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Radiopacity of Resin-based Materials Measured in Film Radiographs and Storage Phosphor Plate (Digora)

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Clinical Relevance

Although wide variations in radiopacity were observed among the same group of resin-based materials, most of the composites investigated had higher radiopacity than enamel. When used in posterior restorations, some packable and flowable composites with low radiopacities may cause some confusion regarding the diagnosis of secondary caries.

SUMMARY

This study compared the radiopacity of 41 resin-based materials using conventional dental x-ray film (Ultraspeed-D) and a digital system (Digora) based on storage phosphor plate technology.

For the film-based technique, optical density measurements were carried out using an X-Rite densitometer. Al equivalents (mm) were calculated as described in the literature using a calibration curve of Optical Density versus the thickness of aluminum. Regarding the digital system after exposures of 0.16 and 0.32 seconds, the images were exported to an image processing software (NIH Image Engineering). An approach similar to that used for optical density was used to generate a calibration curve for gray pixel values.

Linear correlations were found between the percentage of fillers by weight and x-ray film radiopacity and the Digora system, and the same coefficient of estimation was recorded (r=0.60; $p \leq 0.05$). A linear correlation was also observed between the conventional x-ray film technique and the Digora system (r=0.93; $p \leq 0.05$). Using two different exposure times did not affect the radiopacity.

Considerable differences were found among materials of the same category. Flowable resin composites were more radiopaque than dentin, while microfine composites were "radiolucent." Most of the available resin-based materials were more radiopaque than enamel. The radiopacity of resin composites depended on their fillers (percentage and type). Using elements with low atomic numbers (Si) resulted in radiolucent materials, while adding elements with high molecular numbers (Ba, Y, Yb), resulted in radiopaque resin composites.

Despite the numerous benefits offered by the digital imaging system (low irradiation dose,

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instant image, image manipulation), the conventional x-ray film technique seems to be more accurate for radiopacity measurements.

INTRODUCTION

Improvements in resin composite formulations and, consequently, their mechanical properties, have increased their use in dental practice. The radiopacity of a composite is an important property to consider, especially when used for posterior restorations (ADA, 1983). A material with a high radiopacity or high density is a strong absorber of x-rays and causes the radiographic image to be light (White & Pharoah, 2000). Objects with low densities are weak absorbers and are referred to as radiolucent.

Resin-based materials are used to replace dental hard tissues, so theoretically, their radiopacity must be compared to enamel and dentin. According to ISO 4049 (1988), the radiopacity of a resin composite must be at least greater than the radiopacity of dentin to allow for the detection of recurrent caries to occur (Roberson, Heymann & Swift, 2002), as well as the detection of voids within the restoration or excess material (overhangs) and steps on the margins of proximal surface in direct and indirect restorations (Cook, 1981).

However, it has been shown that the radiopacity of human teeth varies considerably depending on the individual, age, site and storage conditions (Williams & Billington, 1987). In order to make comparisons between the different studies possible, aluminum stepwedge was chosen as a standard for measuring radiopacity, because its linear absorption coefficient (μ) is of the same order as dental enamel (Cook, 1981).

Many authors have used different techniques to study the radiopacity of resin composites (Cook, 1981; van Dijken, Wing & Ruyter, 1989; Bouschilcher, Cobb & Boyer, 1999). Radiographic images using a transmission or photographic densitometer were the most widely used (Cook, 1981; Stanford & others, 1987; Curtis, von Fraunhofer & Farman, 1990; Akerboom & others, 1993; Marouf & Sidhu, 1998).

A few years ago, digital imaging systems (DIS) were introduced to dental practice. They claim to be more beneficial than conventional radiography, because with less exposure time, an immediate image can be obtained on the screen. Two main systems are now available for direct digital dental radiology. The first, based on charge coupled devices (CCD), uses an intra-oral sensor connected directly by a cable to the computer such as CDR (Computed Dental Radiology), RVG (Radiovisiography) and SenS-A-Ray (Mason & Bourne, 1998). The second system is based on storage phosphor technology and uses a photostimulable phospor (PSP) imaging plate such as Digora and DenOptix. The conventional film-based x-rays suffer from the constraint that neither brightness nor contrast can be changed after the film has been processed, except by alterations of the viewing light (Börg, 1999). With the Digora system, imaging plates can be reused thousands of times, their size is the same as conventional film x-rays and the plates are inexpensive.

