©Operative Dentistry, 2014, **39-1**, 90-97

Influence of Radiopacity of Dental Composites on the Diagnosis of Secondary Caries: The Correlation Between Objective and Subjective Analyses

AD Cruz • RG Esteves • IAVP Poiate
PP Portero • SM Almeida

Clinical Relevance

Distinguishing among images of restorative materials, carious lesions, and sound dental tissue is challenging when making a radiographic diagnosis. Therefore, assessing the adaptation and integrity of restorations depends on the radiopacity of the restorative material. If the material is too radiopaque, it may be difficult to distinguish from dental tissues. If poorly radiopaque, it can camouflage possible failures.

*Adriana Dibo Cruz, DDS, PhD, Dental School of the Fluminense Federal University, Polo of Nova Friburgo, Department of Specific Formation, Area of Dental Radiology, Nova Friburgo, Rio de Janeiro, Brazil

Renata Gama Esteves, DDS student, Dental School of the Fluminense Federal University, Polo of Nova Friburgo, Nova Friburgo, Brazil

Isis Andréa Venturini Pola Poiate, DDS, PhD, Dental School of the Fluminense Federal University, Polo of Nova Friburgo, Department of Specific Formation, Area of Dental Clinic, Nova Friburgo, Rio de Janeiro, Brazil.

Priscila Paiva Portero, Dental School of the Fluminense Federal University, Polo of Nova Friburgo, Department of Specific Formation, Area of Dental Clinic, Nova Friburgo, Rio de Janeiro, Brazil.

Solange Maria Almeida, DDS, MS, PhD, Dentistry School of Piracicaba, State University of Campinas, Department of Oral Diagnostic, Piracicaba, Brazil

*Corresponding author: 22, Dr Silvio Henrique Braune Street, Nova Friburgo, Rio de Janeiro 28625-650, Brazil; e-mail: adrianadibo@id.uff.br

DOI: 10.2341/12-377-L

SUMMARY

This study aimed to objectively evaluate the radiopacity of different dental composites and their subjective influence on diagnosing secondary caries–like lesions and how these results correlate. For objective analysis, three resin specimens (1 mm thick, with a 4-mm internal diameter) were made with four composites: 1) Charisma; 2) Filtek Z250; 3) Prisma AP.H; and 4) Glacier. Three human teeth were selected and then mesio-distally sectioned (1 mm thick) to make the dental specimens. An aluminum (Al) wedge (12 steps, 1 mm thick, 99.8% purity) was used as an internal standard to calculate the radiopacity. For subjective analysis, 20 human teeth were selected and then prepared with a mesio-occluso-distal (MOD) inlay cavity, with half the teeth receiving a round cavity to simulate the carious lesion. The MOD was restored using the com-

Downloaded from https://prime-pdf-watermark.prime-prod.pubfactory.com/ at 2025-08-31 via free access

posites at four different times. Standardized radiographs were acquired and then digitized (300 dpi and eight-bit TIFF) for both analyses. A histogram objectively measured the pixel intensity values of the images, which were converted into millimeters of Al using linear regressions. Eight observers subjectively evaluated the images using a five-point rating scale to diagnose the caries. The data were statistically analyzed using the Student *t*-test, the Kappa test, diagnostic testing, and the Pearson correlation coefficient (α=0.05). All materials showed radiopacity values compatible with dental tissues ($p>0.05$); Glacier was similar to dentin and Prisma AP.H was similar to enamel, while the remaining materials showed a middle radiopacity. Prisma AP.H and Glacier differed ($p<0.05$) in relation to their accuracy to caries diagnosis, with Glacier having greater accuracy. There was a correlation between objective and subjective analyses with negative linear dependence. An increase in the material's radiopacity could have a subjectively negative influence on the diagnosis of secondary caries; thus, an ideal radiopacity for a dental composite is closer to the dentin image and produces similar attenuation to X-rays than does dentin.

INTRODUCTION

Dental composites have been routinely used as the dental restorative material of choice to fulfill the growing concern over esthetics. However, despite improvements in these composites, some disadvantages still need to be overcome, including secondary caries, detecting marginal overhangs, or contouring and adaptation failures.[1-3] Secondary caries is a common cause of restoration loss. An accurate diagnosis of this condition is key to determining the use of these restorations.

