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TECHNICAL NOTE

Iain A. Pretty,[1] BDS (Hons), M.Sc.; Philip W. Smith,[2] BDS (Hons), MD.S, Ph.D.; W. Michael Edgar,[3] BDS, B.Sc., DDSc, Ph.D.; and Susan M. Higham,[4] B.Sc., Ph.D.

The Use of Quantitative Light-Induced Fluorescence (QLF) to Identify Composite Restorations in Forensic Examinations

ABSTRACT: There has been a large increase in the number of tooth colored restorations "white fillings" placed in recent years. An increased demand from the public for more aesthetic dental restorations causes a potential problem for forensic dentists who may find the fillings difficult to identify and hence include in postmortem odontograms. This has implications for the accuracy of dental identifications, particularly in situations where limited time is available for postmortem identification, e.g., mass casualty incidents. A new method for the detection of composite restorations is presented. Quantitative Light-induced Fluorescence (QLF) is a technique currently employed to detect small changes in enamel mineral content. An experiment was conducted to determine if the technique would afford a greater degree of contrast between composite and enamel and thus enable the accuracy of composite identification in enamel. Twenty-four previously extracted human premolars were gently cleaned with pumice and wet-and-dry paper. Twelve were subsequently randomly selected and restored on their buccal surfaces with Spectrum (a composite) following manufacturer's instructions. No attempt was made to color match the teeth and all were filled with shade B3. Twelve teeth were left unrestored. QLF and normal white light images were taken of both restored and non-restored surfaces with teeth wet and then dried. Ten forensic dentists were asked on two separate occasions (one month between each attempt) to indicate whether or not they thought the surface was: a) restored or b) unrestored. Results indicate that forensic dentists detected a significantly higher proportion ($p < 0.005$) of filled surfaces with QLF.

KEYWORDS: forensic science, forensic dentistry, identification, QLF, accuracy, reliability, composite, resin, restoration

Composite fillings

White, or composite fillings have been available for dental restoration for many years. Historically their use was on the smooth surfaces of anterior teeth, although, recent years have seen increased use of these restorations in posterior teeth. This increased use has been driven by both the availability and improved clinical performance of the materials as well as an increased demand by dental consumers for more aesthetic restorations. The purpose of such restorations is to blend with the color and optical properties of the tooth and thus create an "invisible" filling. Such materials are made of, usually, a resin filled with glass particles that afford greater wear resistance (1). See Fig. 1.

As part of the postmortem identification process, it is necessary to perform a thorough dental examination and charting of the teeth, restorations and any pathologies that are present (2). These are noted onto a postmortem odontogram that is then compared with the ante-mortem notes and similarities, explainable, and unexplainable discrepancies, are noted (2). The detection of composite restorations is made difficult because not only is the shade matching to natural teeth often very good, the margin between the filling and the tooth may also be imperceptible and difficult to detect with a dental explorer. The task of identifying composite restorations requires the teeth under examination to be clean, dry, and also well illuminated, preferably by a dental examination light. Often these ideal conditions do not exist within the morgue environment and, in mass casualty incidents; the additional pressure of time and temporary facilities may further confound detection. In addition to a comprehensive oral inspection, dental radiographs are also taken as part of an identification protocol. However, Chesne (3) found that 40% of aesthetic dental restorations could not be detected on dental radiographs at an acceptable resolution. It was recommended that a supplemental technique should be employed. The use of the ante-mortem treatment record to indicate locations of such fillings may also be flawed, as Borrman reports that 17% of dental records have incomplete restorative information and in 3% it is absent (4).

Supplemental methods for detecting composite restorations have been described including ultra-violet light, dyes, and radiographic techniques (5–8). The use of ultra-violet light is potentially harmful and requires the use of protective eyewear, while dyes can be cumbersome to use and will often fail to discriminate between restorations or any other porosity on the tooth surface. Many re-

[1] Doctoral student, Dept. of Clinical Dental Sciences, Faculty of Medicine, The University of Liverpool, England.
[2] Lecturer, Honorary consultant, Unit of Prosthodontics, University Dental Hospital of Manchester, England.
[3] Emeritus professor, Senior Research Fellow, Dept. of Clinical Dental Sciences, Faculty of Medicine, The University of Liverpool, England.
[4] Senior lecturer, Dept. of Clinical Dental Sciences, Faculty of Medicine, The University of Liverpool, England.
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quire cleaned, dry teeth and may, therefore, be impractical within the forensic environment.