Many authors have described the Digora system in detail (Brettle & others, 1996; Van Der Stelt, 1996; Börg, 1999; Hildebolt, Couture & Whiting, 2000). Other researchers compared film characteristics such as limiting spatial resolution (lp/mm), noise and signal-to-noise ratio to those of the digital systems (Börg & Gröndahl, 1996; Huda & others, 1997; Yoshiura & others, 1999).

Two studies compared the optical densities of dental resin composites using different systems: CCD, storage phosphor and Ektaspeed Plus radiographic film (Farman & others, 1996; Wenzel, Hintze & Horsted-Bindslev, 1998). Radiopacities were expressed in optical density for conventional films and in pixels and gray shades for digital systems. To date, no study has tried to establish any correlation between the systems or convert pixel values into equivalent aluminum or determine the exact relationship between the two systems.

This study compared the radiopacity of resin-based materials using conventional dental x-ray film (Ultraspeed D) and a digital system (Digora) based on storage phosphor plate technology. The x-ray film technique, most widely used by researchers and manufacturers to study the radiopacity of a material, was considered as a gold standard technique. The authors tried to investigate the extent to which the results of Digora could be compared to those of the x-ray film technique. The pixel values obtained by the digital system were converted into equivalent millimeters of aluminum. Correlations were also established between both techniques and between the percentage of fillers by weight.

METHODS AND MATERIALS

Thirty-six commercially available light-curing composites were investigated in this study. Two chemically cured resin composites and three compomers were also examined. All materials and their specifications are listed in Table 1.

Specimen Preparation

For each material, three circular specimens were prepared in a cylindrical stainless steel mold with a diameter of 6 mm and a thickness of 2 mm. After filling the mold to capacity, the material surface was covered with a mylar strip and a glass slide, then pressure was applied to force out excess material. The specimens were light-cured using two visible hand-held curing

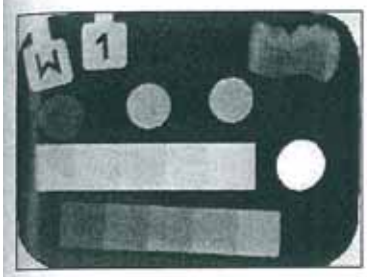

Figure 1. *Image of a radiographic film-setting showing a section of tooth, aluminum step-wedges (1 to 10 mm) and in the center from left to right: samples of Silux-Plus (2 mm), Solitaire-II (2 mm), Admira (2 mm) and lead (10 mm).*

lights (XL-3000, 3M, St Paul, MN, USA, tip diameter 8 mm) that were applied for 60 seconds on each side. Before separation of the specimens, the mold was ground flat with carbide paper (500 grit). The specimens were then stored in a dry place until testing. Enamel and dentin specimens were obtained from 2-mm thick longitudinal sections of recently extracted human molars. Just before testing, the specimens were measured with a digital micrometer to ensure their standardization.

Conventional Ultraspeed D Film

Radiopacity was first measured using conventional dental film (Kodak Ultra speed D DF-57 C, 31x41 mm, Kodak Co, Rochester, NY, USA) in accordance with the ISO-4049 (1988). Forty-two films from the same box were used so that they had the same emulsion numbers. Pure Aluminum (99.99%) step-wedge (1 to 10 mm) was used as a standard. Each x-ray included three specimens from three different materials, enamel, dentin and aluminum step-wedge (Figure 1). A 10-mm cylinder of lead was also placed on each film to ensure an unexposed part of the film that would be used as a correction for inherent film fog. A special holder was mounted to ensure a fixed focus/film distance. Films were exposed for 0.32 seconds at 70 kV and 8 mA using a Siemens dental x-ray unit (Bensheim, Germany). All films were processed immediately in an automatic processor (XR24 Nova Dürr Dental, D-74321, Germany) to minimize any variation in the process.

Radiographic densities, defined as the overall degree of darkening of an exposed film (White & Pharoah, 2000), were measured with a transmission densitometer (X-Rite model 331, MI, USA) with an aperture of 1 mm. Three readings were made for each specimen, including the aluminum step-wedge. For each x-ray, a graph of the optical density versus the thickness of the aluminum was

Table 1: *List of Materials Used in This Study. VLC: Visible Light Cured, CC: Chemically Cured, CS: Composite, CM: Compomer, Flow: Flowable, Pack: Packable, Univ: Universal, Hyb: Hybrid*