The radiographic exam remains the primary method of diagnosing secondary caries in posterior teeth. However, optical factors may influence this diagnosis, such as factors derived from different radiopacities, including those from restorative material, carious lesions, and dental tissues.[4] For better diagnosis, a restoration needs to have a radiopacity similar to that of dental tissues.[3] Therefore, it has been recommended[3,5,6] that the restorative material be more radiopaque than dentin and, preferably, have a radiopacity closer to that of enamel. However, an increase in the restorative material's radiopacity can reduce secondary caries detection and increase the incidence of false-positive results.[7]

There are technical groups that have developed guidelines[8,9] on how to define a level of radiopacity of the material for clinical use, generally in relation to a reference image, such as enamel, dentin, or aluminum (Al). Thus, it is recommended that the radiopacity of composite materials needs to be equal to or greater than that of the same thickness of Al, with 98% purity (less than 0.1% copper and less than 1% iron) and no less than 0.5 mm below any value. However, the primary challenge is establishing the quantity of radiopacity that the material should have for the ideal diagnosis.

For that reason, considering radiopacity as a property of great importance for making a radiographic diagnosis, the aim of this study was to objectively evaluate the radiopacity of different dental composites and their subjective influence on the diagnosis of secondary caries–like lesions and to make a correlation between both results.

MATERIALS AND METHODS

After receiving approval to conduct this research from the Research Ethics Committee, 23 human, noncarious permanent teeth, 12 premolars and 11 molars, were selected as test teeth. Three teeth (two premolars and one molar) were randomly selected for use in the objective analysis of radiopacity, whereas the 20 remaining teeth were used in the analysis of the subjective influence of radiopacity. To confirm the absence of caries, the teeth were clinically examined, and their proximal faces could not have any apparent lesions. Another five nontest teeth were included in the sample to serve as the contact point to simulate the anatomical condition during the analysis of the subjective influence of radiopacity. All of the teeth were cleaned by removing debris and were stored in distilled water at 4°C for no more than six months postextraction.

Objective Analysis of Radiopacity

The materials evaluated in this study (listed in Table 1) consisted of four different resin composites, as follows: 1) Charisma; 2) Filtek Z250; 3) Prisma AP.H; and 4) Glacier. Three resin specimens of each material were produced according to the manufacturers' instructions. These dental composites were inserted into 1-mm-thick stainless-steel ring molds with an internal 4-mm-diameter hole. In order to achieve uniformly smooth surfaces, the molds were placed between two glass slides covered with Mylar strips and were then

Downloaded from https://prime-pdf-watermark.prime-prod.pubfactory.com/ at 2025-08-31 via free access

Table 1: *List of Materials Tested in this Study*

Composite Resins	Manufacturer	Shade	Filler by Volume, %	Lot No.
Charisma®	Heraeus Kulzer GmbH, Hanau, Germany	A3	61	010325 2013-02
Filtek™ Z250	3M ESPE, Saint Paul, MN, USA	A3	60	9YH 2012-03
Prisma AP.H™	Dentsply International Inc, Petrópolis, RJ, Brazil	A3	57	L257026C V02/13
Glacier®	SDI Limited Bayswater, Melbourne, Vic., Australia	A3	62	080790 2013-07

submitted to one minute of 1 kg/cm^2 pressure to remove the excess material. The resin specimens were light-cured using the Elipar S10 LED Curing Light (3M/ESPE, St Paul, MN, USA), according to the manufacturer's instructions. They were then stored at 37°C (±1°C) and 95% (±5%) relative humidity until radiographic examination.

Dental crowns of three test teeth were mesio-distally sectioned 1 mm thick using a diamond saw at low speed (KG Sorensen 7020 flexible diamond disc, KG Sorensen, Barueri, SP, Brazil) in an IsoMet Low Speed Saw machine (Buehler Ltd, Lake Bluff, IL, USA) and water-cooling. The dental specimens with dentin and enamel were stored at 37°C (±1°C) and 95% (±5%) relative humidity.

An Al wedge (99.8% purity) with 12 steps, each 1 mm thick, was used as an internal standard to calculate the radiopacity of the resin and dental specimens in terms of their Al equivalent thicknesses (mmAl).

Standardized sets of radiographs (radiographic film, Al wedge, resin and dental specimens) were acquired in an X-ray machine (Heliodent 60B, Siemens, Erlangen, Germany) operating at 60 kVp (10 mA, 0.20 seconds, 40-cm target-to-receptor distance), with total filtration at 2 mm of Al. As the image receptor, E-speed radiography films (Ektaspeed Plus; Carestream Health Inc, Kodak Dental System, Rochester, NY, USA), which were processed automatically (GXP; Dentsply International/Gendex; Dentsply International Inc, York, PA, USA), were used. Each set was radiographed three times, producing nine radiographs.