A new method for detecting composite restorations is described here.

Quantitative Light-induced fluorescence (QLF)

Quantitative light induced fluorescence (QLF) is a new technique for the detection of very early mineral changes (early decay) in enamel (9). The QLF system is based upon the auto-fluorescence of human enamel and that this fluorescence will decrease with decreased mineral content (10). Early caries are, therefore, seen as dark areas and these can be quantified and longitudinally monitored. The QLF device (Inspektor Research Systems, BV, The Netherlands, www.inspektor.nl) increases the contrast between sound and carious enamel by a factor of ten compared with natural light images. The QLF device comprises of an intra-oral camera, a light source and a PC unit (Windows) for displaying and capturing the images. The device is shown in a diagrammatic form in Fig. 2 and in photographic form in Fig. 3. A liquid light guide is used to deliver the blue colored, visible light to the handpiece to which a mirror can be attached. The arc lamp is filtered to a wavelength of 370 nm (blue) and this is altered by a band-pass filter to a wavelength of 520 nm prior to be captured by the CCD camera within the handpiece.

A live image of the tooth is shown on the PC's screen and this can be captured and stored using either a foot pedal or keyboard press. Images are stored to the PC's hard drive in Windows bitmap format (*.BMP) and can be archived with ease. It is possible to attach an identifier and date information to each image.

The following study investigates the possibility of using QLF to detect, through enhanced contrast, composite fillings placed within human enamel.

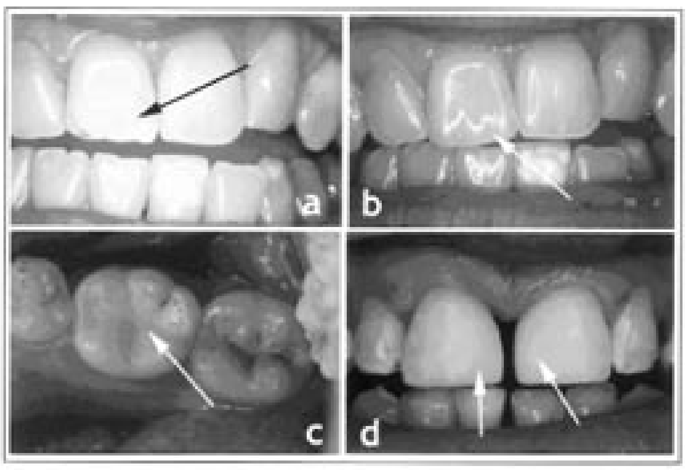

FIG. 1—*Clinical examples of composite (white) restorations:*
a) Fractured incisal edge.
b) Same tooth as in (a) with a composite placed to restore the fracture.
c) Composite restoration of the occlusal surface of a molar.
d) Composite has been placed on the mesial edges of these central incisors to decrease the mid-line diastema.

Material and Methods

Tooth Preparation

Twenty-four previously extracted (for orthodontic reasons) human premolars were selected based upon their lack of dental caries,