Material	Classification	Manufacturer	Batch and Shade
Admira	VLC "Ormocer"	Voco, Cuxhaven, Germany	94545 (A3)
Aeliteflo	VLC Hyb Flow CS	BISCO, Inc, Itasca, IL, USA	039317 (A3)
Amelogen	VLC Hyb Univ CS	Ultradent Products, South Jordan, Utah, USA	2CPM (A2)
Arabesk	VLC Hyb Univ CS	Voco, Cuxhaven, Germany	70500 (A3)
Arabesk-Flow	VLC Hyb Flow CS	Voco, Cuxhaven, Germany	82777 (A3)
Arabesk-Top	VLC Hyb Univ CS	Voco, Cuxhaven, Germany	81594 (A3)
Ariston-pHc	VLC "Smart Material"	Vivadent, Schaan, Liechtenstein	A00001 (-)
Brilliant-Dentin	VLC Hyb Univ CS	Coltène Whaledent, Alstatten, Switzerland	GE931 (A3)
Brilliant-Enamel	VLC Hyb Univ CS	Coltène Whaledent, Alstatten, Switzerland	GE902 (A3)
Charisma-F	VLC Hyb Univ CS	Heraeus Kulzer, Wehrheim, Germany	23 (A20)
Charisma-PPF	CC Hyb Univ CS	Heraeus Kulzer, Wehrheim, Germany	2 (A10)
Clearfil Photo Posterior	VLC Hyb Univ CS	Kuraray, Osaka, Japan	0035A (UL)
Clearfil Photo Anterior	VLC Hyb Univ CS	Kuraray, Osaka, Japan	0024C (A3)
Coltène-SE	VLC Hyb Univ CS	Coltène Whaledent, Alstatten,Switzerland	FBJ01 (A3)
Concise	CC Conventional CS	3M, St-Paul, MN, USA	19970303 (U)
Durafill VS	VLC Microfine CS	Heraeus Kulzer, Wehrheim, Germany	030122 (A3)
Dyract-Flow	VLC Flow CM	Dentsply De Trey, Konstanz, Germany	9809000103 (A2)
Elan	VLC CM	Sybron/Kerr, Orange, CA, USA	805872 (A3,5)
F-2000	VLC CM	3M, St Paul, MN, USA	19970905 (A3)
Flow-Line	VLC Hyb Flow CS	Heraeus Kulzer, Wehrheim, Germany	010021 (A2)
Glacier	VLC Hyb Univ CS	Southern Dental Industries, Victoria, Australia	60506 (B3)
Metafil-CX	VLC Microfine CS	Sun Medical, Shiga, Japan	71201 (A3,5)
P-60	VLC Hyb Pack CS	3M, St Paul, MN, USA	030998 (A3,5)
Pertac-II	VLC Hyb Univ CS	ESPE, Seefeld, Germany	00634764 (A3)
Polofil-Molar	VLC Hyb Univ CS	Voco, Cuxhaven, Germany	63596 (U)
Point-4	VLC Hyb Univ CS	Sybron/Kerr, Orange, CA, USA	003156 (A3)
Prodigy Condensable	VLC Hyb Pack CS	Sybron/Kerr, Orange, CA, USA	904665 (A2)
Pyramid	VLC Hyb Pack CS	BISCO, Inc, Itasca, IL, USA	009803 (A2)
Quadrant Anterior	VLC Hyb Univ CS	Cavex Haarlem, Holland	22C (A2)
Quadrant Posterior	VLC Hyb Pack CS	Cavex Haarlem, Holland	30C (A2)
Revolution	VLC Hyb Flow CS	Sybron/Kerr, Orange, CA, USA	710669 (A3)
Silux-Plus	VLC Microfine CS	3M, St Paul, MN, USA	6DH (U)
Solitaire	VLC Hyb Pack CS	Heraeus Kulzer, Wehrheim, Germany	26 (A30)
Solitaire II	VLC Hyb Pack CS	Heraeus Kulzer, Wehrheim, Germany	VP150499 (A1)
Spectrum	VLC Hyb Univ CS	Dentsply De Trey, Konstanz, Germany	9608244 (A3)
Surefil	VLC Hyb Pack CS	Dentsply De Trey, Konstanz, Germany	980818 (A2)
Tetric-Ceram	VLC Hyb Univ CS	Vivadent, Schaan, Liechtenstein	900513 (A3)
Tetric-Flow	VLC Hyb Flow CS	Vivadent, Schaan, Liechtenstein	901232 (A3)
Wave	VLC Hyb Flow CS	Southern Dental Industries, Victoria, Australia	80608 (A3)
Z-100	VLC Hyb Univ CS	3M, St Paul, MN, USA	19960229 (UD)
Z-250	VLC Hyb Univ CS	3M, St Paul, MN, USA	030998 (A3,5)

drawn and a calibration curve was generated using best-fit logarithmic regression (Cook, 1981; Stanford & others, 1987; Shah & others, 1997). These gave straight-line plots from which the mean net radiographic density values of the materials and their equivalents related to the thickness of the aluminum were derived. The optical density value for each material was the arithmetic mean of the values of the three radiographs.

