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ORIGINAL ARTICLE

In vitro analysis of the radiodensity of indirect composites and ceramic inlay systems and its influence on the detection of cement overhangs

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Abstract The purpose of this study was to evaluate the radiodensity of indirect restorative systems and to determine its influence on detection of resin cement overhangs. Sixty sound molars with similar dimensions were selected, and MOD inlay preparations were made in a standardized fashion with 6° taper of the walls. Restorations were made with a porcelain, Duceram LFC, and with three indirect composites, Solidex, Artglass, and Targis. Digital radiographic images were taken before and after cementation of the inlays (Digora system) and were analyzed on two regions, the cervical and the isthmus floor. Digital radiodensity measurements were performed on standardized points symmetrically distributed over each restoration and tooth structure. Cement overhangs were detected through visual analysis by three evaluators. Data were statistically analyzed utilizing ANOVA following Tukey's test ($p<0.05$), showing that Solidex presented lower radiodensity than Duceram LFC, and both Artglass and Targis presented similar higher levels of radiodensity than the other groups. Radiodensity of cervical regions was always greater than for isthmus floor regions. Detection of the resin cement overhangs is easier observed on Solidex and Duceram LFC. Radiodensity is highly influenced by restorative material type and tooth regions. The detection of radiopaque resin cement overhangs is influenced by radiodensity of restorative materials.

Keywords Radiodensity · Porcelain · Indirect composite resins · Resin cement · Digital radiographs

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Introduction

The use of esthetic materials has become more popular due to the increased interest in tooth-colored filling appearance [9, 14, 16]; however, it is not clear if rules and principles of prosthodontics adaptation are correctly followed [4].

The interfacial distance between the restoration and the tooth structure is critical for the longevity of the restoration [12]. Clinically, the marginal adaptation in the cervical region of proximal surfaces is difficult to assess. One of the desirable properties of any restorative materials is that it should be radiopaque to enable the detection of secondary caries, marginal defects, contour of restoration, contact with adjacent teeth, cement overhangs, and interfacial gaps [5, 7, 21]. Historically, restorative materials, used in posterior teeth, have demonstrated a wide range of radiodensity. The degree of radiodensity required for optimal clinical radiographic evaluation in composite resins has been established in former studies [18, 21]. However, while manufactures state that their materials are radiopaque, there is no clear agreement on the degree of radiodensity to facilitate the detection of caries and defects adjacent to restorations [2, 7, 21].

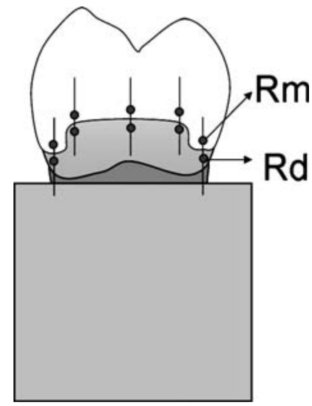
Ceramics are normally radiopaque, but there are several new laboratory composite resins available in the market as alternatives in some clinical situations [19]. These materials use less complex laboratory techniques, have improved flexural strength and resilience, and reduced risk of fracture during try-in and fixation [17]. Because these materials have different compositions, their radiodensity is expected to be highly variable, and this has an important influence on postoperative clinical follow-up. In addition, adhesive cementation with resinous cements can leave cement overhangs in several regions, principally in cervical floors of proximal regions, if the cement is not correctly removed before polymerization. Because resinous cements have tough mechanical properties, it may be difficult to remove their excesses in proximal areas [8]. These materials should present radiopacity levels high enough to facilitate not only the analysis of their distribution into inner and proximal surfaces but also the possibility of excesses. It seems that different composition of indirect restorative materials can result in different radiodensity levels, and this fact can have an influence in the detection of resinous cement overhangs.

The purpose of this study was to evaluate the radiodensity of four types of inlay materials, three resin composite systems, and one porcelain system around the cervical and isthmus floor regions and its influence on the detection of resinous cement overhangs.

