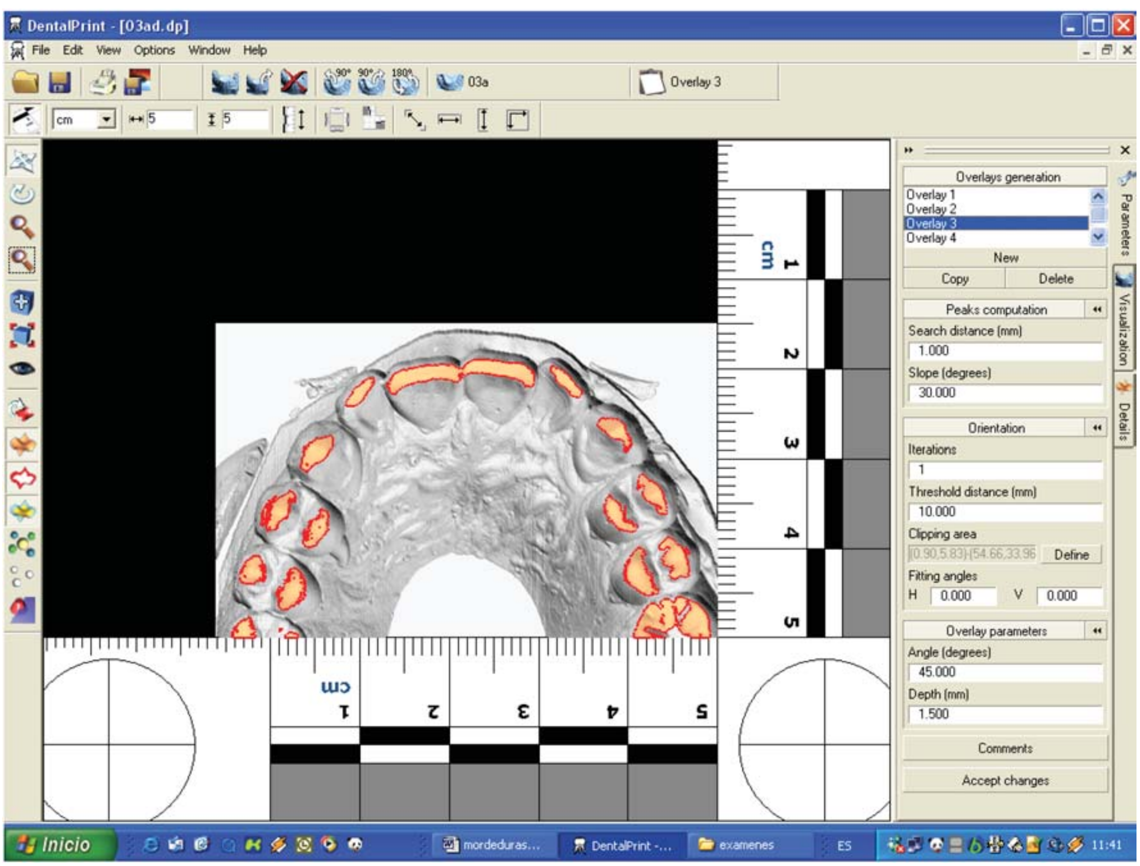

FIG. 4—*Areas of the biting edges from the data model of the dental cast.*

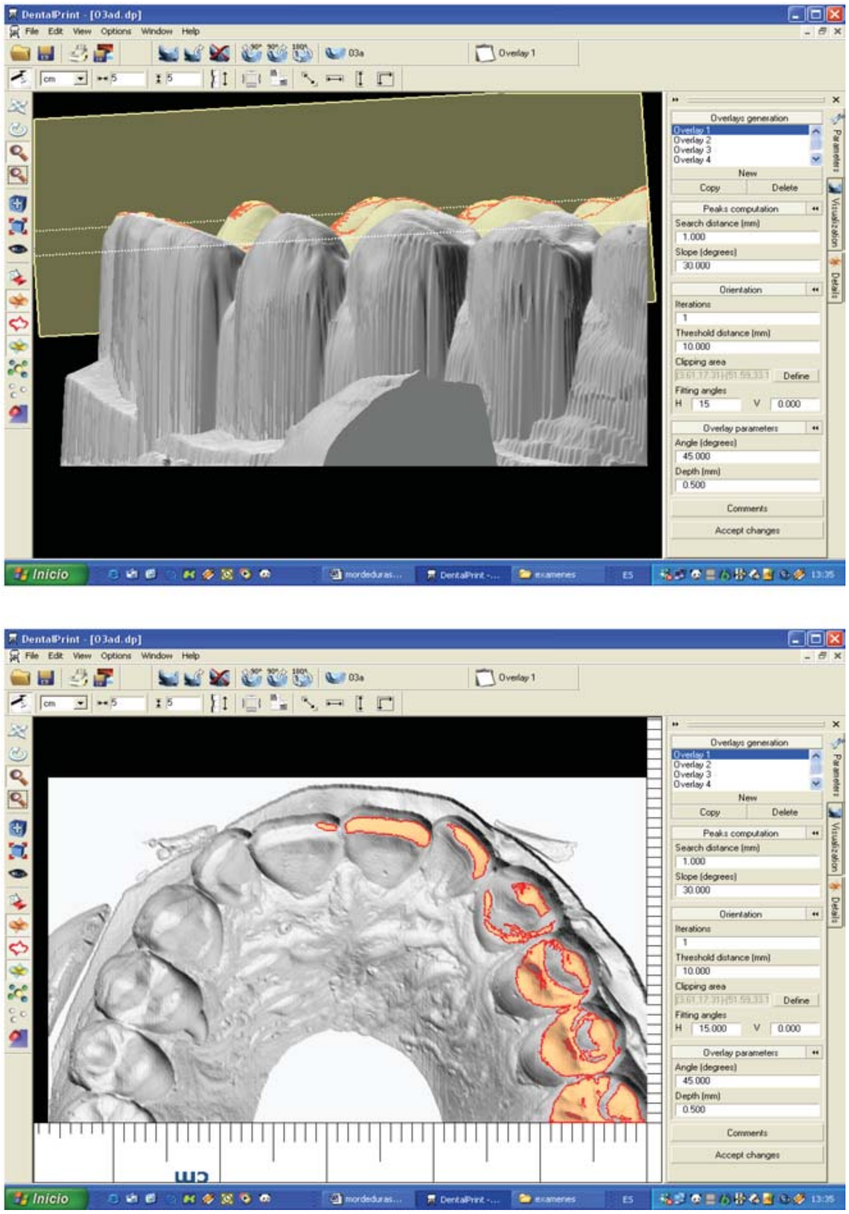

FIG. 5—*Generation of a comparison overlay by selecting the angle of the bite plane (15 degrees horizontally).*

Figure 5 shows an example of one possible display of the biting edges, ready for printing to the overlay.

4. Print biting edges from a 3D image of the dental cast—The perimeter of the biting edges obtained from the 3D image of the dental cast can be printed on transparent acetate film (Fig. 6). The upper and lower biting edges can be printed separately or together on the same sheet, with or without the ABFO scale.
5. Other tools—DentalPrint software also offers different visualization and movement options. The ABFO scale is incorporated as a screen display and print-out option (see Fig. 6). Distances are accurately measured in horizontal, vertical and both directions.

Experimental Design and Statistical Analysis

Several experiments were carried out to analyze reliability and objectivity of the new software. First, the same dental cast was scanned eight times and a single observer generated overlays with the same conditions from each scan. Then, seven mesio-distal distances of bite areas were measured in each overlay by the observer (intraobserver assay). Second, in order to check for objectivity, the same experiment described previously was repeated by five different operators (interobserver assay). Data were exported to an Excel spread sheet and intraclass correlation coefficients (ICC) and their confidence intervals (CI) were calculated using the SPSS version 12.0 program for PCs.