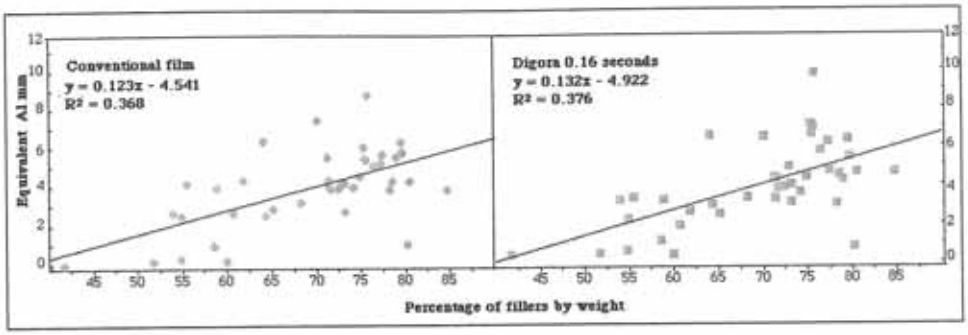

Figure 2. *Correlation between the percentages of fillers by weight and the radiopacity obtained with conventional x-ray films and Digora at 0.16 seconds. Linear regression curve was obtained with r=0.60 and p≤ 0.05.*

Digital Imaging

The photostimulable phosphor plates (Digora FMX) (n° 2, 30-mm x 40-mm size) were exposed using the same process described above. The same PSP plate was used for all exposures to avoid possible differences between plates. Two different exposure times were used (0.32 and 0.16 seconds). These values were chosen in order to investigate whether reducing the exposure time by half affected the radiopacity. After exposure, gray values of the images had to be calibrated, so images were sent as TIFF files to an image processing software, NIH Image Engineering (http://rsb.info.nih.gov/nih-image). This software allows the transformation of pixel values directly from a linear scale into a scale that correlates with OD (Optical Density).

An approach similar to that used for optical density was used to produce a calibration curve for gray pixel values, then convert those values to equivalent mm Al.

Statistical Analysis

The mean values of the radiopacity of the different materials were compared using a one-way ANOVA and post-hoc Scheffe's tests at $p<0.05$ level. These were performed separately for each technique. Simple regression analyses were carried out to study the relationship between the radiopacity and the percentages of fillers by weight determined in a previous experiment (Sabbagh, Vreven & Leloup, 2002) and also to study the relationship between both techniques.

RESULTS

Table 2 shows the mean values and standard deviations of the radiopacities of the materials investigated and their percentages of fillers by weight. Radiopacities were expressed in millimeters of aluminum (Al), and higher values represented greater radiopacity, ranging between 0.0 for Metafil-CX and 8.8 mm Al equivalent for Tetric-Ceram.

Using conventional x-ray film, considerable differences were found between materials of the same category. Radiopacities of the flowable composites ranged between 2.5 (Aeliteflo) and 6.5 (Tetric-Flow) mm of Al equivalent. Packable resin composites ranged between 2.6 (Solitaire) and 6.4 (Surefil). The same observation was made for the universal hybrid composite, with radiopacities ranging between 2.8 (Polofil-Molar) and 8.8 (Tetric-Ceram) mm of Al equivalent.

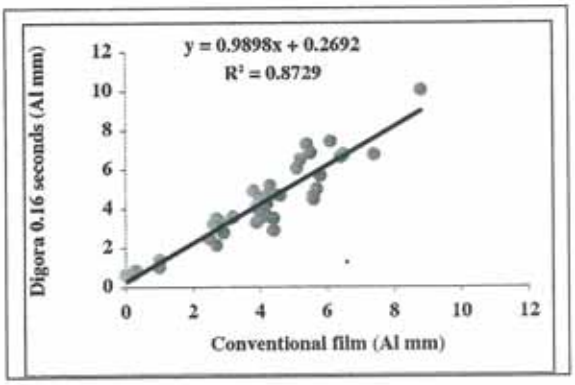

Figure 3. *Correlation between the radiopacity of conventional film and Digora at 0.16 seconds. Linear regression curve was obtained with r=0.93 and p≤0.05.*

With the Digora system, considerable variations were also observed among materials of the same category. Values ranged between 0.6 for Clearfil Anterior and Metafil-CX and 10.1 mm Al equivalent for the Tetric-Ceram, respectively.

