RESEARCH

Influence of materials radiopacity in the radiographic diagnosis of secondary caries: evaluation in film and two digital systems

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Objectives: The aim of this study was to evaluate the influence of restorative materials on false-positive diagnoses of secondary caries using three imaging systems.

Methods: Class II preparations were made on the occlusal and mesial or distal faces of extracted healthy third molar teeth. The teeth were divided into five groups and, with the exception of Group 5, they received a flow resin base. Groups 1, 2, 3 and 4 received a layer of Natural Flow (DFL, Rio de Janeiro, Brazil), Filtek Flow (3M-ESPE, St. Paul, MN), Tetric Flow (Ivoclar/Vivadent, Liechtenstein, Germany) and Protect Liner F (Kuraray, Okayama, Japan) resins, respectively, and were restored with Filtek Supreme resin (3M-ESPE). Group 5 was restored with Filtek Supreme resin. The images on film and on the Digora Optime[®] (Helsinki, Finland) and charge coupled device (CCD) IOX (IOX, Monninkylä, Finland) digital systems were evaluated by five examiners and the data were analysed using the Fisher's exact and Friedman tests at a 5% level of significance.

Results: Group 3 showed the highest rate of correct answers (restored tooth) and the lowest proportion of secondary caries diagnosis ($P \leq 0.05$). Group 4 showed the highest rate of secondary caries diagnosis and the lowest proportion of correct answers ($P \leq 0.05$). The systems for obtaining images presented were similar for each material.

Conclusions: The restorative material was found to have an influence on the diagnosis of secondary caries lesions by imaging. The imaging system had no influence. Materials with greater radiopacity, higher than that of enamel, were favourable for a true-negative diagnosis.

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Introduction

Radiopacity is a physical property of great interest with regard to restorative materials, particularly for posterior teeth,¹ and the requirements for radiopacity have been incorporated into standards for dental resins for use in class I and class II restorations.^{1,2} This property enables excess material at the cervical margins and contours of proximal faces to be detected and it is important in the radiographic differential diagnosis of secondary caries lesions to distinguish them from restorations.^{3–6} Diagnosis of secondary caries is a challenge to the clinician,⁷ and it is favoured by the radiopacity of materials. The manufacturers have added radiopacifying agents to

resins. Nevertheless, materials with high radiopacity frequently mask defects in certain projections in the images, making diagnosis difficult.⁸ For a restorative material to be used in posterior teeth, it must have a higher radiopacity than enamel.⁹ For the American National Standard/American Dental Association (ANSI/ADA)—Specification 27 (1993) for resin-based filling materials, the material must exhibit two or more millimetres of equivalence in thickness to aluminium (eq mm Al) or at least equal to or greater than the same thickness of aluminium and not less than 0.5 mm of any value alleged by the manufacturer, in accordance with International Organization for Standardization (ISO) 4049 (E) (2000).²

The benefit of the radiographic information in diagnosing proximal caries lesions is unquestionable in modern dentistry, and this is based on the judgment and interpretation of the findings by the observer. Experience

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in radiographic interpretation differs among clinicians with respect to the detection of lesions.⁶ In the diagnosis of secondary caries lesions by imaging, numerous factors influence detection, such as the proximity of the lesion to adjacent restorations, the initial size of the lesion, geometry, projection of the image and orientation of the lesion.⁷ The introduction of digital systems in dental practice has brought about some benefits, such as reduction in exposure time and an immediate image on the computer screen.¹⁰ However, in Nair *et al*'s study⁷ the performance in detecting defects simulating secondary caries on radiographs was similar to that of images obtained using the charge coupled device (CCD) IOX system (IOX, Monninkylä, Finland) and with a phosphorus plate; when the latter was enhanced with brightness and contrast, it was superior to images obtained with phosphorus plates without enhancement. The mode of visualizing digital images on flat panel monitors was compared, with the histological examination used as the gold standard. It has been proven that the overall accuracy for detection of carious lesions did not differ for different types of flat panel monitors.¹¹

The prevalence of secondary caries lesions and the need to replace restorations when this occurs emphasize the importance of radiographic evaluation and the decision-making process based on images.^{7,12} The removal of restorations invariably results in over extension of the cavity, irrespective of the type of material removed, when using 2× magnification lenses or photochromatic agents.¹³ The aim of this study was to evaluate the interpretation of images of teeth restored with composite resin on differential diagnosis by images of secondary caries lesions and the influence of the systems used to obtain images on this diagnosis.

