RESEARCH ARTICLE

Evaluation of low-contrast perceptibility in dental restorative materials under the influence of ambient light conditions

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Objectives: This study aimed to assess how details on dental restorative composites with different radio-opacities are perceived under the influence of ambient light.

Methods: Resin composite step wedges (six steps, each 1-mm thick) were custom manufactured from three materials, respectively: (M1) Filtek™ Z350 (3M/ESPE, Saint Paul, MN); (M2) Prisma AP.H™ (Dentsply International Inc., Brazil) and (M3) Glacier® (SDI Limited, Victoria, Australia). Each step of the manufactured wedge received three standardized drillings of different diameters and depths. An aluminium (Al) step wedge with 12 steps (1-mm thick) was used as an internal standard to calculate the radio-opacity as pixel intensity values. Standardized digital images of the set were obtained, and 11 observers independently recorded the images, noting the number of noticeable details (drillings) under 2 dissimilar conditions: in a light environment (light was turned on in the room) and in low-light conditions (light in the room was turned off). The differences between images in terms of the number of details that were observed were statistically compared using ANOVA, Cronbach's alpha coefficient and Wilcoxon and Kruskal–Wallis tests, with a significance level setting of 5% ($\alpha = 0.05$).

Results: The M2 showed higher radio-opacity, the M1 displayed intermediate radio-opacity and the M3 showed lower radio-opacity, respectively; however, all three were without significance ($p > 0.05$) compared with each other. The differences in radio-opacity resulted in a significant variation ($p < 0.05$) in the number of noticeable details in the image, which were influenced by characteristics of details, in addition to the ambient-light level.

Conclusions: The radio-opacity of materials and ambient light can affect the perception of details in digital radiographic images.

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Introduction

Radiographs of two-dimensional images obtained using conventional methods remain the method of choice for oral diagnoses owing to their low cost and low radiation dose, despite the current revolution that has been driven by the advent of CBCT.¹ The radiographic

diagnosis, a “visual specialty”,² continues to depend on the observer's ability to interpret these radiographic images,^{2,3} even though digital imaging systems that are gradually replacing conventional analogue films in dentistry have promoted innovations in image acquisition systems and are used in image processing programs to improve individual visual perception for specific diagnoses.

A radiographic image is the result of a wide range of dissimilar contrasts created by complex, three-dimensional structures of different radiological densities. These variances by contrast can promote several optical phenomena, such as Mach band and background contrast effects, in the “mind’s eye”.² This could result in misinterpretation.^{2,4} As part of everyday dental practice, a radiographic diagnosis is very challenging, because the dentist must be able to distinguish images of different radio-opacities, including those from restorative materials, such as composites, carious lesions and dental tissues. If the material is too radio-opaque, it may be difficult to distinguish from dental tissues; however, if it is poorly radio-opaque, it can camouflage possible failures. Thus, to improve the diagnosis, it has been recommended that the restorative material needs to be more radio-opaque than dentin and, preferably, should have a radio-opacity closer to dentin, because an increase in the restorative material’s radio-opacity can reduce the detection of secondary caries.⁵

The healthy human eye has a wide dynamic range to luminous intensity as a result of light adaptation controlled by the pupil’s ability to adjust to the luminescence that reaches the retina,⁶ and the human eye can discern approximately 60 shades of grey at one time without using any aids. Compare this with a standard computer monitor, which shows images with 256 shades of grey.⁷ However, there is controversy regarding changes in observational conditions of digital radiography related to ambient-light levels^{8–13} if the light interferes with any diagnostic performance owing to non-linearity of the photoreceptors responding to incremental stimuli related to a gain in overall luminance levels.¹⁴

Thus, the aim of this study was to assess the perception of details in dental restorative composites of different radio-opacities under the influence of ambient light. A null hypothesis, that there would be no noticeable difference in details among the various dental materials and also among the same images in different overall luminance levels, was considered.

Methods and materials

This study was based on using the three different dental materials listed in Table 1.

Image objects

Resin composite step wedges were custom manufactured (Figure 1) from each of the materials studied. The custom step wedges contained six steps, each step was

incrementally 1-mm thick, and was measured using a digital caliper. The step wedges were made using the incremental filling technique and light cured using an Elipar™ S10 light-emitting diode curing light unit (3M/ESPE, Saint Paul, MN), according to the manufacturer’s instructions. To finish and polish the custom step wedges, flexible discs with an aluminium oxide coating (Sof-Lex™; 3M/ESPE) were used in a low-speed air turbine handpiece. Each step involved in manufacturing the wedge received three standardized drillings (one in the central portion and two in the lateral portions of the step) of different diameters and depths, using Nos 1, 2 and 3 round burs at a depth approximately equal to one-half of the bur in a high-speed handpiece. The wedges were then stored at 37 °C (61 °C) and 95% (±5%) relative humidity until radiographic examination.