As a result of regression analyses, linear correlations were found between the percentages of fillers by weight and conventional radiopacities (r=0.60; $p\leq 0.05$) and between the percentages of fillers by weight and Digora radiopacities (r=0.60; $p\leq 0.05$ for both exposure values) (Figure 2).

Radiopacity values measured with Digora, at both exposure times, were nearly identical. This is illustrated by the regression curve (r=0.99; $p\leq 0.05$).

Radiopacities measured with conventional x-ray films correlated significantly with those measured with Digora at 0.32 and 0.16 seconds (r=0.93; $p\leq 0.05$) (Figure 3).

DISCUSSION

This study included a large number of materials representing all the categories of resin-based materials used for direct restorative techniques.

Using conventional x-ray films, all the materials, except the microfine anterior composites Concise (chemically cured resin composite) and Quadrant-Anterior, showed greater radiopacity than dentin. According to the manufacturer, Quadrant-Anterior contains SiO_2 and a small percentage of Ba-Al-F-Si fillers in its formulation (Table 2). Therefore, it is classified as a hybrid rather than a microfine composite. All the hybrid universal (with the exception of Quadrant-Anterior) packable and flowable composites and compomers met ISO-4049 (1988) recommendations. Only a few hybrid composites were less radiopaque than enamel. Apart from Solitaire and Quadrant Posterior, the radiopacity of all packable composites was greater than enamel. Wide variations

Table 2: *Radiopacity mean values expressed in mm Al with standard deviation (SD), obtained with conventional film and Digora at 0.16 and 0.32 seconds, percentages of fillers by weight, type and range of fillers. A separate test (Anova-one factor) was performed for each group. Values represented by the same letters are not significantly different. (Type and range of fillers were obtained from manufacturers. NA : Not Available).*