FIG. 3—*The QLF camera, approximately 90 mm long.*

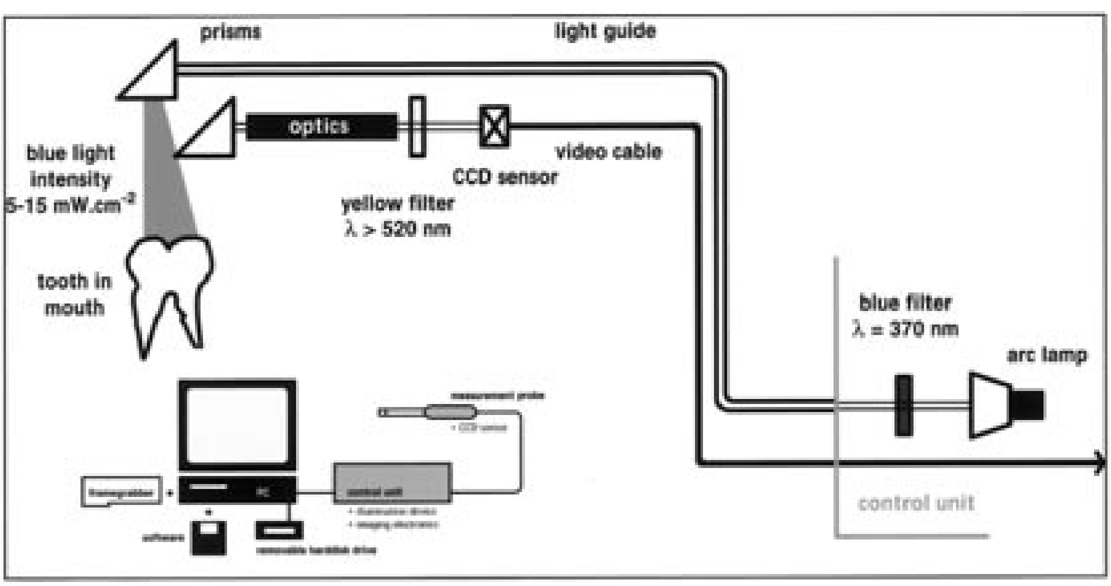

FIG. 2—*Diagrammatic representation of the QLF device.*

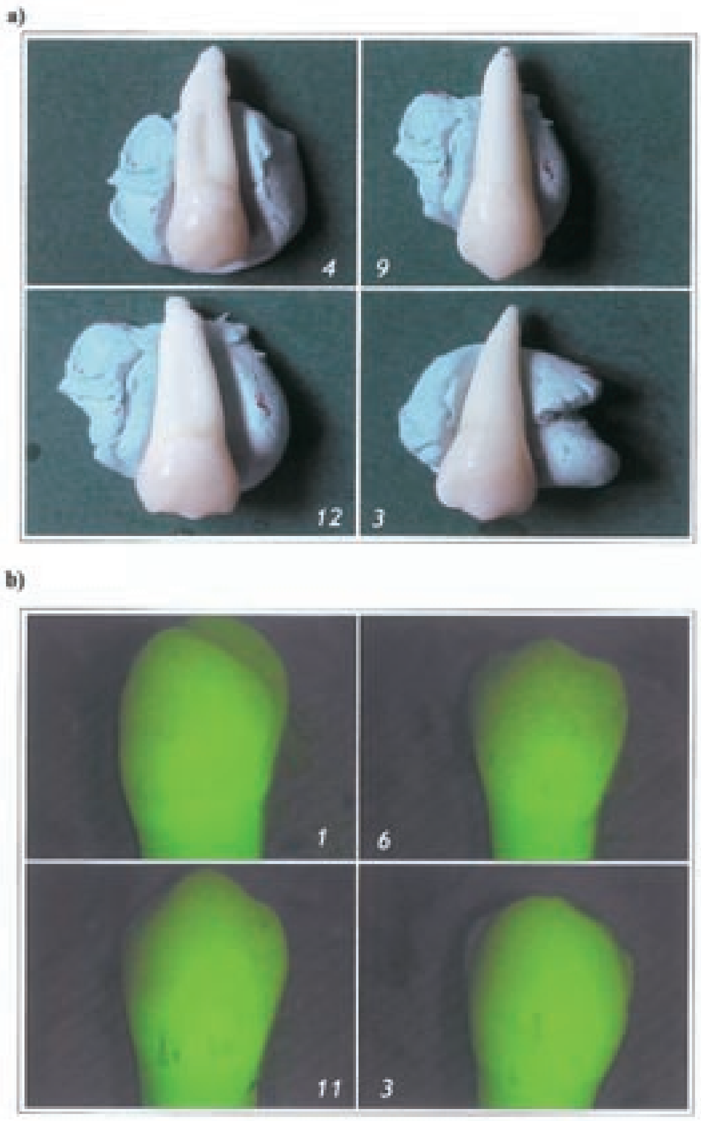

FIG. 4—*Example of non-restored tooth images supplied to examiners: (a) white light. (b) QLF.*