Conventional radiographs were digitized by means of a laser scanner (HP Scanjet G4050; Hewlett Packard Corporation, Palo Alto, CA, USA) at 300 dpi and stored as eight-bit TIFF images. Each digital image was measured using the histogram function of the ImageJ 1.43u software (Wayne Rasband, National Institutes of Health, Bethesda, MD, USA). A trained evaluator collected three areas with the same size in regions of interest (ROIs) on the center of each resin and dental specimen and on each step of the wedge. The image was enlarged in order to accurately delimit ROIs. Data relating to pixel intensity values were tabulated and converted to mmAl using a function of linear regressions.

Analysis of the Subjective Influence of Radiopacity

In all 20 test teeth, a mesio-occluso-distal (MOD) inlay cavity was prepared[2] with a No. 1094 cylindrical diamond bur in a water-cooled, high-speed air turbine handpiece coupled in standardized equipment (Figure 1). For premolars, the MOD inlay preparations had a depth of 1.5 mm in the occlusal box and 3 mm in the proximal boxes, and in molars, the depth was 2 mm in the occlusal box and 4 mm in the proximal boxes. The MOD width was the same as the bur width (3 mm). The teeth were randomly divided into two groups: the experimental group (n=10, with five molars and five premolars), which received a round cavity in the floor of the proximal box (medial or distal) to simulate the carious lesion, and the control group (n=10, with five molars and five premolars), which did not receive a simulated lesion. The round cavities that simulated secondary carious lesions were made with a No. 1 round bur at a depth approximately equal to one-half of the bur. These cavities were filled with No. 7 wax to provide a nonradiographic image.

The MOD cavities were sequentially filled with four resin composites at four different times. The same protocol was followed for all teeth: restoration with one of the four resin composites, radiographic examination, removal of the restoration with a No. 1094 diamond bur at high speed, and restoration with another resin until all four materials were used in each tooth. To standardize the process, the cavity preparation or removal of the restoration needed to be done in a day, while the restoration and radiographic examination needed to be done on the following day. The teeth were stored at 37°C (±1°C) and 95% (±5%) relative humidity during all experimental procedures.

Using an imaging phantom and bitewing projection geometry, six teeth were mounted for each radiographic exposition—five nontest teeth and one test

Downloaded from https://prime-pdf-watermark.prime-prod.pubfactory.com/ at 2025-08-31 via free access

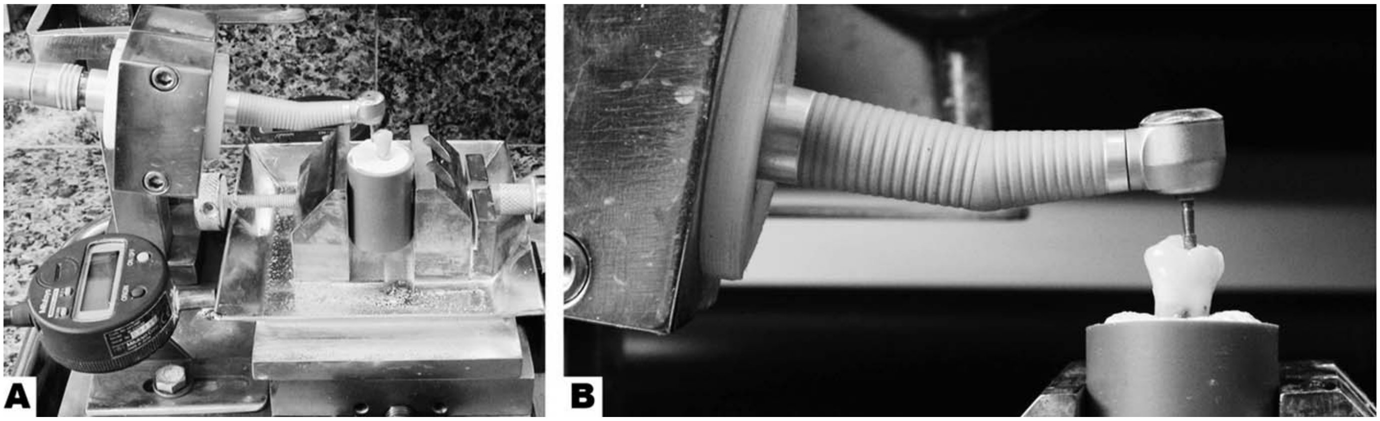

Figure 1. *Equipment for standardization of the mesio-occluso-distal (MOD) inlay cavity. (A) Wide view; (B) Detail.*

tooth. A restored test tooth was mounted in contact with two nontest teeth in a phantom, simulating the upper dental arch; the remaining three nontest teeth were mounted to simulate the lower dental arch. All radiographic images of this phantom were obtained, changing only the restored test tooth.