Materials	Conventional Film Radiopacity	Digora 0.32 Sec	Digora 0.16 Sec	% Fillers Weight	Range of Fillers (mean)	Type of Fillers
Admira	4.2 (0.4)^{efghijk}	4.3 (0.2)^{efghijk}	4.2 (0.1)^{ghij}	73	NA	Quartz, SiO_2
Aeliteflo	2.5 (0.2)^{abcdef}	2.6 (0.2)^{abcdef}	2.5 (0.3)^{bcdef}	54.9	0.7 µm	Ba
Amelogen	4.3 (0.6)^{efghijk}	5.3 (0.4)^{ghijklmn}	5.2 (0.0)^{ijklm}	72.9	0.7 µm	NA
Arabesk	3.9 (0.2)^{efghijk}	4.5 (0.6)^{efghijkl}	4.1 (0.2)^{fghij}	71.6	0.5-2 µm (0.05)	NA
Arabesk-Flow	4.4 (1.5)^{efghijk}	2.9 (0.1)^{abcdefg}	2.9 (0.1)^{cdef}	61.8	0.7 µm	SiO_2, Ba, Borosilicate, Sr
Arabesk-Top	4.0 (0.3)^{efghijk}	4.1 (0.5)^{efghij}	4.6 (0.2)^{ghijk}	71.5	0.05-0.7 µm	NA
Ariston-pHc	4.6 (0.4)^{ghijkl}	4.6 (0.2)^{efghijkl}	4.7 (0.1)^{ghijk}	74.8	NA	Ba-Al-F Si, YtF_3
Brilliant-Dentin	5.4 (0.0)^{ghijkl}	7.8 (1.4)^{no}	7.3 (0.4)^{o}	75.6	0.04-2.8 µm (0.5)	SiO_2, Ba
Brilliant-Enamel	5.5 (0.4)^{hijkl}	7.0 (0.2)^{lmno}	6.9 (0.2)^{no}	75.4	0.04-2.8 µm (0.5)	SiO_2, Ba
Charisma-F	5.1 (0.3)^{fghijkl}	6.2 (0.6)^{ijklmn}	6.1 (0.2)^{klmn}	76.4	0.02-2 µm (0.7)	AlF, Ba, SiO_2
Charisma-PPF	3.2 (0.2)^{defghij}	3.4 (0.3)^{bcdefgh}	3.6 (0.3)^{defgh}	68.3	0.02-2 µm	Si-F-Al-Ba, SiO_2
Clearfil Photo Anterior	0.2 (0.1)^{ab}	0.6 (0.0)^{a}	0.7 (0.1)^{a}	59.9	0.04-10 µm (2.8)	SiO_2, Glass, prepolymerized fillers
Clearfil Photo Posterior	3.8 (0.1)^{efghijk}	4.7 (0.1)^{efghijklm}	4.9 (0.1)^{ghijkl}	84.7	0.1-20 µm (4)	SiO_2, Ba, Si
Coltène-SE	4.4 (0.6)^{efghijk}	3.6 (0.1)^{cdefgh}	3.5 (0.2)^{defgh}	71.3	0.04-2.7 µm (0.7)	SiO_2, Sr, Ba
Concise	1.0 (0.1)^{abcd}	0.8 (0.1)^{ab}	1.1 (0.1)^{ab}	80.2	1-40 µm (9)	Quartz
Dentin	1.8 (0.2)^{abcde}	1.4 (0.2)^{abcd}	1.4 (0.1)^{abc}	-	-	-
Durafill VS	0.2 (0.1)^{ab}	0.9 (0.1)^{abc}	0.7 (0.1)^{a}	51.7	0.01-0.04 µm	SiO_2
Dyract-Flow	4.2 (0.2)^{efghijk}	3.7 (0.1)^{defghi}	3.6 (0.3)^{defghi}	55.4	(1.6)	Sr-Al-F, Si
Elan	5.6 (0.2)^{ijkl}	4.8 (0.1)^{efghijklm}	4.7 (0.1)^{ghijk}	71.2	(1.4)	NA
Enamel	3.1 (0.3)^{bcdefghij}	2.6 (0.2)^{abcdef}	2.7 (0.2)^{cdef}	-	-	-
F-2000	4.3 (1.0)^{efghijk}	4.9 (0.1)^{efghijklm}	4.9 (0.1)^{ghijkl}	80.5	1-10 µm (3)	Zr/Si
Flow-Line	4.0 (0.4)^{efghijk}	3.7 (0.3)^{defghij}	3.5 (0.2)^{defgh}	58.8	0.7 µm	NA
Glacier	3.9 (0.4)^{efghijk}	3.5 (0.5)^{bcdefghi}	3.3 (0.0)^{defg}	78.2	40nm-1µm (0.7)	NA
Metafil-CX	0.0 (0.2)^{a}	0.7 (0.2)^{ab}	0.6 (0.1)^{a}	41.7	20 µm	SiO_2, TMTP
P-60	5.6 (0.1)^{ijkl}	4.6 (0.1)^{efghijkl}	4.5 (0.2)^{ghijk}	78.9	0.01-3.5 µm (0.6)	Zr/Si
Pertac-II	7.4 (1.0)^{lm}	6.8 (0.4)^{klmn}	6.8 (0.2)^{mn}	70	0.1-2 µm	SiO_2, Quartz, YtF_3
Point-4	4.3 (0.3)^{efghijk}	5.0 (0.2)^{ghijklm}	4.8 (0.1)^{ghijk}	73.1	0.4 µm	SiO_2, Ba Al-Si,
Polofil-Molar	2.8 (0.2)^{abcdefgh}	3.3 (0.4)^{bcdefgh}	3.4 (0.2)^{defg}	78.5	0.05-25 µm	NA
Prodigy Condensable	5.2 (0.4)^{ghijkl}	6.4 (0.7)^{klmn}	6.5 (0.4)^{lmn}	77.2	0.6 µm	SiO_2, Ba
Pyramid	4.0 (0.1)^{efghijk}	4.2 (0.6)^{efghij}	3.9 (0.1)^{efghi}	74.1	NA	NA
Quadrant Anterior	1.0 (0.2)^{abcd}	1.4 (0.2)^{abcd}	1.4 (0.1)^{abc}	58.6	<0.1 µm	SiO_2, Ba-Al-F-Si,
Quadrant Posterior	2.9 (0.2)^{bcdefghi}	2.8 (0.0)^{abcdefg}	2.8 (0.1)^{cdef}	65.2	0.1-10 µm	SiO_2, Ba-Al-F-Si, SrF2
Revolution	2.7 (0.1)^{abcdefg}	3.3 (0.2)^{bcdefgh}	3.5 (0.4)^{defgh}	53.9	(1.7)	Ba
Silux-Plus	0.3 (0.0)^{abc}	0.8 (0.1)^{ab}	0.8 (0.1)^{a}	54.8	10-50 µm (0.04)	SiO_2
Solitaire	2.6 (0.3)^{abcdef}	3.5 (0.4)^{cdefghi}	3.2 (0.3)^{defg}	64.3	0.7-22 µm	SiO_2, Ba-Al-B-Si-F, SrF2
Solitaire II	3.9 (0.4)^{efghijk}	4.1 (0.1)^{efghij}	4.1 (0.4)^{fghij}	72.4	0.7-25 µm	SiO_2, Ba-Al-B-Si-F
Spectrum	6.1 (0.5)^{klm}	7.4 (0.1)^{mn}	7.4 (0.8)^{n}	75.3	0.04-5 µm	SiO_2, Ba, Al, B-Si
Surefil	6.4 (0.3)^{klm}	6.8 (0.2)^{klmn}	6.7 (0.2)^{lmn}	79.4	0.04-0.1 (0.8)	Ba-F-Al-BSi
Tetric-Ceram	8.8 (0.3)^{n}	10.1 (0.7)^{p}	10.1 (0.1)^{p}	75.7	0.04-3 µm (0.7)	SiO_2, Ba-Al-F, YbF_3
Tetric-Flow	6.5 (0.1)^{klm}	6.9 (0.2)^{lmn}	6.8 (0.4)^{mn}	64	0.04-3 µm (0.7)	SiO_2, Ba-Al-F, YbF_3
Wave	2.7 (0.4)^{bcdefg}	2.2 (0.0)^{abcde}	2.1 (0.2)^{abcd}	60.7	(1.5)	Sr
Z-100	5.8 (0.2)^{jkl}	5.5 (0.9)^{hijklmn}	5.7 (0.3)^{klmn}	79.6	0.01-3.5 µm (0.6)	Zr/Si
Z-250	5.7 (0.2)^{jkl}	5.2 (0.2)^{ghijklmn}	5.0 (0.4)^{hijkl}	77.4	0.01-3.5 µm (0.6)	Zr/Si