Results and Discussion

Biting is a dynamic process comprising multiple component movements by the perpetrator and the victim. Therefore, every episode of contact is a unique event, and the same dentition can produce bite marks with variations in appearance (15). This is one of the reasons for the complexity of bite mark analysis, and emphasizes the need to apply objective techniques and incorporate

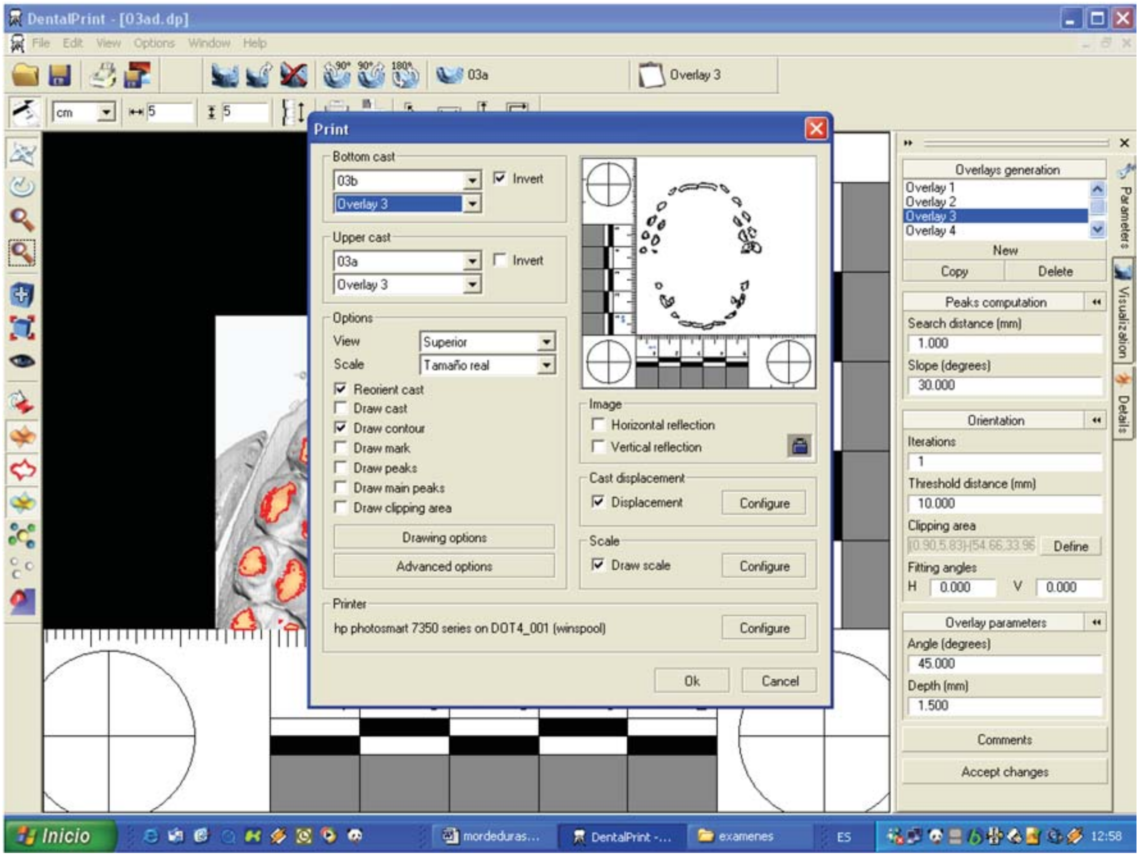

FIG. 6—*Dialog box for printing biting edges from 3D dental cast images on transparent acetate film.*

movement in the analysis. These challenges can be met with a 3D approach to bite mark analysis. Thali et al. (14) recently described their 3D/CAD software, designed mainly to superimpose photographs of the bite mark obtained with a photogrammetry procedure onto dental casts digitized with a 3D scanner.

The present research, based on a similar approach, focuses on generating comparison overlays, since these are the aids used most frequently to compare the patterns in life-sized photography of the bite mark with the biting surface of the suspect's teeth.

It is important to remember that at present, indirect methods to generate comparison overlays may involve a certain amount of bias. Overlays generated with Adobe Photoshop software (10–11) still retain an element of subjectivity, as selection of the biting edge profiles relies on the operator placing the "magic wand" onto the areas to be highlighted within the digitized image.

DentalPrint software selects the highest points from the data model of the dental casts and defines a contact plane that allows users to generate the biting edges of the dental casts without interference from the observer. Furthermore, the biting edges of the data model of the dental casts can be printed to a transparent acetate overlay or converted to a .bmp file. These files can also be imported to Adobe Photoshop software to compare them with digital photographs of the bite mark, as described by Johansen and Bowers (10). DentalPrint software generates comparison overlays while avoiding the bias inherent to observer subjectivity, as the entire procedure for generating overlays is automatic. To check for reliability of the method, experiments were carried out as described in the Materials and Methods section. Moreover, excellent ICC (0.9985) and CI at 95% (0.9959;0.997) were obtained for all measurements undertaken for the same examiner.