Standardized bitewing radiographs from the phantom were acquired using the same X-ray machine, Heliodent 60B (Siemens), following the same procedure as previously mentioned. A 12-mm-thick soft tissue–equivalent material was placed between the tube extension and the phantom to simulate radiation scatter. The conditions for processing and digitizing the conventional radiographs followed all previously mentioned procedures.

Digital images from digitized radiographs were randomly ordered in four PowerPoint presentations, each containing 20 images. Eight observers (all undergraduate dental students one semester prior to receiving their academic degree) independently recorded the images using a five-point rating scale, as follows: 1) secondary caries–like lesion definitely absent; 2) secondary caries–like lesion probably absent; 3) unsure if a secondary caries–like lesion is present or absent; 4) secondary caries–like lesion probably present; and 5) secondary caries–like lesion definitely present. Prior to the appraisals, a rehearsal session was held, allowing the observers to become familiar with the scoring program and with how to evaluate the images for secondary caries–like lesion diagnosis. The reading order of the presentations varied for each observer, and a period of at least one day separated the sessions. When viewing the images, the room light was turned off. Upon conclusion of the four presentations, 50% of the samples were reevaluated to obtain intraobserver reliability.

Statistical Analysis

Data in mmAl from the objective analysis of the radiopacity were tabulated and then statistically analyzed using the two-tailed, unpaired Student t-test. An independent comparison was made between images from each resin and dental reference (dentin or enamel). The data in the five-point rating scale from the analysis of the subjective influence of radiopacity were binarized, considering 1, 2, and 3 scores as “0” (absence of caries-like lesions) and 4 and 5 scores as “1” (presence of a caries-like lesion). The Kappa test (κ) was used to evaluate the intra- and interobserver reliability response pattern. Diagnostic testing (accuracy, specificity, sensitivity, negative predictive value [NPV], and positive predictive value [PPV]) was used to assess the observers' performance in detecting secondary caries–like lesions. The significance between each measure of the performance was obtained by the two-tailed, unpaired Student t-test. The Pearson correlation coefficient was used to determine the degree of linear dependence between the objective and subjective analyses. All statistical analyses were conducted with a significance level setting of 5% (α=0.05).

RESULTS

Regression analyses provided linear equations with a good fit (mean R^2=0.969 [0.961-0.973]) for converting pixel intensity values to mmAl. Table 2 shows the results in mmAl from the objective analysis of the radiopacity. All materials showed radiopacity values compatible with dental tissues. The radiopacity material Glacier did not differ statistically from dentin ($p>0.05$), and Prisma AP.H did not differ from enamel ($p>0.05$). Filtek Z250 showed a middle radiopacity between Prisma AP.H and both Charis-

Downloaded from https://prime-pdf-watermark.prime-prod.pubfactory.com/ at 2025-08-31 via free access

Table 2: *The Mean and Standard Deviation (SD) Values in Al Equivalent Thickness (mmAl) of each Material Tested Against Dental References*[a]

Specimens	Mean ± SD
Enamel	3.45 ± 0.46
Dentin	1.09 ± 0.36
Charisma®	1.47 ± 0.33[bc] C
Filtek™ Z250	2.46 ± 0.39[bc] B
Prisma AP.H™	3.55 ± 0.46[c] A
Glacier®	1.39 ± 0.43[b] C

[a] *Different capital letters designate materials that differed by* t-test (p<0.05).
[b] *Values that differed from enamel by* t-test (p<0.05).
[c] *Values that differed from dentin by* t-test (p<0.05);

ma and Glacier, which were similar to each other ($p<0.05$).