in radiopacity were observed among the same group of materials (Table 2).

According to Langland and Langlais (1997), radiopacity is influenced by several factors classified as primary and secondary factors. Primary factors include milliampere, exposure time, kilovoltage and source-film distance, while secondary factors concern development conditions, type of film, intensifying screens and grids. Since two completely different systems were used in this study, factors relating to the imaging system were expected to differ.

Filler percentages and their types are the most important factors that influence materials' radiopacity. In fact, as a result of regression analysis, linear correlation was found between radiopacity values and the percentages of fillers by weight (Figure 2), which is in line with the findings of Toyooka and others (1993). A closer look at this curve shows two opposite groups of resin-based materials deviating from the center of the curve. The first group includes Pertac-II, Tetric-Ceram and Tetric-Flow, with high radiopacities, while the second one contains materials with low radiopacities (Metafil-CX, Durafill-VS, Silux-Plus, Clearfil Anterior and Concise). As shown in Table 2, these materials contain different kinds of fillers. SiO_2 is the only filler used in Metafil-CX, Durafill-VS, Silux-Plus and Clearfil Anterior. The quartz fillers used in Concise are also based on silicium. This element has a low atomic number (14) and does not provide radiopacity. On the other hand, Pertac-II, Tetric-Ceram and Tertic-Flow contain Yttrium (Y atomic number 39) and Ytterbium (Yb atomic number 70). These elements have high atomic numbers and provide a high level of radiopacity. Barium (Ba atomic number 56) is the element most commonly incorporated into composite-based resins to increase radiopacity (Table 2).

Watts (1987) found that radiopacity values higher than those in enamel can be achieved in composites with a filler loading of approximately 70% by volume when the mass percentage of radiopaque oxide in the filler particles exceeds about 20%. Toyooka and others (1993) demonstrated that radiopacity is linearly proportional to the amount of radiopaque oxide in the filler.

Some of the materials used in this study were investigated by other researchers (Toyooka & others, 1993; Bouschilcher & others, 1999; Murchison, Charlton & Moore, 1999; Choi & others, 2000; Lutz & Krejci, 2000). In some cases, the authors did not follow the ISO-4049 (1988) recommendations. Murchison and others (1999) and Choi and others (2000) observed lower radiopacities than those obtained in this study. Using higher exposure times or kV or mA may explain the differences observed.