enamel malformations, or restoration. Following selection teeth were gently pumiced (SS White, UK) and lightly abraded with wet and dry paper. Subsequently, each tooth was examined (by a dental clinician) and 12 of the teeth were randomly selected and these were restored with a composite restorative material, (Spectrum Shade B3 Lot No. 0012000329) using the following protocol. A single bur hole was created using a high-speed dental turbine on either the buccal or lingual surface. This was then prepared to receive the composite by firstly acid etching (37% phosphoric acid, Gel Etch, ScientificPharma, Inc, Pomona, CA) and then by using a bonding agent (Dentsply Prime & Bond NT, Lot 010 3001099). This was polymerized using a light-curing unit (3M model no XL1000 700341, output checked using curing radiometer model 100 (P/N 1053) at 550mW/cmsq). The composite resin was then placed and set using the curing unit. This protocol follows the manufacturers instructions for the placement of the material and reflects the manner in which such restorations are placed intra-orally.

The remaining 12 teeth were cleaned but not prepared for restoration with composite. Digital photographs were then taken of all 24 teeth under the same lighting conditions (Cybershot, 3.3 Mega pixels, Sony, USA): a) when dry and b) when moistened with distilled water from a cotton wool roll. QLF images were then taken under the same conditions. Each of the images was then allocated a number and then laid out onto two Word documents: a) white light images dry, b) QLF images dry, c) white light images wet, and d) QLF images wet. See Figs. 4 and 5 for examples of the images supplied to the examiners. Each sheet contained both restored and unrestored images placed in a random order.

Examiners

These documents were then emailed to ten experienced dental clinicians who has previous experience of forensic identifications. The examiners were asked to state, for each tooth under each condition (48 decisions in total) whether or not they believed that the tooth had been restored with composite. After a period of at least one month they were asked to repeat the study to determine intra-examiner reliability (11,12). Their responses were recorded on a

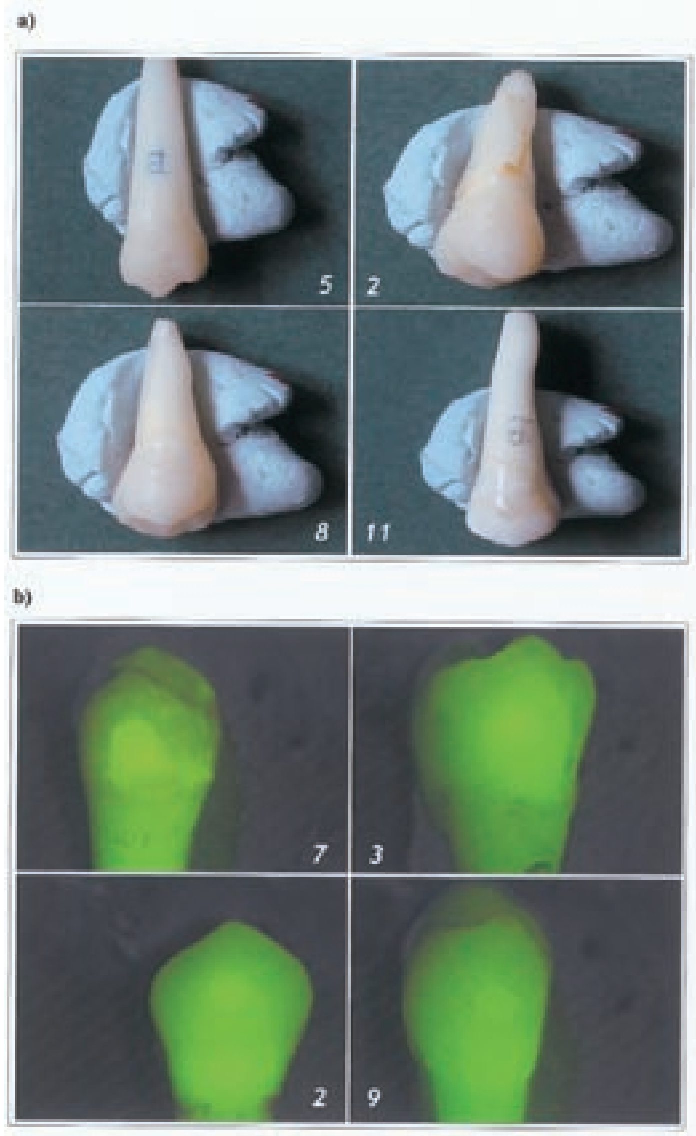

FIG. 5—*Example of restored tooth images supplied to examiners: (a) white light. (b) QLF.*

proforma and sent back to the authors. All examiners correctly completed both attempts.