Materials and methods

Approval for the study was obtained from the Research Ethics Committee of the University of Pernambuco (106/06; CONEP 93471). 100 extracted healthy third molar teeth were selected. The teeth were initially stored in 0.5% chloramine and, after being cleaned, they were

stored in distilled water under refrigeration; the water was changed weekly (ISO). To confirm the absence of caries, the teeth were clinically and radiographically examined by a radiologist.

The teeth were divided into five groups and in each tooth class II type cavity preparation was performed on the occlusal and mesial or distal face. The preparations were performed by a single operator with a cooled turbine at high speed and carbide bur no. 245 (KG-Sorensen, Cotia, Brazil). One bur was used for every three preparations, with the aid of a device made to standardize the preparations. The preparations were made to the following measurements: vestibular-lingual distance 3 mm; depth 3 mm; and mesiodistal distance 2 mm; all the measurements were confirmed using a millimetric probe.

With the exception of the teeth in Group 5, a flow resin base was used in all the other teeth. For the restorative procedure, the substrate was initially etched with 37% phosphoric acid for 15 s, then washed for 20 s and excess moisture removed with absorbent paper. The Adper Single Bond 2 (3M-ESPE, St. Paul, MN) adhesive system was applied with the aid of a microbrush and it was polymerized according to the manufacturer's recommendations. A layer of the following flow resins was used in Groups 1, 2, 3 and 4: Natural Flow (NF) from DFL (Rio de Janeiro, Brazil), Filtek Flow (FF) from 3M-ESPE, Tetric Flow (TF) from Ivoclar/Vivadent (Liechtenstein, Germany) and Protect Liner F (PLF) from Kuraray (Okayama, Japan), respectively; the material was placed 0.5 mm from the amelodentinal junction (Table 1). All the groups were restored with FS resin from 3M-ESPE, using an incremental restorative technique. The composites were polymerized in accordance with the manufacturers' recommendations using an Optilight Plus (Gnatus, Ribeirão Preto, Brazil) light polymerizer unit with a power of 450–600 mW cm⁻².

With the aim of representing the positioning of teeth in the dental arch, 50 phantoms were prepared, 25 simulating the maxillary and 25 simulating the mandibular arch, and each containing 2 teeth simulating the region of the first and second molars; images were then obtained in the same way as those obtained in the oral cavity. The purpose of this random disposition was to

Table 1 Selected resins and their specifications

Product	Composition	Manufacturer	Batch	Eq mmAl
Natural Flow (NF)	BIS-GMA, dimethacrylate polymer, filler: zirconium and silica 43% in volume; 60% in weight	DFL Dental Products, Rio de Janeiro, Brazil	5020105	1.50 ²¹
Filtek Flow (FF)	BIS-GMA, UDMA and BIS-EMA, filler: zirconium and silica, 47% in volume and 68% in weight	3M-ESPE, St. Paul, MN	4GG	2.25 ²¹
Tetric Flow (TF)	BIS-GMA, UDMA and TEGDMA, filler: barium glass, ytterbium trifluoride, Ba-Al-fluorosilicate glass, high dispersed silica and mixed oxides; 39.7% in volume and 64.6% in weight	Ivoclar/Vivadent Liechtenstein	F60885	6.50 ¹⁰
Protect Liner F (PLF)	BIS-GMA, TEGDMA, fluoride-methyl methacrylate; silanized colloidal silica; prepolymerized organic filler; 42% in weight	Kuraray Co., Ltd, Okayama, Japan	0056B	<1.00 ²¹
Filtek Supreme (FS)	BIS-GMA, UDMA, BIS-EMA and TEGDMA, filler: zirconium and silica, 57.7% in volume and 72.5% in weight	3M-ESPE, St. Paul, MN	5FM	4.52*