Materials and methods

Sixty freshly extracted, sound, caries-free human mandibular molars of similar size and shape were selected for the study. Calculus and soft-tissue deposits were removed with a hand scaler; the teeth were cleaned using rubber cup and pumice water slurry and then were stored in 0.9% saline solution at 4°C until experimental procedures began. Each tooth was individually fixed in a cylinder so that resin embedded the roots up to 2 mm below the cement–enamel junction. Teeth received standardized MOD inlay preparations with 8° convergence angles using #3131 diamond burs (KG Soresen, São Paulo, Brazil) on a cavity preparation device so that all the cavities would have uniform dimensions. Different from facing intraoral operative difficulties, preparations were done under clear conditions of visibility and accessibility (CJS) and fulfilled the required guidelines for the four different restorative systems used in this study [1]. The dimensions of the cavity preparation for the inlays were: 5.0 mm buccal–lingual width, 2.5 mm pulp wall depth, and 4.0 mm gingival wall depth. A one-stage impression was taken for each prepared tooth (CJS) using a double-viscosity polyvinyl-siloxane (Aquasil, Dentsply De Trey, Konstanz) in a stock plastic tray. After 2 h, the impressions were poured with type IV dental stone, Velmix (Kerr, Romulus, USA).

Fig. 1 Location of the cervical and isthmus floor measures, radiodensity of restorative material (RM), and radiodensity of tooth (RT)



Four indirect restorative materials were employed in this study: Duceram LFC (Ducera, Rosbach, Germany), Solidex (Shofu, Kyoto, Japan), Artglass (Heraeus Kulzer, Dormagen, Germany), and Targis (Ivoclar, Schann, Liechtenstein). Teeth were randomly divided into four groups (n=15) according to the restorative material. One technician, who employed a standardized technique in accordance with the manufacturers' instructions, made all restorations. For the ceramic groups, the 15 stone models were duplicated in a refractory die material (Ducera Lay, Ducera, Rosbach, Germany), and the porcelain inlays were made with Duceram LFC in the fumace Austramt-M (Dekemakeramiköfen, Germany) according to the programmed schedule. The porcelain inlays were removed from refractory dies, were placed on the master die, to ensure passive seating, and were glazed with natural glaze. Solidex indirect composite resin inlays were cured with a laboratory multifocal light-curing unit, Solidilite (Shofu, Kyoto, Japan). Artglass inlays were cured with a xenon stroboscopic light-curing unit, UniXS (Heraeus Kulzer, Dormagen, Germany). Targis inlays were first prepolymerized with a halogen light source (Targis Quick, Ivoclar, Schann, Liechtenstein) and then were cured with Targis Power (Ivoclar, Schann, Liechtenstein).

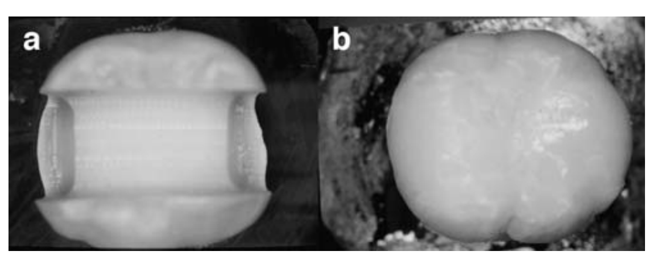


Fig. 2 Photograph of preparation and restored tooth. **a** Prepared tooth for inlay restoration. **b** Cemented inlay

Table 1 Radiodensity of materials and tooth structure, and radiodensity differences in general analysis

Groups	Number of teeth (measurements)	Restorative materials' radiodensity (SD)	Tooth radiodensity (SD)	Difference of radiodensity between materials and tooth
Duceram LFC	15 (75)	220.53 (6.64)	212.80 (9.19)	7.73
Solidex	15 (75)	206.85 (11.70)	212.37 (9.77)	−5.52
Artglass	15 (75)	231.51 (4.89)	212.34 (9.96)	19.17[a]
Targis	15 (75)	233.44 (4.40)	212.61 (10.70)	20.83[a]