Although variations in test methodologies render comparisons between the studies difficult, the results of this investigation are in line with some other studies. Toyooka and others (1993) had similar radiopacities for Clearfil-Photo Posterior, enamel and dentin. Bouschlicher and others (1999) used the same parameters as recommended by the ISO-4049. Apart from Pertac-II, Tetric-Flow and Z-100 (which differed slightly), the tested resin composites and dentin and enamel had radiopacity values similar to those in this study. Recent changes in the formulation of these materials may be responsible for these variations. Other variables such as speed of the film or processing solution (temperature and age) could have influenced the results.

A digital imaging technique, the Digora system, was also used to study the radiopacity of resin-based materials using two exposure times (0.16 and 0.32 seconds). Similar results were observed with both exposure times, as shown in Table 3. Having carried out regression analysis, linear correlation was found between the radiopacity values and percentages of fillers by weight.

As with conventional x-ray films, differences between the same groups of composites were observed. Although a strong correlation exists between both techniques (Figure 3), for some materials radiopacity measured with the Digora system was lower or higher than that obtained with the conventional technique. Enamel and dentin showed lower values with Digora.

In order to understand the variations observed between the conventional and digital methods, some information and explanations regarding their technologies need to be noted.

A conventional radiographic image consists of the arrangement of silver grains in photographic emulsion. The density of the silver grains depends on the intensity of the x-ray beam (Van der Stelt, 2000). The radiation contrast is an analog signal with continuous intensities.

In digital systems, output of the measurements is stored on the computer as numbers. These values are absolute numbers of available gray shades (from 0 to 255) in contrast to the continuous density curve in the analog film image (Van der Stelt, 2000). The Digora PSP system has a much wider dynamic range than film, giving this system a much broader exposure latitude (White & Pharoah, 2000). An important characteristic of a receptor is its latitude. Latitude refers to the range of useful densities that can be recorded (Miles, 1992). In practical terms, this means that Digora can provide a similar quality of image irrespective of whether the exposure is relatively low or high and, thus, eliminates all under and over exposure (Hayakawa & others, 1998).

This explains why other exposures times (0.32 and 0.16 seconds) produced similar radiopacities.

Moreover, Digora has an autoranging function whereby signal intensities from an exposed phosphor are obtained during a prescan and are used to adjust gains

for the internal amplifiers. As a result, there is no direct relationship between the measured pixel value and phosphor exposure (Huda & others, 1997).

The image "noise" is not the same in an exposed and unexposed plate as it is in a film (background fog) since, in an exposed plate, the program will find sufficient information to extract (Stamatakis, Welander & McDavid, 1999). Thus, it was not necessary to perform any subtraction (as is done with conventional x-ray films) when calculating the radiopacity.

Stamatakis and others (1999) studied the dose response of the Digora system. Special software was required to obtain information about the values of the internal registers of the scanner's microcontroller. They concluded that the gray levels may be used as a relative measure of exposure.

Wenzel and others (1998) compared the radiopacity of some resin-based materials to amalgam using a conventional film (Ektaspeed-Plus) and a phosphor plate system (Digora). Amalgam had the highest density with Ektaspeed-Plus film, while with the Digora system, it was not significantly different from Herculite. With regard to the digital systems, differences between the distributions of the gray shade values for the various materials were less significant than those observed when using film. As stated above, digital systems operate with an absolute number of available gray shades (256) in contrast to the continuous density curve in the analog film image. Wenzel and others (1998) concluded that when using conventional film radiographs, filling materials can be differentiated with a high level of probability, while the digital system is less reliable.

This study shows that gray pixel values could be converted into millimeters of aluminum using special software and this aluminum could be used to measure the radiopacity of resin-based materials.

CONCLUSIONS

1. Most of the materials investigated were complied with ISO-4049 and were more radiopaque than enamel when specimens 2-mm thick were used. Different levels of radiopacities were observed among materials of the same group.
2. Some flowable and packable composites are less radiopaque than enamel and may cause some confusion regarding the diagnosis of secondary caries when used in posterior cavities.
3. The radiopacity obtained with the Digora system correlated with conventional x-ray films. Consequently, the conversion of pixel values into equivalent millimeters of aluminum seemed adequate.
4. Many factors affect radiopacity measurements. The type and percentage of fillers by weight determine the radiopacity of resin-based materials. Exposure time did not affect digital radiopacity, because of the wide latitude of the phosphor storage plate.
5. There is a great need for the standardization of radiopacity measurements using digital imaging techniques.

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