*Data obtained in a previous study under review for publication

avoid familiarity for the observer when interpreting the images. Industrial silicone (PlatSil gel 10, Moldflex, São Paulo, Brazil) was used to keep the teeth in the correct position; the stability and flexibility of this material after its chemical reaction has been completed allows the teeth to be manipulated, removed and inserted without losing the pre-established relationships. The phantoms were made in acrylic polymer matrices, measuring 20 mm high, 3 mm wide, 35 mm long and 4.5 mm thick. Superimposition of the proximal faces on the radiographic images was avoided by fixing a lead slide between the proximal faces of the teeth until the silicone was completely polymerized. After the material was polymerized, the sets were removed from the matrices and excess materials were removed to avoid interference during evaluation of the images.

Agfa M2 Confort (Heraeus Kulzer, Hanau, Germany) periapical films, a CCD IOX system (IOX, Monninkylä, Finland) and a Digora Optime® (Helsinki, Finland) phosphorus plate system were used to obtain the images. An X-ray Electronic Spectro 70× (Dabi Atlante, Ribeirão Preto, Brazil) was used with 8 mA, 70 kVp, and a focus–film distance of 40 cm was maintained for all exposures. The exposure time was 0.4 s for the film and 0.2 s for the sensors in the digital systems; these times were established by selection by three examiners with expertise in the area and the accuracy and reproducibility were confirmed using an RMI 242 (Gammex, Middleton, WI). The central X-ray beam was directed parallel to the interproximal surfaces of the teeth, thus avoiding the overlap of these faces.

After processing the images, they were mounted on black gouache paper so that only one image was

observed at a time during interpretation in a TFT-LCD negatoscope (VH Essence Dental, Araraquara, Brazil) using standardized illumination. The digital images were exported in TIFF format with resolution of 300 dpi (Figures 1 and 2) and opened in PowerPoint 2003 (Microsoft Redmond, WA). There was no loss of information after being transferred and the images were visualized on a HP Pavillon Dv 4000 (Hewlett-Packard Palo Alto, CA) laptop with a 15.1 inch screen, also using standardized illumination.

Five examiners were selected: three specialists in dentistry and two radiologists. The examiners received a questionnaire and instructions on how to answer it, which reported that each image has four teeth, representing two mandibular and two maxillary teeth. They were not informed about the conditions of the teeth, whether it had had some restoration in one or both faces or whether they were healthy. Each examiner observed the images from only one system or radiograph at a time, and the other analyses were made after an interval of at least 3 days. By visualizing the images, the examiners were asked if the tooth was healthy or had had some restoration, and when there were restorations, whether they were affected by secondary caries or not.

After the analyses, the data were tabulated and submitted to statistical analysis by Fisher's exact test and the Friedman test.

Results

There was a statistically significant association between the type of material and the diagnosis, taking the system

Figure 1 Charge coupled device image. The tooth (a) shows radiolucent image under restoration (arrow). Higher rate of incorrect response

Figure 2 Charge coupled device image. The tooth (a) shows radiopaque image under restoration (arrow). Highest rate of correct answer

into consideration ($P \leq 0.05$) (Table 2). According to the adjusted analysis of the residues (Table 3), for any one of the three systems, TF+FS was significantly associated with a higher percentage of correct diagnoses (adjusted residues (AR) > 2.0) and a lower proportion of secondary caries diagnoses (AR < -2.0). However, PLF+FS was significantly associated with a higher proportion of secondary caries diagnoses (AR > 2.0) and a lower proportion of correct diagnoses (AR < -2.0). With the CCD system, NF+FS behaved similarly to TF+SF; both were significantly associated with a higher percentage of correct diagnoses (AR > 2.0). With the Digora system, FS behaved similarly to TF+FS; both were significantly associated with a higher percentage of correct diagnoses (AR > 2.0) and a lower proportion of incorrect diagnoses (AR < -2.0). With the Digora system, NF+FS was also significantly associated with a higher percentage of correct diagnoses; FF+FS was significantly associated with a lower percentage of incorrect diagnoses, emphasizing that material PLF+FS was significantly associated with a higher percentage of secondary caries diagnoses.