[a] Statistically similar groups ($p>0.05$)
SD Standard deviation values

Radiopacity measurement method

The restorations were placed in the cavities and stabilized with colorless glue (Tenaz, São Paulo, Brazil) at two points of the occlusal surface. An aluminum step wedge was used for calibrating the X-ray [7], with three exposures for each step (12 steps; 36 measurements). The samples were positioned over a phosphor plate, and the radiographic exposure was performed using the X-ray machine GE 1000 (General Electric, Milwaukee, WI, USA), exposing it for 0.4 s at 70 kV and 10 mA. The focal spot to object distance was 50 cm. Three exposures were performed for each sample. The radiographs were transferred from the phosphor plate to the computer via a Digora scanner (Digora, Soredex, Helsinki, Finland). The radiodensity (in pixels) of the samples were determined with the resident software provided by the manufacturer. The Digora system has a Windows-based software, Digora for Windows 2.0, that is capable to measure density curves of digital radiographies obtained by X-ray impregnation on the imaging phosphor plate. Five measurement lines were defined: two in the cervical margin, for mesial and distal surfaces, and three points at isthmus floor. All the measurements were taken symmetrically on the axial plane of teeth and restorative surfaces (Fig. 1). Each digital image had its radiodensity measured on each measurement line (Fig. 1), immediately after scanning, without any modification in contrast or brightness. The mouse cursor was positioned under this measurement line on tooth structure or restorative material to obtain the radiodensity values for each sample, and the means of readings were calculated and used in further data analysis [23].

All inlays were then fixed (CJS) with a resinous cement, Rely X (3M-ESPE, St. Paul, USA), to enable comparison within groups of different restorative materials (Fig. 2). After removing marginal excesses, new radiographic images were recorded for each tooth, as described before, to analyze the influence of restorative materials' radiodensity on the visualization of the resinous cement layer and cement overhangs. This analysis was performed by three evaluators (CJS, FRS, and RBF), according to the following nonparametric scale, after an exhaustive practice during a pilot study:

0 impossible to detect the resin cement layer;
1 difficult to detect the resin cement layer;
2 easy to detect the resin cement layer.

The restorative material radiodensity, which was the difference of radiodensities recorded for tooth and indirect restorations with and without the presence of a resin cement layer, was defined for all measurement lines for each region, the cervical and the isthmus floor, and was statistically analyzed utilizing ANOVA following Tukey's test ($\alpha=0.05$).

Results

Significant differences in radiodensity were found between cervical and isthmus floor regions and among the restorative materials ($p<0.05$). To evidence the significant difference between groups, Tukey's test was applied (Table 1).

Table 2 Radiodensity difference between materials and tooth regions (cervical–isthmus floor)

Groups	*n*	Variation of radiodensity for regions				
		Mesial	Isthmus floor/mesial	Isthmus floor/center	Isthmus floor/distal	Distal
Duceram LFC	15	10.42	6.04	5.93	6.02	10.26
Solidex	15	−8.06	−5.13	−4.20	−4.15	−6.05
Artglass	15	25.44	16.19	15.22	15.62	23.40
Targis	15	28.73	17.33	15.60	17.02	25.46