An aluminium (Al) step wedge (99.8% purity) with 12 steps, each 1-mm thick, was used as an internal standard to calculate the radio-opacity of materials in the image as pixel intensity values.

Standardized digital images were obtained from the set of custom step wedges (Figure 2), and an Al step wedge was superimposed above the image receptor of the photo-stimulable phosphor plate system (DIGORA® Optime; Soredex, Milwaukee, WI) in a Heliodent 60B X-ray machine (Siemens, Erlangen, Germany) that operated at 60 kVp, 10 mA, 40-cm focus–receptor distance, using three different exposure times: 0.12, 0.25 and 0.32 s. A 1.2-cm-thick acrylic plate was placed between the objects and the cylindrical locator device of the X-ray tube to replicate soft tissue. Each set was radiographed three times.

Analysis of the images

All 27 images (Figure 2b,c; 3 dental materials, ×3 repetitions and ×3 standardized drillings) were randomly ordered in 1 PowerPoint presentation on a dark background. The transitioning time between slides was pre-programmed for 5 s. 11 observers, general dentists who routinely use digital images, independently recorded the images, relating the number of noticeable details (drillings). The observer noted the same evaluation twice on a computer with a 15-inch liquid crystal display monitor that had a resolution of 1024 × 768 pixels and 32 bits. The observation was made in a secluded, quiet room, sequentially under two dissimilar conditions of ambient-light levels. One observation was made in a light environment (where the light was turned on in the room) and also under low-light conditions (where the light in the room was turned off). All observers made a second evaluation of the images following the same protocol 2 days later.

Table 1 List of materials tested in this study

Abbreviation	Composite resins	Manufacturer	Shade	Filler by volume (%)
M1	Filtek™ Z350	3M/ESPE (Saint Paul, MN)	A3	55.6
M2	Prisma AP.H™	Dentsply International Inc. (Brazil)	A3	57.0
M3	Glacier®	SDI Limited (Victoria, Australia)	A3	62.0

Figure 1 Sample of resin composite step wedges and aluminium step wedge used in this study.

Statistical analysis

The image quality was accessed by regression analysis, taking into consideration the pixel intensity values from different images. The pixel intensity values among the different dental materials were compared using ANOVA. The observers' responses were tabulated according to the quantity of noticeable details by image. The correlation of response pattern, intra- and interobservers, was evaluated by Cronbach's alpha coefficient. The Wilcoxon and Kruskal–Wallis tests were used to identify differences between images of different dental materials and ambient-light levels concerning the quantity of noticeable details. All statistical analyses were conducted with a significance level setting of 5% ($\alpha = 0.05$).

Results

Figure 3 shows the polynomial regression analysis with good-fit ($R^2 > 0.99$) to pixel-intensity values from different images, with the Prisma AP.H™ (M2) (Dentsply International Inc., Brazil) composite showing a higher radio-opacity, Filtek™ Z350 (M1) (3M/ESPE, Saint Paul, MN) having an intermediate radio-opacity and Glacier® (M3) (SDI Limited, Victoria, Australia) having a lower radio-opacity; however, each image showed no statistically significant differences ($p > 0.05$) between them by ANOVA.

On the subject of reliability of intraobserver responses, between the first and second evaluation, an excellent internal consistency with Cronbach's alpha coefficient in the range of $0.909 \leq \alpha \leq 0.997$ was observed. Based on reliability of the interobserver responses, an internal consistency varying from excellent to good with Cronbach's alpha coefficient in the range of $0.839 \leq \alpha \leq 0.993$ was observed.

The results of the number of noticeable details in the image observed under the influence of two dissimilar conditions of ambient-light levels that are presented in Table 2 show a variation in the perception of statistically significant ($p < 0.05$) details, with improved performance in the order of 24.24% from the light environment, the median of 38.5 of the sum of details (58.33%) to low-light conditions and the median of 54.5 of the sum of details (82.58%). In relation to the diameter and drilling depths presented in Table 3, a variation in the perception of statistically significant ($p < 0.05$) details was observed, with improved performance in the order of 28.79% from smaller drillings, a median of 36.5 of the sum of details (55.30%), to greater drillings, median of 55.5 of the sum of details (84.09%). With regard to the different materials presented in Table 4, there are also variations in the perception of statistically significant ($p < 0.05$) details, with improved performance in the order of 57.58% from the M3 composite, median of 26 of the sum of details (39.39%), to M2 composite, and median of 64 of the sum of details (96.97%). The M1 composite showed an intermediate performance median of 56 of the sum of details (84.85%).