Table 4 presents the analysis of the association between the systems and the diagnoses, controlling for the type of material. The results of Friedman's test showed that the systems presented similar behaviour for NF+FS ($P = 0.368$), FF+FS ($P = 0.368$), TF+FS ($P = 0.223$), PFL+FS ($P = 0.307$) and FS ($P = 0.311$).

Discussion

In the radiographic diagnosis of secondary caries, the evaluator's experience is, without doubt, the most

important characteristic.^{14,15} However, the aim of this study was not to evaluate the individual characteristics of each evaluator, but the influence of the materials and systems in the diagnosis of secondary caries by imaging.

Restorative materials can influence the diagnosis of secondary caries lesions by imaging,^{14,16} a fact that corroborates the results of this study, in which significantly different behaviour was observed in all the systems used.

Adequate radiopacity allows a restorative material to be distinguished from enamel and dentine because of the difference in contrast, making it easier to diagnose recurrent caries, the presence of bubbles between the material and the interface, excess restorative material and inefficient adaptation of the restoration, particularly in posterior teeth.¹⁷ When adaptation is inadequate, secondary caries may appear, located between the restorative material and the tooth. High radiopacity may mask a defect in certain projections, making it difficult to visualize an image suggestive of secondary caries.¹⁴

The radiopacity of resinous materials is related to content as a percentage by weight and volume, and the chemical composition of the load particles, particularly in radiopaque oxides, such as the vitreous loads of barium, strontium and zirconia,^{18,19} and can be influenced by the thickness of the material used. In this study, the cavities were made in a standardized manner, with the use of a device and by a single operator, so that the thickness factor would not interfere in the observation of the images.

The resin composites used in this study had adequate radiopacity,^{10,20} with the exception of the PLF resin,

Table 2 Association between type of material and diagnosis, controlling for the type of system

System	Material	Diagnosis			Total	P value*
		Restored	Secondary caries	Healthy		
Film		N (%)	N (%)	N (%)	N (%)	0.007
	NF + FS	16 (80.0)	3 (15.0)	1 (5.0)	20 (100.0)	
	FF + FS	13 (65.0)	4 (20.0)	3 (15.0)	20 (100.0)	
	TF + FS	19 (95.0)	1 (5.0)	0 (0.0)	20 (100.0)	
	PLF + FS	9 (45.0)	9 (45.0)	2 (10.0)	20 (100.0)	
	FS	18 (90.0)	1 (5.0)	1 (5.0)	20 (100.0)	
CCD	Total	75 (75.0)	18 (18.0)	7 (7.0)	100 (100.0)	<0.001
	NF + FS	19 (95.0)	1 (5.0)	0 (0.0)	20 (100.0)	
	FF + FS	11 (55.0)	7 (35.0)	2 (10.0)	20 (100.0)	
	TF + FS	20 (100.0)	0 (0.0)	0 (0.0)	20 (100.0)	
	PLF + FS	6 (30.0)	12 (60.0)	2 (10.0)	20 (100.0)	
	FS	15 (75.0)	4 (20.0)	1 (5.0)	20 (100.0)	
Digora	Total	71 (71.0)	24 (24.0)	5 (5.0)	100 (100.0)	0.001
	NF + FS	17 (85.0)	3 (15.0)	0 (0.0)	20 (100.0)	
	FF + FS	9 (45.0)	8 (40.0)	3 (15.0)	20 (100.0)	
	TF + FS	18 (90.0)	2 (10.0)	0 (0.0)	20 (100.0)	
	PFL + FS	5 (25.0)	13 (65.0)	2 (10.0)	20 (100.0)	
	FS	17 (85.0)	1 (5.0)	2 (10.0)	20 (100.0)	
	Total	66 (66.0)	27 (27.0)	7 (7.0)	100 (100.0)	

NF, Natural Flow; FF, Filtek Flow; TF, Tetric Flow; PLF, Protect Liner F; FS, Filtek Supreme; CCD, charge coupled device. *Fisher's exact test

which showed radiopacity of lower than 1 mm in the equivalent aluminium thickness.²¹ This value is below the recommended radiopacity value (2 mm Al; specification no. 27 of the ANS/ADA Specification¹ or at least the same thickness in mm Al as the test specimen²).