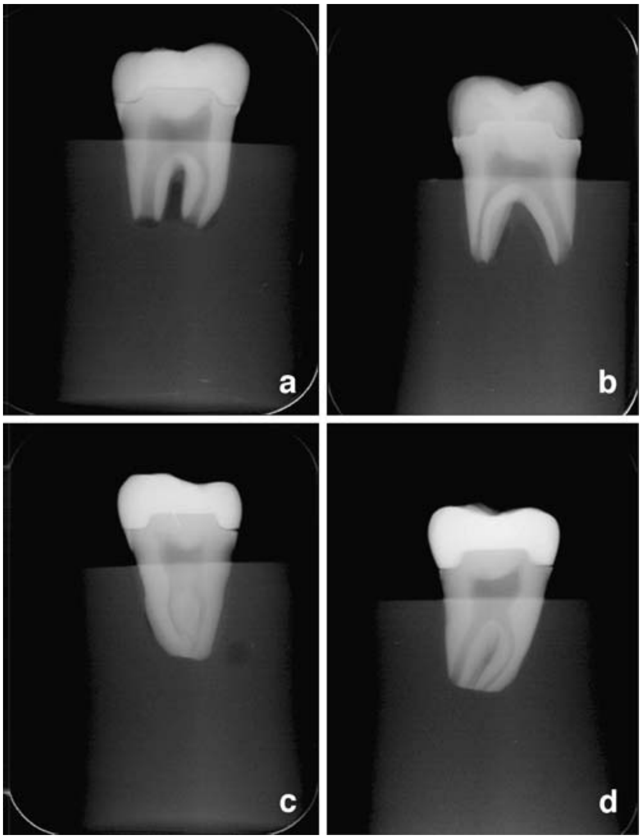


Fig. 3 Radiographs of inlay systems: **a** Duceram LFC, **b** Solidex, **c** Artglass, **d** Targis

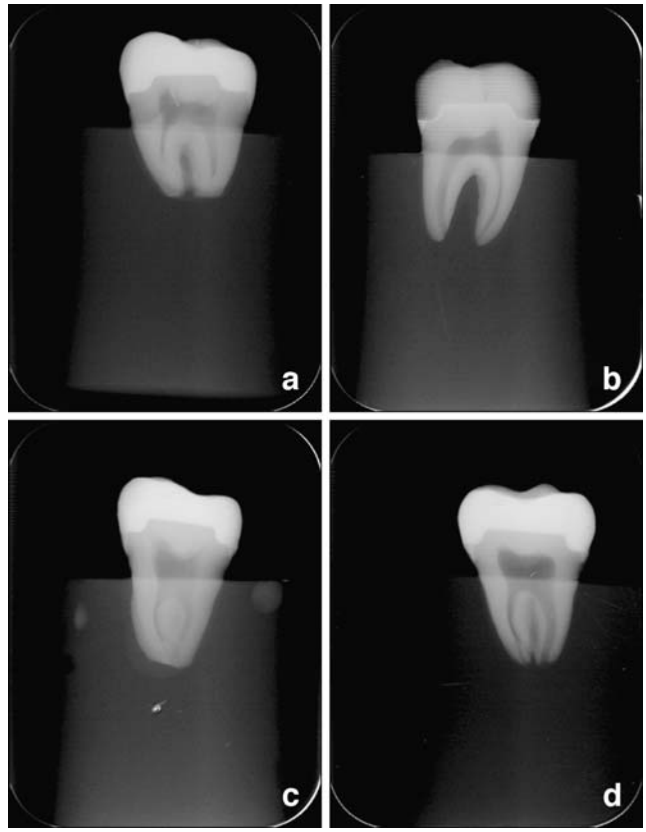


Fig. 4 Radiographs of inlay systems cemented with a radiopaque resin cement: **a** Duceram LFC, **b** Solidex, **c** Artglass, **d** Targis

The radiodensity difference between tooth structure and restorative material for cervical regions was greater than for isthmus floor regions for all materials (Table 2 and Fig. 3). Concerning just the restorative materials, the indirect resin Solidex presented lower radiodensity than Duceram LFC, which showed a smaller radiodensity variation between tooth and restorative material. Artglass and Targis were the most radiopaque materials. Solidex was considered to be radiolucent, and Duceram LFC, Artglass, and Targis were regarded to be radiopaque (Table 1).

The data related to the analysis of the influence of restorative materials' radiopacity on detection of the resinous cement layer are demonstrated in Table 3 and Fig. 4. The cement layer visualization was easier in Solidex and Duceram LFC groups than in Artglass and Targis groups.