TABLE 1—*Interobserver reproducibility of measurements of seven mesio-distal distances between bite areas.*

Distance*	Observer‡ 1	2	3	4	5
Canine (13) to Canine (23)†	3.380	3.400	3.414	3.415	3.406
Tooth 13†	0.512	0.515	0.531	0.528	0.531
Tooth 12†	0.575	0.576	0.573	0.567	0.575
Tooth 11†	0.728	0.733	0.731	0.731	0.730
Tooth 21†	0.769	0.761	0.761	0.764	0.766
Tooth 22†	0.529	0.533	0.528	0.521	0.517
Tooth 23†	0.282	0.284	0.292	0.297	0.311

* Distances between bite areas are expressed in cm.
† Teeth are named according to FDI notation.
‡ Interobserver reproducibility of measurements between observers were ICC = 0.9999; CI (0.999; 1.000) at 95%.

Otherwise, DentalPrint doesn't enhance 3D images and, therefore, the evidence is not in any way manipulated or altered. Documentation with metric 3D measurement is possible, as are orientation and subsequent analysis in 3D space. Interobserver reproducibility of the measurements with the new software was evaluated using the ICC and CI (Table 1). No significant differences in the measures were found between observers.

A recurring difficulty in bite mark analysis arises from distortions produced by the dynamics of the action of biting. When multiple bite marks are produced by a single dentition in a single victim, the bite marks vary in appearance because of the unique dynamics of each biting episode (15). Variability in the process of recording the