Statistical Analysis

Data were entered into Microsoft Excel from where it was used in the PEPI suite of statistical programs (13). Analysis obtained values for percentage agreement (% correct), specificity, sensitivity, and Kappa (chance corrected agreement). A paired t-test was run on the P% scores to determine if QLF images afforded a statistically significant improvement in composite detection over standard white light conditions.

Results

Accuracy and Validity

Table 1 shows the data from the QLF examination, Table 2 for white light. Table 3 shows the Landis and Koch measurement scale

TABLE 1—*QLF examination of dry and wet teeth.*

QLF Examinations—Dry Teeth						
Examiner	Agree (%)	Kappa	SPEC %	SENS %	FPR	FNR
1	92	0.83	91.6	91.6	8.3	8.3
2	92	0.83	100	83.3	0	16.67
3	100	1	100	100	0	0
4	79	0.58	83	75	25	16.6
5	88	0.75	91.6	75	8.3	16.6
6	100	1	100	100	0	0
7	83	0.67	88	75	8.3	25
8	83	0.67	88	75	8.3	25
9	92	0.83	91.6	100	8.3	0
10	100	1	100	100	0	0
Mean	90.9	0.816	93.38	87.49	6.65	10.817
SD	7.651434	0.150864	6.239979	11.9464	7.653794	10.42339
QLF Examinations—Wet Teeth						
Mean	87.2	0.712	91.23	81.6	8.2	13.2
SD	8.5623	0.1859	7.235	8.56651	5.698	11.2544

Agree = Percentage agreement.
Spec = Specificity.
Send = Sensitivity.
FPR = False positive rate.
FNR = False negative rate.
SD = Standard deviation.

TABLE 2—*White light examinations of dry and wet teeth.*

White Light Examinations—Dry Teeth						
Examiner	Agree (%)	KAPPA	SPEC %	SENS%	FPR	FNR
1	46	0.08	50	41	67	72
2	58	0.17	83	33	6	16
3	50	0.5	50	50	50	50
4	33	0.06	58	75	25	41
5	83	0.67	83	83	16	16
6	54	0.08	33	75	25	66
7	79	0.58	66	50	50	33
8	75	0.5	58	83	16	41
9	33	0.06	58	75	25	41
10	83	0.67	83	83	16	16
Mean	59.4	0.337	62.2	64.8	29.6	39.2
SD	19.53458	0.268206	16.71859	19.21111	19.45479	19.92653
White Light Examinations—Wet Teeth						
Mean	45.2	0.288	54.3	45.369	32.256	42.35
SD	25.3	0.156	17.895	24.56	15.623	18.568

Agree = Percentage agreement.
Spec = Specificity.
Send = Sensitivity.
FPR = False positive rate.
FNR = False negative rate.
SD = Standard deviation.

TABLE 3—*Kappa values and strength of agreement.*

Kappa	Strength of Agreement
0.00–0.01	Poor
0.01–0.20	Slight
0.21–0.40	Fair
0.41–0.60	Moderate
0.61–0.80	Substantial
0.81–1.00	Almost perfect

for Kappa scores (11,12). Paired t-tests revealed significant differences between the agreement scores, with QLF proving significantly more accurate than white light examination ($p<0.005$). When the Kappa scores were compared, QLF also provided a significant improvement over the white light images ($p<0.003$).

Reliability

The Kappa scores for intra-examiner reliability were calculated and QLF examinations achieved 0.86 (±0.15) and white light examinations 0.73 (±0.25). No significant difference was detected between the intra-examiner reliability scores.

Discussion

The results show that examination under QLF conditions significantly increases the detection of composite restorations placed on the smooth surfaces of extracted teeth. Within clinical practice it is normal to color or shade match the composite material to the tooth. This was not done in this case, a single shade, B3, was used throughout to avoid the effect of subjective assessment of color matching. Because of this, we could expect the white light scores to be lower if the shade was matched accurately, although it is unlikely to affect the QLF ratings (shade does not affect fluorescence).