Secondary caries behaves in a similar manner to primary caries, except for location.^{22,23} Radiolucent

Table 3 Adjusted residues showing the sources of the association between type of material and diagnosis, controlling for the type of system

System	Material	Diagnosis		
		Restored	Secondary caries	Healthy
Conventional	NF + FS	0.6	-0.4	-0.4
	FF + FS	-1.2	0.3	1.6
	TF + FS	2.3	-1.7	-1.4
	PLF + FS	-3.5	3.5	0.6
	FS	1.7	-1.7	-0.4
CCD	NF + FS	2.6	-2.2	-1.1
	FF + FS	-1.8	1.3	1.1
	TF + FS	3.2	-2.8	-1.1
	PLF + FS	-4.5	4.2	1.1
	FS	0.4	-0.5	0.0
Digora	NF + FS	2.0	-1.4	-1.4
	FF + FS	-2.2	1.5	1.6
	TF + FS	2.5	-1.9	-1.4
	PLF + FS	-4.3	4.3	0.6
	FS	2.0	-2.5	0.6

NF, Natural Flow; FF, Filtek Flow; TF, Tetric Flow; PLF, Protect Liner F; FS, Filtek Supreme; CCD, charge coupled device. An adjusted residue with absolute value ≥ 2.0 in any cell indicates a statistically significant association between the level of 0.05 between material and diagnosis in this cell. An adjusted residue set with absolute value < 2.0 in any cell indicates that, in this cell, there was no statistically significant association at the level of 0.05 between material and diagnosis

images resulting from maladaptations of restorations at the tooth-material interface, the presence of residual caries and non-infected demineralized dentine must not be confused with secondary caries in the radiographic diagnosis; this frequently leads to the dentist replacing the restoration involved when measures to control dental plaque should be established because these conditions are located in regions where it is easy for plaque to accumulate and cleaning is difficult.²²

The responses "secondary caries" and "healthy tooth" were considered errors of diagnosis, because all the teeth were restored and were caries-free. The TF resin, used as a base, in association with the FS resin, used as a restorative material, presented a higher number of correct responses than errors in the other systems. Studies have shown that TF resin has a radiopacity of 5.31 mm Al²⁰ and 6.5 mm Al,¹⁰ therefore justifying the higher number of correct responses with the answer "restored tooth" because there is greater efficacy in diagnosis when the materials have a radiopacity equal to or higher than that of enamel in mm Al equivalence.^{6,10,14,16}

Nevertheless, the PLF resin used as a base in association with FS resin was the one that presented the highest number of errors, irrespective of the system. Imperiano *et al*²¹ showed that PLF resin had a radiopacity lower than 1 mm Al, favouring the higher number of errors, such as the diagnosis of secondary caries.

The FF resins showed radiopacity values of 2.25 mm Al²¹ and 2 mm Al²⁴ and NF resin showed 1.5 mm Al.²¹

In the diagnosis of proximal caries by imaging, no difference has been observed between conventional and digital systems in several studies.^{25,26} For the diagnosis of marginal gaps, it was shown that there is a significant influence between the type of system and diagnosis by imaging with greater detection of gaps with a conventional system than with the Digora Optime digital

Table 4 Association between type of system and response, controlling for the type of material

Material	System	Response			Total N (%)	P value*
		Restored	Secondary caries	Healthy		
		N (%)	N (%)	N (%)		
NF + FS	Conventional	16 (80.0)	3 (15.0)	1 (5.0)	20 (100.0)	0.368
	CCD	19 (95.0)	1 (5.0)	0 (0.0)	20 (100.0)	
	Digora	17 (85.0)	3 (15.0)	0 (0.0)	20 (100.0)	
FF + FS	Conventional	13 (65.0)	4 (20.0)	3 (15.0)	20 (100.0)	0.368
	CCD	11 (55.0)	7 (35.0)	2 (10.0)	20 (100.0)	
	Digora	9 (45.0)	8 (40.0)	3 (15.0)	20 (100.0)	
TF + FS	Conventional	19 (95.0)	1 (5.0)	0 (0.0)	20 (100.0)	0.223
	CCD	20 (100.0)	0 (0.0)	0 (0.0)	20 (100.0)	
	Digora	18 (90.0)	2 (10.0)	0 (0.0)	20 (100.0)	
PLF + FS	Conventional	9 (45.0)	9 (45.0)	2 (10.0)	20 (100.0)	0.307
	CCD	6 (30.0)	12 (60.0)	2 (10.0)	20 (100.0)	
	Digora	5 (25.0)	13 (65.0)	2 (10.0)	20 (100.0)	
FS	Conventional	18 (90.0)	1 (5.0)	1 (5.0)	20 (100.0)	0.311
	CCD	15 (75.0)	4 (20.0)	1 (5.0)	20 (100.0)	
	Digora	17 (85.0)	1 (5.0)	2 (10.0)	20 (100.0)	