The reliability response pattern to the presence of caries-like lesions ranged from good to very good ($0.65 \leq \kappa \leq 0.83$) in the intraobserver analyses and ranged from fair to moderate ($0.31 \leq \kappa \leq 0.45$) in the interobserver analyses. Table 3 shows the results of diagnostic testing from the subjective influence of radiopacity. The materials Prisma AP.H and Glacier differed statistically ($p<0.05$) in relation to their accurate determination of the presence of caries-like lesions, with Glacier showing greater accuracy, whereas Charisma and Filtek Z250 showed middle-level accuracy. Non–statistically significant differences in all other measures of the performance were observed ($p>0.05$).

Figure 2 shows the results of the correlation between the objective and subjective analyses. In terms of results, a greater strength ($-0.701 \leq \rho \leq -0.922$) of negative linear dependence between the analyses, excluding specificity that showed a medium strength ($\rho=-0.410$) of negative linear dependence, was observed.

DISCUSSION

Generally, two distinct types of study evaluations of the radiopacity of dental composites have been found in the literature. There are those studies[1,4-6,10-12] that conducted this evaluation using objective analysis, comparing the image of materials to a reference image, and other studies[2,3,7,13-15] that made this evaluation by means of subjective analysis, comparing the observers' performance to a specific diagnosis. In this *in vitro* study, both analyses, objective and subjective, were used. Radiopacity values were objectively measured, and then their subjective influence was assessed through the diagnosis of secondary caries–like lesions, finishing with a correlation between the results based on both analyses.

In the current study, in terms of the objective analysis of radiopacity, all materials show a radiopacity similar to that of dental tissues, ranging from dentin to enamel, as represented by Glacier and Prisma AP.H materials, respectively. According to the guidelines,[8,9] radiopacity should be similar to or higher than that of an equal thickness of Al, and dentin has a radiopacity similar to an equal thickness of Al. In the current study, all materials conformed to these guidelines. Other studies[1,5,10] related that currently the composite materials have presented an appropriate radiopacity to the guidelines, despite a wide range of radiopacity, as observed in the current study as well. These wide ranges of radiopacity occur principally as a result of different kinds and proportions by volume of radiopacifying agents, considering the diversity of the manufacturers. Variations in radiopacity values of the same restorative materials among different studies can already occur because there are many methodological factors, such as those relating to film, X-ray machines, radiographic processing, and image analysis, that could induce such ranges.[10] Another important factor to be considered is the pureness of the Al wedge used in the conversion unit, considering the different alloys used as potent filtering objects for radiation; any alloy changes, related to a contaminating agent with a higher or lower atomic number, can significantly modify the radiation

Downloaded from https://prime-pdf-watermark.prime-prod.pubfactory.com/ at 2025-08-31 via free access

Table 3: *The Mean and Standard Deviation (SD) Values of the Diagnostic Testing for Observers' Performance in Detecting Secondary Caries-like Lesion*[a]

Summary	Charisma®	Filtek™ Z250	Prisma AP.H™	Glacier®
Accuracy	0.558 ± 0.072 AB	0.525 ± 0.050 AB	0.533 ± 0.014 B	0.625 ± 0.025 A
Specificity	0.500 ± 0.058 A	0.489 ± 0.069 A	0.511 ± 0.051 A	0.567 ± 0.067 A
Sensitivity	0.733 ± 0.115 A	0.633 ± 0.058 A	0.600 ± 0.200 A	0.800 ± 0.265 A
NPV	0.847 ± 0.072 A	0.799 ± 0.031 A	0.801 ± 0.069 A	0.912 ± 0.108 A
PPV	0.429 ± 0.124 A	0.336 ± 0.044 A	0.324 ± 0.117 A	0.541 ± 0.198 A

Abbreviations: NPV, negative predictive value; PPV, positive predictive value.
[a] *Different on-line letters designating the observers' performance that differed by* t-test (p<0.05).