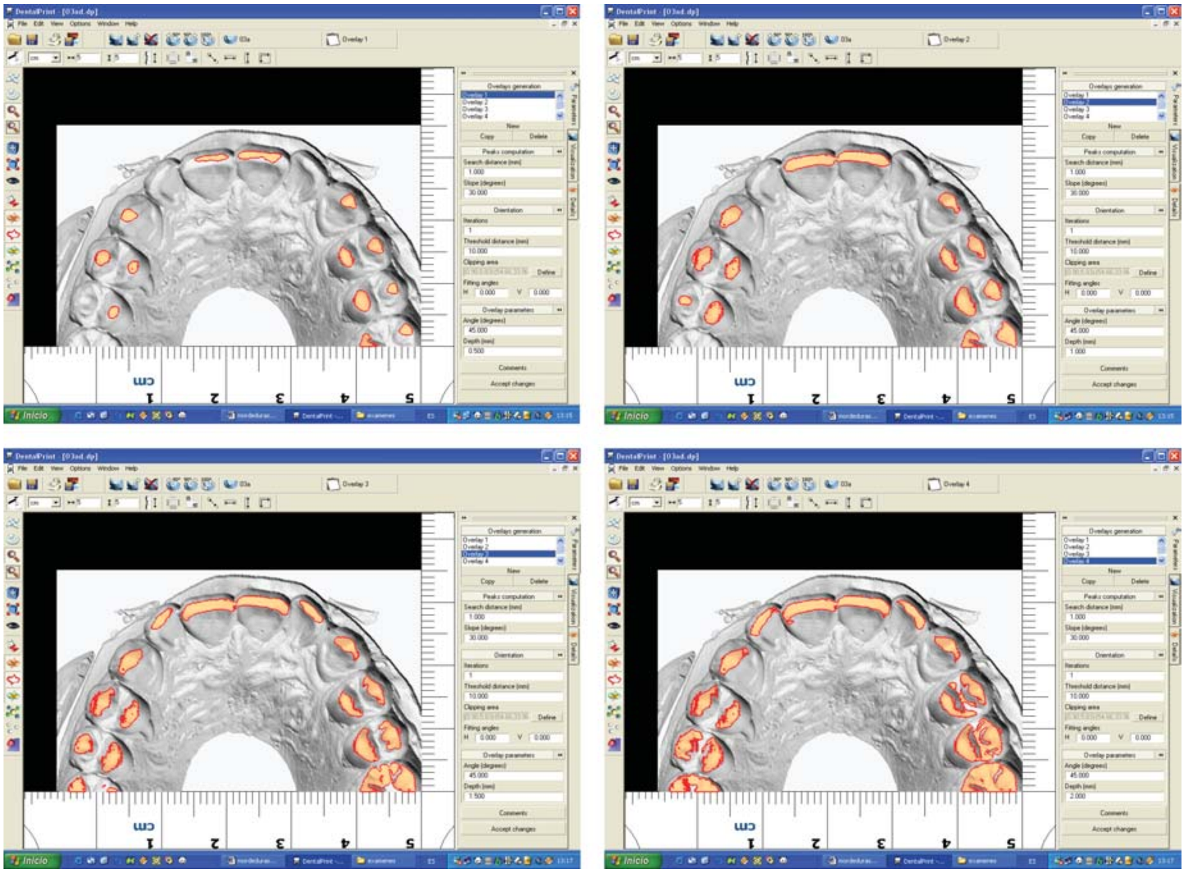

FIG. 7—*Sequence of different comparison overlays from a single dentition with biting edges highlighted for different depths of the contact plane. These images simulate different pressures of the bite.*

biting edges make it necessary to obtain different comparison overlays from a single dentition in actual forensic practice. DentalPrint software allows users to generate a variety of comparison overlays depending on the teeth involved in the bite mark, the distortion caused by victim-biter interaction (Fig. 5) and even the pressure of the biting episode (Fig. 7).

We conclude that DentalPrint software improves the process for creating comparison overlays, and is therefore an important step forward in forensic sciences for bite mark analysis. However, further research in the comparison process is needed to enhance the reliability of bite mark analysis.

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References

1. Vale GL. Bite mark evidence in the investigation of crime. J Calif Dent Assn 1986;14(3):36–42.
2. ABFO bite mark methodology guidelines. In: Bowers CM, Bell GL, editors. Manual of forensic odontology. Colorado Springs: American Society of Forensic Odontology, 1995;334–7.
3. Pretty IA, Sweet D. Adherences of forensic odontologists to the ABFO bite mark guidelines for suspect evidence collections. J Forensic Sci 2001;46(5):1152–8. [PubMed]
4. Luntz L, Luntz P. Handbook for dental identification. Philadelphia: Lippincott, 1973;154.
5. Cameron J, Sims BG. Bite marks. In: Cameron J, Sims BG, editors. Forensic dentistry. Edinburgh: Churchill Livingstone, 1974;129–45.
6. West M, Friar J. The use of videotape as an aid in bite mark analysis: a case report. J Forensic Sci 1987;34:85–95.
7. Farrel WL. Computerized axial tomography as an aid in bite mark analysis: a case report. J Forensic Sci 1987;32:266–72. [PubMed]
8. Dailey JC. A practical technique for the fabrication of transparent bite mark overlays. J Forensic Sci 1991;36:565–70. [PubMed]
9. Naru AS, Dykes E. The use of a digital imaging technique to aid bite mark analysis. Sci Justice 1996;36(1):47–50. [PubMed]
10. Sweet D, Parhar M, Wood RE. Computer-based production of bite mark comparison overlays. J Forensic Sci 1998;43(5):1050–55. [PubMed]
11. Johansen RJ, Bowers CM. Digital analysis of bite mark evidence using Adobe® Photoshop®. Santa Barbara, California: Forensic Imaging Services, 2000.
12. Sweet DJ, Bowers CM. Accuracy of bite mark overlays: a comparison of five common methods to produce exemplars from a suspect's dentition. J Forensic Sci 1998;43(2):362–7. [PubMed]
13. Pretty IA, Sweet D. Digital bite mark overlays-an analysis of effectiveness. J Forensic Sci 2001;46(6):1385–91. [PubMed]
14. Thali MJ, Braun M, Markwalder ThH, Brueschweiler W, Zollinger U, Naseem JM, et al. Bite mark documentation and analysis: 3D/CAD supported photogrammetry approach. Forensic Sci Int 2003;135:115–21. [PubMed]
15. Sheasby DR, MacDonald DG. A forensic classification of distortion in human bite marks. Forensic Sci Int 2001;122:75–8. [PubMed]

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