Table 5 shows the results from all factors considered in this study. There were variations ($p < 0.05$) in the perception of details between smaller drillings in both ambient-light levels; however, greater drillings in low-light conditions only indicate that smaller drillings are the most difficult to perceive independent of the overall luminance, whereas an improvement in perception in low-light conditions can occur with greater drilling. Also, there were variations in the perception of details ($p < 0.05$) considering the different materials for M2 composite in low-light conditions and for M1 composite in both ambient-light levels. Thus, depending on the material's radio-opacity, there may be differences in perception. On other hand, there were no variations in perception of details ($p > 0.05$) between dissimilar ambient-light levels, considering the same drillings and materials.

Discussion

As an alternative to classical studies^{15–22} of psycho-physical evaluations using an Al phantom as the object of performance tests for different variables, in this study, the perception of details in objects with different radio-opacities, custom-step wedges made of varied materials were the tested variable. Already serving as confounding factors for this tested perception were the different evaluation conditions and variations in diameter and depth of the details.

While the current composite materials presented an appropriate radio-opacity based on the guidelines, there is a wide range of radio-opacities that occur principally as a result of the different kinds and proportions by volume of the radio-opacifying agents in view of the diversity of the manufacturers.⁵ The human eye has a wide dynamic range to luminous intensity, and it can

Figure 2 Standardized digital images used in this study. (a) Image of the set of custom step wedges and the aluminium step wedge. (b) Selection of regions of interest (three per image). (c) Assembling the region of interest on a dark background in a PowerPoint presentation.

distinguish between the different shades only if subsequent intensities of shades differ by $>1\%$,⁶ with the underlying visual response varying in dependence of stimulus context at the luminance-to-lightness mapping.²³ A previous study⁵ reported that, when radiographic images of composites were evaluated for recurrent caries diagnosis, even if only insignificant differences in radio-opacity existed, they were able to

somewhat influence a radiographic diagnosis. In the present study, a variation very close to the radio-opacity described by pixel-intensity values was observed among the different resin composites, showing no statistically significant differences. However, these insignificant differences in radio-opacity resulted in significant variation in the quantity of noticeable details in the image, as influenced by the characteristics of details, diameter and depth

Figure 3 Results of evaluating the radio-opacity of materials in images through measurement of the pixel intensity values. A, no statistically significant difference ($p > 0.05$, by ANOVA); Adj., adjusted; Al, aluminium; M1, Filtek™ Z350 (3M/ESPE, Saint Paul, MN); M2, Prisma AP.H™ (Dentsply International Inc., Brazil); M3, Glacier® (SDI Limited, Victoria, Australia).

drillings, and also by the ambient-light level of the local evaluation.

Radio-opacifying agents can be considered potent filtering objects for radiation, and they can effectively modify the radiation spectrum, resulting in different images, mainly considering digital systems, owing to changes to the signal-to-noise ratio.^{5,24} However, an adjustment in characteristic curves of the images can occur, because photostimulable phosphor digital systems use a histogram equalization algorithm (automatic range control) during image acquisition, which corrects the contrast from the images.²⁴ Histogram equalization algorithm is very important, because these systems own high latitude, which makes it possible to deviate from the optimal exposure and continue generating images that are subjectively very similar. However, it cannot be regarded as an advantage owing to the risk of over-exposing the patient to high exposures or a lack of diagnostic quality with noisy images in low exposures.²⁵ This fact can be seen in the present study as the result of an increase in noise in the more opaque portion of the

image, with greater variability (increase in standard deviation) of values of pixel intensity. Other factors such as spatial resolution of the receptor image, size of the focal spot of the X-ray machine and geometry and parameters of the exposure could also interfere with image formation of the object, and it could change the observer's performance, making it a very challenging exercise for clinical practice. Conversely, in a clinical setting that cannot be extrapolated by psychophysical evaluations,^{5,18} changes in image contrast through the process of adjusting the characteristic curve pose a potential risk to creating artefacts that could mimic pathology, particularly at high-contrast boundaries of the images.²⁶

In terms of the characteristics of the details, it is already well known that the size and shape of the details influence their perception;^{5,17,18} this has been widely explored in numerous studies of caries diagnoses. In this study, an object used standardized details to construct a perceptibility curve, a test that assesses the observers' performance to visual stimuli, regardless of their level of

Table 2 Median (minimum–maximum) of the sum of noticeable details in images in accordance to ambient-light levels

Material/drillings	Ambient-light level	
	Light	Low light
Blended	38.5 (15–66) ^a	54.5 (17–66) ^a

^aStatistically significant difference ($p < 0.05$, by the Wilcoxon test).