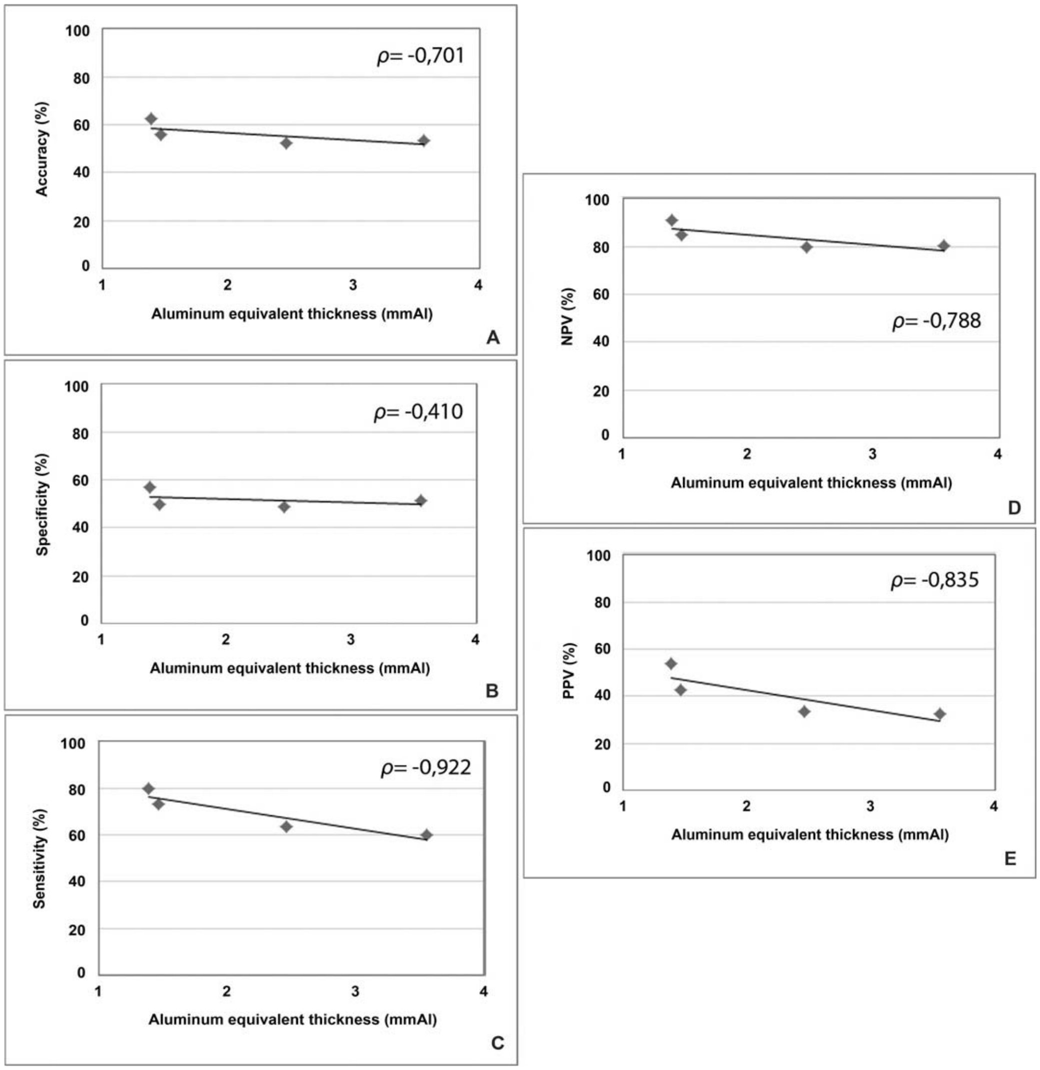

Figure 2. *Results of the degree of linear dependence between the objective and subjective analyses. (A) Accuracy; (B) Specificity; (C) Sensitivity; (D) Negative predictive value; (E) Positive predictive value.*

spectrum and result in a different image.[16] In the current study, the Al wedge had 99.8% purity, similar to the alloy used in the tube of the X-ray machine, such as Al X-ray filters.[16] However, another important factor is that the 12 steps of the Al wedge used in the current study are 1 mm thick. This could result in a model of regression with a good fit, which could perhaps not be obtained if each step was thicker.

In relation to the subjective influence of radiopacity, the Glacier material provided greater accuracy in detecting secondary caries, while there was no difference with Charisma and Filtek Z250, which differed only from Prisma AP.H, because it had a higher radiopacity. These results corroborate those of a previous study[2] that found that the accuracy was statistically similar and in which the worst accuracy of secondary caries detection was observed with materials of higher radiopacity. On the other hand, these results failed to support the findings of another previous study[7] that showed no difference in the accuracy of secondary caries detection as a result of very similar clinical radiopacities of the tested materials, which were similar to the radiopacity of dental tissues. As a consequence of the wide range of radiopacity of resin composites, care must be taken when choosing an appropriate material to facilitate secondary caries detection under posterior composite restorations;[1] diagnosis of carious lesions under esthetic restorations is more challenging as a result of optical interference from the radiopacity of the restoration added to the carious lesion image.[15,17]