NF, Natural Flow; FF, Filtek Flow; TF, Tetric Flow; PLF, Protect Liner F; FS, Filtek Supreme; CCD, charge coupled device; *Friedman's test

system.²⁷ This fact reveals the importance of diagnosing these failures because they may be confounded by secondary caries lesions as the location of the failure and/or lesion interferes with the diagnosis⁷ and can lead to incorrect treatment of these teeth. In this study, no difference in the behaviour of the systems was observed.

Although the systems behaved in a similar manner, there were a large number of errors; caries lesions were observed where they did not exist and restorations were not found when they were indeed present. Over 50% of the incorrect diagnoses were made for the Digora Otime system in teeth with FF resin as base and FS as restorative material and in the three systems analysed in teeth with PLF resin as base and FS as restorative material.

The presence or absence of secondary caries is one of the most difficult diagnoses to make and often results in decisions to replace restorations unnecessarily.²⁸ However, during the removal of a restoration, in addition to the time spent, healthy tissue is removed, particularly when the material is resin,¹³ resulting in discomfort and cost to the patient. Even though there is a decrease in caries prevalence, replacement of restorations is responsible for the largest amount of time used

by clinicians, particularly in preventing or treating secondary caries lesions.^{17,29}

Conclusions

From the results it is observed that the restorative material influences the diagnosis of secondary caries lesions by imaging. Materials with radiopacities higher than those of enamel favour the diagnosis because they differentiate dental structures by means of contrast. Resins with radiopacity values between the values of enamel and dentine, or lower than those of dentine, tend to generate confusion in the examiner and higher susceptibility to false-positive diagnoses of secondary caries lesions.

The imaging system was found to have no influence on the diagnosis, as the systems tested presented similar behaviour.

Continuity in the study of radiopacity of materials is important so that during the development of new materials, or in the evaluation of those that come onto the market, this radiolucency is investigated, thus preventing the occurrence of errors of interpretation during diagnosis by imaging.

References

1. American National Standard/American Dental Association Specification No. 27. *Resin-based filling materials*. Chicago, IL: American Dental Association Council on Dental Materials and Equipment; 1993.
2. ISO 4049. *Polymer-based filling, restorative and luting materials*. Geneva, Switzerland: International Organization for Standardization; 2000.
3. de Abreu MJ, Tavares D, Vieira DF. Radiopacity of restorative materials. *Oper Dent* 1977; **2**: 3–16.
4. Abou-Tabl ZM, Tidy DC, Combe EC. Radiopacity of composite restorative materials. *Br Dent J* 1979; **147**: 187–188.
5. Beyer-Olsen EM, Orstavik D. Radiopacity of root canal sealers. *Oral Surg Oral Med Oral Pathol* 1981; **51**: 320–328.
6. Espelid I, Tveit AB. A comparison of radiographic occlusal and approximal caries diagnoses made by 240 dentists. *Acta Odontol Scand* 2001; **59**: 285–289.
7. Nair MK, Ludlow JB, May KN, Nair UP, Johnson MP, Close JM. Diagnostic accuracy of intraoral film and direct digital images for detection of simulated recurrent decay. *Oper Dent* 2001; **26**: 223–230.
8. Sewerin IB. Radiographic identification of simulated carious lesions in relation to fillings with adaptive radiopaque. *Scand J Dent Res* 1980; **88**: 377–381.
9. Council on dental materials, instruments, and equipment, Status report on posterior composites. *J Am Dent Assoc* 1983; 107.