Table 3 Median (minimum–maximum) of the sum of noticeable details in images in accordance to diameter and depth drillings of the phantom

Ambient/material	Drillings		
	Small	Median	Great
Blended	36.5 (15–66) ^a	53 (19–66) ^a	55.5 (22–66) ^a

^aStatistically significant difference ($p < 0.05$, by the Kruskal–Wallis test).

Table 4 Median (minimum–maximum) of the sum of noticeable details in images in accordance to different materials tested

Ambient/drillings	Material		
	M1	M2	M3
Blended	56 (29–63) ^a	64 (35–66) ^a	26 (15–56) ^a
M1, Filtek™ Z350 (3M/ESPE, Saint Paul, MN); M2, Prisma AP.H™ (Dentsply International Inc., Brazil); M3, Glacier® (SDI Limited, Victoria, Australia).			
^a Statistically significant difference ($p < 0.05$, by the Kruskal–Wallis test).			

knowledge, thus they only reported on what they saw.²² Conversely, in studies^{8–13} that seek to evaluate the observer’s performance for a specific diagnosis in a condition for a given combination of factors, the level of knowledge of the observer¹³ can be considered as a bias because an observer’s lack of knowledge can invalidate the results. Regarding a second matter that relates to the ambient-light level, only the study by Schriewer *et al*¹¹ has evaluated the influence of ambient-light levels on the observer’s performance for detecting standardized details; however, these researchers’ results differed from the present study in that ambient light was not a factor of influence for their perception. Perhaps these different results are owing to the fact that the experimental conditions under which these studies were conducted were unrelated. In the cited study,¹¹ the images were obtained in a cephalometric unit with a charge-coupled device sensor, which has a low latitude and requires optimal exposure parameters, differing substantially from all factors of the image formation and signal-to-noise ratio of the present study. Another important point was observation of the images, in that the observation was made without any time limit, in addition to the response being based on a five-point confidence scale—factors that differ from the study of psychophysical properties.^{15–17,20–22} Others studies^{8,9,13} using the clinical diagnoses of carious lesions also did not find that diagnostic perceptions were influenced by ambient light; however, in this case, we believed this insignificance could be owing to a more intrinsic cause, because the clinical caries diagnosis is very challenging, indeed, even to expert observers in any condition of observation. At this point, the study by Hellén-Halme and Lith¹⁰ agreed with the results of the present study in that the researchers observed that ambient light can influence the perception of details in diagnosed images, making it ideal to make image observations in ambient, low-light conditions without direct sunlight.

Furthermore, it must be emphasized that the results of psychophysical evaluations are not directly applicable

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Table 5 Median (minimum–maximum) of the sum of noticeable details in images considering factors separately

Material	Drillings	Ambient-light level	
		Light	Low-light
M1	Small	55.5 (29–60) ^{a,b}	53 (29–63) ^{a,b}
	Median	57.5 (32–61) ^b	55 (34–61) ^b
	Great	58 (34–59) ^b	58.5 (34–63) ^{a,b}
M2	Small	62.5 (35–66) ^a	62.5 (36–66) ^{a,b}
	Median	64 (53–66)	65 (53–66) ^b
	Great	66 (45–66)	64 (44–66) ^{a,b}
M3	Small	31.5 (15–34) ^a	33.5 (17–39) ^a
	Median	23.5 (19–27)	23 (19–26)
	Great	50 (22–56)	53.5 (23–56) ^a

M1, Filtek™ Z350 (3M/ESPE, Saint Paul, MN); M2, Prisma AP.H™ (Dentsply International Inc., Brazil); M3, Glacier® (SDI Limited, Victoria, Australia).
There were no statistically significant differences ($p > 0.05$, by the Wilcoxon test) between different ambient-light levels (under the same drillings and materials).
^aStatistically significant difference ($p < 0.05$, by the Kruskal–Wallis test) between different materials (under the same drillings and ambient-light levels).
^bStatistically significant difference ($p < 0.05$, by the Kruskal–Wallis test) between drillings of different diameter and depth (under the same ambient-light levels and materials).

to clinical radiographic diagnoses of dental materials because, in the oral environment, there are several anatomical structures and objects that cause an increase in X-ray attenuation and generate image overlapping and optical phenomena, which was a limitation of this study. In the oral cavity, the principles of generation, acquisition and observation of imaging signals may be more complex than the experimental ones used in this study. Other important factors include the possibility that the digital system that was used could have responded to stimuli in a specific way; thus, further studies comparing the different digital systems would be necessary to determine whether every digital system would have similar results.

Conclusion

Both radio-opacity of the materials and ambient light can affect the perception of details in digital radiographic images, therefore, rejecting the null hypothesis. Under the conditions of the present study, the combination of high radio-opacity and M2 material in ambient low-light conditions allowed for better observer performance.

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