The sensitivity of this test is its ability to detect correctly teeth that have been restored. A test that is 100% sensitive will identify *every* restored tooth; an insensitive test will lead to missed restorations. A sensitive test results in very few false negative results. The specificity of the test is the percentage of non-restored teeth that are correctly identified. A test that is always negative for non-restored teeth will have a specificity of 100%. A highly specific test produces few false positive results. From these data QLF is both sensitive and specific, being slightly more specific, i.e., having slightly more false negatives than false positives. No significant difference ($p>0.05$) was detected between the examinations of wet or dry teeth using QLF. White light image assessment was more sensitive under dry conditions, and more specific when assessing wet teeth, although again these differences were not significant. This is an important factor in postmortem examinations where time constraints and physical factors may preclude the drying of each tooth.

Kappa is a measure of agreement that corrects for chance, i.e., those responses that occurred by chance rather than because of a correct decision. A Kappa score of 0.50 is equivalent to a random allocation of teeth to either restored or un-restored. Landis and Koch have developed a scale for the interpretation of these values (Table 3) (11). The assessment of agreement (i.e., examiner's decisions compared with the correct answer) of QLF was almost perfect under dry conditions and substantial when assessing wet teeth. Decisions made for both wet and dry teeth under white light can be described as fair. The intra-examiner data shows that both methods are reliable, i.e., repeated measures produce the same results. It is important to recognize that the white light assessments, while reliable, were still broadly incorrect, with a correct response of 59.4% (dry) compared with 90.9% (dry) with QLF.

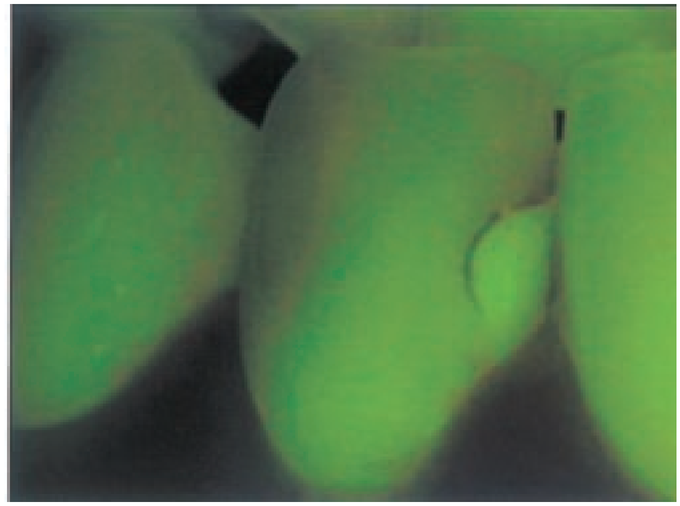

FIG. 6—*Intra-oral QLF image of a wet tooth showing a composite restoration on the lower right lateral incisor.*

This was preliminary study to investigate the potential for QLF to be employed within a forensic context. Further work is required to determine the effect of composite stain, age, shade and the device's use *in vivo* and on occlusal surfaces. The authors have used the device intra-orally on living individuals. An example of a composite restoration examined under such conditions is shown in Fig. 6. The data presented from this pilot study suggest that QLF will be a reliable and accurate method for the detection of composite restorations. The QLF device is currently a research tool and not currently in mass production and, as such, is costly. Despite this, its use in mass casualty incidents may be warranted as the time/cost ratio may be of less importance. For more information on QLF, readers can visit www.cariology.com, and for its application in forensic science, www.forensicdentistryonline.org. Color versions of the images in this technical note are available from both websites.

Acknowledgments

Figure 1 is reproduced with permission from the DerWeb image library, www.derweb.ac.uk. Figure 2 is reproduced with permission of Inspektor Research Systems, BV, *www.inspektor.nl*. The authors would like to thank the forensic dentists who have taken part in this study.

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Additional information and reprint requests to:
I.A. Pretty
Dept. of Clinical Dental Sciences
Edwards Building
Daulby Street
Liverpool, L69 3GN
England
Tel: 0151 706 5288
Fax: 0151 706 5809
E-mail: ipretty@liv.ac.uk