10. Sabbagh J, Vreven J, Leloup G. Radiopacity of resin-based materials measured in film radiographs and storage phosphor plate (Digora). *Oper Dent* 2004; **29**: 677–684.
11. Isidor S, Faaborg-Andersen M, Hintze H, Kirkevang LL, Frydenberg M, Haiter-Neto F, et al. Effect of monitor display on detection of approximal caries lesions in digital radiographs. *Dentomaxillofac Radiol* 2009; **38**: 537–541.
12. Mjör IA, Qvist V. Marginal failures of amalgam and composite restorations. *J Dent* 1997; **25**: 25–30.
13. Szep S, Baum C, Alamouti C, Schmidt D, Gerhardt T, Heidemann D. Removal of amalgam, glass-ionomer cement and compomer restorations: changes in cavity dimensions and duration of the procedure. *Oper Dent* 2002; **27**: 613–620.
14. Goshima T, Goshima Y. Radiographic detection of recurrent carious lesions associated with composite restorations. *Oral Surg Oral Med Oral Pathol* 1990; **70**: 236–239.
15. Wenzel A, Haiter-Neto F, Gotfredsen E. Influence of spatial resolution and bit depth on detection of small caries lesions with digital receptors. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2007; **103**: 418–422.
16. Nair MK, Tyndall DA, Ludlow JB, May K, Ye F. The effects of restorative material and location on the detection of simulated recurrent caries. A comparison of dental film, direct digital radiography and tuned aperture computed tomography. *Dentomaxillofac Radiol* 1998; **27**: 80–84.
17. Mjör IA. Clinical diagnosis of recurrent caries. *J Am Dent Assoc* 2005; **136**: 1426–1433.
18. van Dijken JWV, Wing KR, Ruyter IE. An evaluation of the radiopacity of composite restorative materials used in Class I and Class II cavities. *Acta Odontol Scand* 1989; **47**: 401–407.
19. Toyooka H, Taira M, Wakasa K, Yamaki M, Fujita M, Wada T. Radiopacity of 12 visible-light-cured dental composite resins. *J Oral Rehabil* 1993; **20**: 615–622.
20. Bouschlicher MR, Cobb DS, Boyer DB. Radiopacity of compomers, flowable and conventional resin composites for posterior restorations. *Oper Dent* 1999; **24**: 20–25.
21. Imperiano MT, Khoury HJ, Pontual MLA, Montes MAJR, Silveira MMF. Comparative Radiopacity of four low-viscosity composites. *Braz J Oral* 2007; **6**: 278–282.
22. Kidd EA. Caries diagnosis within restored teeth. *Adv Dent Res* 1990; **4**: 10–133.
23. Opdam NJ, Bronkhorst EM, Roeters JM, Loomans BA. A retrospective clinical study on longevity of posterior composite and amalgam restorations. *Dent Mater* 2007; **23**: 2–8. Epub 2006 Jan 18.
24. Attar N, Tam LE, McComb D. Flow, strength, stiffness and radiopacity of flowable resin composites. *J Can Dent Assoc* 2003; **69**: 516–521.
25. Syriopoulos K, Sanderink GC, Velders XL, van der Stelt PF. Radiographic detection of approximal caries: a comparison of dental films and digital imaging systems. *Dentomaxillofac Radiol* 2000; **29**: 312–318.
26. Haak R, Wicht MJ, Noack MJ. Conventional, digital and contrast-enhanced bitewing radiographs in the decision to restore approximal carious lesions. *Caries Res* 2001; **35**: 193–199.
27. Haak R, Wicht MJ, Hellmich M, Noack MJ. Detection of marginal defects of composite restorations with conventional and digital radiographs. *Eur J Oral Sci* 2002; **110**: 282–286.
28. Heaven TJ, Firestone AR, Weems RA. The effect of multiple examinations on the diagnosis of approximal caries and the restoration of approximal surfaces. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 1999; **87**: 386–391.
29. Burke FJ, Crisp RJ, Bell TJ, Healy A, Mark B, McBirnie R, et al. One-year retrospective clinical evaluation of hybrid composite restorations placed in United Kingdom general practices. *Quintessence Int* 2001; **32**: 293–298.