Clinically, there are more challenges, because in addition to the characteristics of the carious lesion,

Downloaded from https://prime-pdf-watermark.prime-prod.pubfactory.com/ at 2025-08-31 via free access

there are also the inherent troubles associated with the radiographic image[2,3] because caries detection is possible when demineralization has occurred in more than 40% of tooth tissue.[18] The use of secondary caries–like lesions for analysis of observers' performance has been previously applied,[2,12,13,16] and the size of the cavity bears an influence in this performance.[12] In this study, a same-sized bur[12] was used in repeated specimens because the perceptive reliability was an important factor under consideration. An oversize cavity of regular borders could make the perception process of the image easier, distancing further from the clinical condition.[19]

Another important factor to be considered is the experience of the observers who are diagnosing the secondary caries.[20] The results of a previous study[20] showed that there is a lack of instruction in how to accurately diagnose secondary carious lesions in everyday clinical practice. Only an accurate diagnosis can provide a good basis for dental treatment planning. According to another study,[21] resin composites maintain a low level of performance as the restorative material in posterior teeth, and they should be periodically checked to prevent secondary caries. In spite of the low precision of bitewing radiographs for secondary caries, they have been recommended as a means by which to periodically check for the presence of secondary carious lesions (in conjunction with a clinical examination), which can help to improve the diagnosis.[22] Nevertheless, in the case of the current study, which used an experimental model of simulated secondary carious lesions, the perception of the image is more important than the experience of the observers. However, even with minimal experience in caries diagnosis, because the observer sample consisted of dental students during their last phase prior to receiving their academic degree, intra- and inter-observer reliability values found in the current study were similar to those observed in previous studies.[3,20]

Diagnostic challenges can occur in a clinical situation as the result of a low perception of differences in radiopacity values that are very similar between materials, making it difficult for observers to distinguish these minor variations on a radiographic image.[23] Others studies[3-7] showed that restorative materials with a radiopacity closer to that of enamel supported greater accuracy in diagnosing secondary caries. To the contrary, the current study observed a correlation between both objective and subjective analyses, wherein an increase in radiopacity decreased the observers' ability to diagnose secondary caries. This can be generally verified with a material that has a greater radiopacity than dental tissue, such as amalgam. The increase in radiopacity of restorative materials reduces caries detection and increases the incidence of false-positive results.[3,14] Thus, when radiographically diagnosing secondary caries under amalgam, sometimes several different X-rays are needed to detect those lesions.[2,14,17] Furthermore, it must be emphasized that the results of any *in vitro* study are not directly applicable to a secondary caries diagnosis in the oral environment because challenges are more complex. In the oral cavity, the perception of caries formed under these materials depends on several other factors, among them radiographic and cognitive factors, and these should be taken into account.

CONCLUSION

Within the limitations of this *in vitro* study, the authors found that a material's radiopacity can have a subjective influence on diagnosing secondary caries–like lesions, and an increase in radiopacity can interfere negatively with rendering this type of diagnosis. Thus, the authors have indicated that an ideal radiopacity for dental composite is the radiographic image that is closer to the dentin image, which ultimately produces a similar attenuation to that of sound dentin tissue.

Conflict of Interest

The authors of this manuscript certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

(Accepted 31 January 2013)

REFERENCES

1. Ergucu Z, Turkun LS, Onem E, & Guneri P (2010) Comparative radiopacity of six flowable resin composites *Operative Dentistry* **35(4)** 436-440.
2. Moreira PL, Messora MR, Pereira SM, Almeida SM, & Cruz AD (2011) Diagnosis of secondary caries in esthetic restorations: Influence of the incidence vertical angle of the X-ray beam *Brazilian Dental Journal* **22(2)** 129-133.
3. Pedrosa RF, Brasileiro IV, dos Anjos Pontual ML, dos Anjos Pontual A, & da Silveira MM (2011) Influence of materials radiopacity in the radiographic diagnosis of secondary caries evaluation in film and two digital systems *Dentomaxillofacial Radiology* **40(6)** 344-350.
4. Sabbagh J, Vreven J, & Leloup G (2004) Radiopacity of resin-based materials measured in film radiographs and

Downloaded from https://prime-pdf-watermark.prime-prod.pubfactory.com/ at 2025-08-31 via free access

storage phosphor plate (Digora) *Operative Dentistry* **29(6)** 677-684.