Discussion

Digital radiographic images consist of pixels (picture elements) which are aligned in rows and columns constituting the matrix of the image, and each pixel is defined by a value corresponding to a particular shade of gray. The number of gray shades available in the digital image is given by the number of binary digits (bits) used to define a pixel. The bit depth resolution and the difference between the highest

Table 3 Classification of groups by ease of visualization of the resinous cement layer

Groups	*n*	Isthmus floor surface			Proximal surface		
		0	1	2	0	1	2
Duceram LFC	15	–	8	7	–	4	11
Solidex	15	–	4	11	–	–	15
Artglass	15	15	–	–	14	1	–
Targis	15	15	–	–	15	–	–

0 Impossible to detect the resin cement layer, *1* difficult to detect the resin cement layer, *2* easy to detect the resin cement layer and the lowest gray shades make possible to determine the image contrast [23]. When reading the storage phosphor plate, the laser beam of Digora system is focused with a diameter of 70 mm and directed to the surface of the plate to scan the radiographic image [22]. The advantages of storage phosphor systems are the wide dynamic range because of automatic exposure control, the low-dose requirements, and the possibility to adjust the contrast and brightness [22].

Marginal discrepancies have been proven to be responsible for several problems caused in indirect restoration, principally when these restored teeth are submitted to fatigue [11]. Radiodensity is an important property of all restorative materials because it makes possible to detect the marginal integrity to check cement excesses and secondary caries. Voids, marginal deficiencies, or recurrent caries are best detected when radiopacity of restorative materials approximates to that of dental enamel [3, 10]. In this study, tooth selection and cavity preparation were standardized because detection of radiolucencies around restorations also depends on the density and thickness of remaining tooth structure [6]. The important factor in the radiodensity analysis method employed in this study is a systematic evaluation of the restoration inserted on the prepared tooth, making possible to analyze the material radiodensity where it is really necessary—at cervical margin of inlay restorations.

The results of this study showed that in the cervical region, materials' radiodensity is greater, and resin cement overhangs are easier to detect, because the remaining tooth structure is reduced in this surface, due to the tooth anatomic configuration [6]. The degree of radiopacity of the composites depends on the amount, type, and particle size of the radiopaque-reinforcing filler and on the thickness and density of the polymer [7]. The composite material type appears to have a significant influence on both the cervical marginal adaptation and on the adaptation to the vertical wall [13]. All four restorative systems showed different radiodensity levels because their compositions are also greatly different. The porcelain system, Duceram LFC, showed sufficient radiopacity to evaluate the marginal discrepancy; Artglass and Targis showed the greatest radiopacity (Fig. 3). This is a result of the greater amount of barium glass in the composition of Artglass and Targis. Solidex inlay system is classified as a radiolucent material because it has a greater amount of nonradiopaque glasses and has a smaller quantity of inorganic components [19, 20].

Radiographic examination may help to detect cement excesses which can make difficult for patients to clean the interproximal regions resulting in plaque retention and injure at gingival tissues or marginal bone loss. Thus, it is necessary that the resinous cement present high radiodensity levels [8]. The detection of the luting cement is easier performed when associated with restorative materials characterized by a reduced radiodensity as shown with Solidex. Helpfully, visualization of the resin cement seemed to be easier at cervical surfaces because of the reduced amount of tooth structure in comparison to the restorative material thickness. Even with the radiopaque employed luting material [7], a substantial marginal ledge could not be detected in association with the most radiopaque resin composite inlays.

According to O'Rourke et al. [15], it is apparent that the radiopacity of the resin composite can mask the image of the luting agent either because of its physical contour or because of an edge enhancement phenomenon. Then, if it is impossible for the clinician to control restorative materials' radiodensity, the use of greatly radiopaque resin cements seems advisable for successful clinical evaluation of indirect restorations during clinical follow-up appointments.

The principal conclusion from this study, according to the employed methodology and within the imposed limitations, was that detection of resin cement layer, and consequently the cement overhangs, is performed in an easier manner when less radiopaque restorative materials are used, but high radiolucent materials (Solidex) can possibly impair radiographic follow-up because of the difficult visualization of the cemented restoration. Hopefully, the difference in radiodensity between tooth and restorative materials at cervical regions is greater than the same difference at the isthmus floor region, which will facilitate clinical follow-up by radiographic examinations. The radiodensity of Duceram LFC was lower than Artglass and Targis, but there was no statistically significant difference between the laboratory composites Artglass and Targis. Solidex was the most radiolucent material.

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