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Radiopacity of Dental Materials: An Overview

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Abstract

Context: This study aimed to provide an overview of the literature on the radiopacity of dental materials in order to emphasize its importance.

Evidence Acquisition: English-language literature was investigated using manual and electronic searches for the terms "radiopacity," "dental material," "cement," "composite," "ceramic," "endodontic root canal sealer," "bone graft," and "acrylic resin" in the databases of Medline, google scholar, and Scopus up to April 2016. Seventy-nine selected publications, including review articles, original articles, and books, were evaluated.

Results: The radiopacity of different dental materials may be lower or higher than that of the replaced tissue depending on the restorative material used. The research revealed that highly-radiopaque materials should not be used in dental restorations, except as bone graft and endodontic root canal filling materials. For most of the dental restorative materials, moderate radiopacity within the range of the replaced dental tissue is recommended. However, the lower radiopacity of polymer-based restorative or prosthetic dental materials is still a significant clinical problem.

Conclusions: The author recommends using highly-radiopaque materials whenever possible for treatment of bone defects and root canals. For dental materials that replace clinical crowns, the radiopacity should be within the range of that of the replaced tooth structure (dentin or enamel). The radiopacity of dental cements should be much higher than that of the enamel in order to facilitate detection of the thin cement remnants.

Keywords: Radiopacity, Dental Material, Cement, Composite, Ceramic, Endodontic Root Canal Sealer, Bone Graft, Acrylic Resin

1. Context

The radiopacity of dental materials is important in order to distinguish dental restorative materials from other tooth and surrounding structures (1-3). It is also a valuable tool for assessing the absorption of materials in bone structures (4). Cement dissolutions and marginal adaptation can be detected based on the different radiopacity levels of restorative materials (5, 6). Hence, radiographic detection of the dental materials can be lifesaving in cases of accidental obstructions of breathing or embedments in neighboring anatomical structures (7, 8).

The radiopacity of dental materials is defined as an optical density value (9). It is converted into an equivalent aluminum (eq Al) thickness value (in mm) from the logarithmic optical dentistry calibration curves for the aluminum step wedge used in each respective study. It is important to express a material's radiopacity in eq Al thickness (mm) for comparison with other studies.

Radiopacity is a desirable property of dental materials, including direct-filling restorative materials (1-3, 5, 10-15), cavity liners (11-14), core build-up materials (12, 16), luting agents (3, 13, 16-20), adhesive systems (21), root canal filling materials (10, 22), provisional crown and bridge materials (23), and ceramic restorative materials (24, 25). The localization of radiolucent dental materials may not be detected if they are aspirated or impacted in the soft tissue because of trauma or iatrogenic reasons (7, 26, 27). This may necessitate the patient being exposed to advanced imaging techniques, such as computerized tomography (8, 28, 29).

Several studies have revealed that the radiopacity level of dental materials is critical and should depend on the purpose of the dental restorative material being used (3, 6, 20, 24). On the other hand, highly radiopaque materials may cause a Mach effect and result in false positive or negative discrimination (30). In dental restorations, the radiopacity level should be within the range of the radiopacity of the dental structure that is being restored. In other words, if the restored part is dentin or an enamel layer, the radiopacity of the restorative material should simulate the conditions of the layer that it is replacing (24, 31).

Dental filling, luting, lining cements, ceramics, metals, root-canal filling materials, composite resins, acrylic resins, endodontic posts, and bone graft materials all need to have a relative degree of radiopacity to be radiologically distinguished, depending on the radiopacity of their surrounding and/or neighboring hard and soft tissue structures. However, the elements that give the restorative material its radiopacity also decrease its translucency (14-16). Radiopaque particles also have negative effects, such as increasing thermal expansion and the hydrolization of silane bonding agents (32). It is therefore critical to add radiopaque materials into a material's composition.