5. Turgut MD, Attar N, & Onen A (2003) Radiopacity of direct esthetic restorative materials *Operative Dentistry* **28(5)** 508-514.

6. Pekkan G, & Ozcan M (2012) Radiopacity of different resin-based and conventional luting cements compared to human and bovine teeth *Dental Materials Journal* **31(1)** 68-75.

7. Haak R, Wicht MJ, Hellmich M, & Noack MJ (2002) Detection of marginal defects of composite restorations with conventional and digital radiographs. *European Journal of Oral Sciences* **110(4)** 282-286.

8. ISO-Standards (2009) ISO 4049 Polymer-based filling, restorative and luting materials *Geneva: International Organization for Standardization*.

9. ANSI/ADA (1993) Specification No. 27. Resin-based filling materials *Chicago, Ill: American Dental AssociationCouncil on Dental Materials and Equipment*.

10. Dukic W, Delija B, Derossi D, & Dadic I (2012) Radiopacity of composite dental materials using a digital x-ray system *Dental Materials Journal* **31(1)** 47-53.

11. Gu S, Rasimick BJ, Deutsch AS, & Musikant BL (2006) Radiopacity of dental materials using a digital X-ray system *Dental Materials* **22(8)** 765-770.

12. Oztas B, Kursun S, Dinc G, & Kamburoglu K (2012) Radiopacity evaluation of composite restorative resins and bonding agents using digital and film x-ray systems *European Journal of Dentistry* **6(2)** 115-122.

13. van der Stelt PF, Ruttiman UE, Webber RL, & Heemstra P (1989) In vitro study into the influence of x-ray beam angulation on the detection of artificial caries defects on bitewing radiographs *Caries Research* **23(5)** 334-341.

14. Espelid I, Tveit AB, Erickson RL, Keck SC, & Glasspoole EA (1991) Radiopacity of restorations and detection of secondary caries *Dental Materials* **7(2)** 114-117.

15. Anbiaee N, Mohassel AR, Imanimoghaddam M, & Moazzami SM (2010) A comparison of the accuracy of digital and conventional radiography in the diagnosis of recurrent caries *Journal of Contemporary Dental Practice* **11(6)** 25-32.

16. Stecke J, da Cruz AD, de Almeida SM, & Bóscolo FN (2012) Alternative x-ray filters for an intraoral digital radiographic system *Dentomaxillofacial Radiology* **41(5)** 361-366.

17. Nair MK, Ludlow JB, May KN, Nair UP, Johnson MP, & Close JM (2001) Diagnostic accuracy of intraoral film and direct digital images for detection of simulated recurrent decay *Operative Dentistry* **26(3)** 223-230.

18. Ferreira RI, Haiter-Neto F, Tabchoury CP, de Paiva GA, & Boscolo FN (2006) Assessment of enamel demineralization using conventional, digital, and digitized radiography *Brazilian Oral Research* **20(2)** 114-119.

19. Charuakkra A, Prapayasatok S, Janhom A, Pongsiriwet S, Verochana K, & Mahasantipiya P (2011) Diagnostic performance of cone-beam computed tomography on detection of mechanically-created artificial secondary caries *Imaging Science in Dentistry* **41(4)** 143-150.

20. Diniz MB, Rodrigues JA, Neuhaus KW, Cordeiro RC, & Lussi A (2010) Influence of examiner's clinical experience on the reproducibility and accuracy of radiographic examination in detecting occlusal caries *Clinical Oral Investigations* **14(5)** 515-523.

21. Kirkevang LL, Vaeth M, & Wenzel A (2009) Prevalence and incidence of caries lesions in relation to placement and replacement of fillings: A longitudinal observational radiographic study of an adult Danish population *Caries Research* **43(4)** 286-293.

22. Newman B, Seow WK, Kazoullis S, Ford D, & Holcombe T (2009) Clinical detection of caries in the primary dentition with and without bitewing radiography *Australian Dental Journal* **54(1)** 23-30.

23. Ando M, Gonzalez-Cabezas C, Isaacs RL, Eckert GJ, & Stookey GK (1993) Radiopacity of posterior composite resins, composite resin luting cements, and glass ionomer lining cements *Journal of Prosthetic Dentistry* **70(4)** 351-355.

Downloaded from https://prime-pdf-watermark.prime-prod.pubfactory.com/ at 2025-08-31 via free access