There are many factors that affect the radiopacity of dental materials in different studies (10-14). Among these, the thickness and the chemical composition are material-related factors. The other documented factors are exposure settings, X-ray beam angulation, X-ray film speed, film-source distance, and the methodology used for evaluation (33). The composition, size, step width and length, and the type of aluminum step wedge should also be taken into consideration.

There are two main methods for the measuring the radiopacity of dental materials. These are the conventional method (using transmission densitometry) and digital image analysis (digital radiography). The digital method can be further divided into two categories, these being the direct or indirect methods. With the direct digital method, the optical density value is obtained directly using digital image analysis. With the indirect digital method, the conventional radiographic films are scanned and the digital images are then obtained. Using a software program, the radiopacity of a material can be measured on a scale of 0 to 255 (34). In the digital method, there is no need to use processing chemicals (35). In radiopacity studies, either the direct or indirect method may be preferred due to a low irradiation dose, instant imaging, and image manipulation. However, the conventional method is generally advantageous in the measurement of the radiopacity of highly-radiopaque dental materials (16, 21, 36).

According to the author's opinion, when all of the experimental parameters are followed with precision, the conventional method is still considered to be a gold-standard technique. On the other hand, it has been stated that the aluminum equivalent values that had been obtained using the conventional method were 7 - 20% higher than those obtained using digital radiography (37). Further studies are therefore required to determine the most convenient and accurate method.

2. Evidence Acquisition

English-language literature was searched using manual and electronic searches for the terms "radiopacity," "dental material," "cement," "composite," "ceramic," "endodontic root-canal sealer," "bone graft," and "acrylic resin" in the databases of Medline, google scholar, and Scopus up to April 2016. Seventy-nine selected publications, including review articles, original articles, and books were evaluated.

3. Results

3.1. Dental Cements

In dental cements, radiopacity depends on the selection of the polymer matrix, the type and proportion of radiopaque filler, its size, density, and addition level (38). The filler particles of magnesium oxide, zinc oxide, fluoroaluminosilicate glass, strontium, barium, and zirconium give the radiopaque property to polycarboxylate, zinc phosphate, and glass ionomer cements. The atomic numbers of the elements of aluminum, silicon, calcium, zinc, strontium, zirconium, and barium are 13, 14, 20, 30, 38, 40, and 56, respectively. The radiopacity of a material increases alongside an increase in the particle ratio of those materials which have an element content with a high atomic number.

Clinicians should be aware of the radiopacity of the cement that they use. The location of the margins of a restoration is of great importance, since the removal of cement remnants is very difficult along the subgingivally-located margins. Some of the glass ionomer cements do not have enough radiopacity to be detected in a radiograph (18). This could lead to a failure to remove the cement overhangs, and, in the future, undetected recurrent caries (5, 39). In restorations with subgingival margins and in patients with recurrent caries, cements with the highest radiopacity should be used.

The radiopacity of provisional luting and filling cements should also be taken into consideration. If these materials do not have sufficient radiopacity, the excess cement would not be detected radiographically, especially in a subgingivally-located cavity or abutment margins. Post-cementation protocols do not presently include radiographic examination. Nevertheless, these cements are also used as implant restorative cements (40). If a provisional luting cement is to be used in the cementation of an implant abutment, the most radiopaque cement available should be used. Radiographic evaluation of the implant margins after abutment cementation has been recommended (41-43). Insufficient removal of cement excess could lead to periodontal and peri-implant problems.

Glass ionomer cements should be used carefully in restorations with subgingival margins and in the cementation of implant abutments because their radiopacity is not as high as that of zinc-based cements (6, 12, 17, 44, 45). If the radiopacity of the dental cements has to be greater than that of the enamel tissue (3), both zinc phosphate and polycarboxylate cements are more efficient in this respect. Usually, the clinical luting cement thickness ranges between 25 - 100 μm. Therefore, using dental cements with a much higher radiopacity than the equivalent thickness of the enamel would facilitate their being detected radiographically. As a result, it would be more beneficial to develop dental cements which have more radiopacity than the enamel tissue.

3.2. Resin-Based Luting Materials

As for the other luting materials, the filler type and the amount of radiopaque filler used affect their radiopacity (46). In resin-based luting materials, the radiopaque features should be considered with more care than with other luting materials. The radiopaque fillers may increase thermal expansion and hydrolyze the silanes, and this may increase the opacity level of the materials (32). This may also cause color instability as well as esthetic failure in highly-light-transmitted direct and indirect ceramic or composite restorations.

The opacifying additives used in resin-based luting materials are aluminum, barium, ytterbium, yttrium, zinc, and zirconium (27). Silica and quartz fillers are the radiolucent particles in these materials.

Radiopacity depends on size, density, chemical nature of the filler molecules, and their quantity in the polymer matrix (46). Resin matrices contribute little to the radiopacity. Further investigations are required to study the contributions of matrix types, such as 2-hydroxyethyl methacrylate (HEMA), urethane dimethacrylate (UDMA), 10-methacryloyloxydecyl dihydrogen phosphate (MDP), bisphenol-A-glycidyl methacrylate (Bis-GMA), and triethyleneglycol dimethacrylate (TEGDMA) to the radiopacity of these materials.

In luting restorations in which esthetics are not a concern, as well as in luting subgingivally-located restorations, highly-radiopaque resin-based luting materials should be used (13, 19, 36).

3.3. Composite Resins

The earlier commercially available composite resins and glass ionomer cements had insufficient radiopacity, limiting their use as restorative materials (19). Later, polyacid-modified compomers became available, which had mechanical properties comparable to glass ionomers but with higher radiopacity (11, 19, 47). Radiopacifying elements include barium, bismuth or lanthanum oxides, strontium, zirconium, sulfates, or carbonates that vary greatly in concentration in composite resins with different compositions. The addition of barium-borosilicate glass into adhesive bonding agents is a promising procedure to increase the radiopacity in composite resin restorations.

The excessive inclusion of radiopaque filler particles jeopardizes the translucency of composite resin restorative materials, but, in turn, they can alter the mechanical properties of these materials (46, 48). There are different composite resin restorative materials, such as anterior, posterior, and bulk-type for core build-up composite resins. Composite resins are generally applied by using the incremental method. Therefore, the radiopacity of the first increment is of great importance in the margins of the posterior restorations that are located subgingivally. The filler particles of the anterior composite resins are smaller in size and lower in percentage. Therefore, they are more translucent and less radiopaque than the posterior ones (49). In fact, moderate radiopaque materials are preferable to those with a high degree of radiopacity, since the latter can obscure caries adjacent to the restorations (13, 19, 50). A new monomodal submicron radiopaque dental glass (Schott AG, Landshut, Germany) is a promising filler for composite materials which provides radiopacity without decreasing the translucency of the material.

3.4. Bone Graft Materials

The radiopacity of graft materials is also a valuable tool for evaluating the localization of the graft and its resorption degree in periodic radiographies (4, 51-54). The radiopacity of a sufficient degree of bone grafts also facilitates the assessment of the success of sinus-lifting procedures. In cases in which radiographic follow-up is critical, the materials with the highest radiopacity should be used.

In the radiological assessment of bone grafts, the superimposition of other oral structures should also be taken into consideration. Soft tissues, bone covering the graft material, and oral fluids may affect the radiopacity of the material, in that materials with low radiopacity may become more radiopaque than they actually are (49).

3.5. Ceramics and Metals

Due to their reinforcing and crystalline additives (leucite, alumina, magnesia, magnesium aluminate, lithium disilicate, zirconia, and sanidine) and required reinforcement procedures, ceramics possess different radiopacities (24, 25, 33, 55-65). Yttria-stabilized tetragonal zirconia polycrystalline (Y-TZP) ceramics have the same high levels of radiopacity as metals such as Cr-Ni alloy and gold (24). On the other hand, titanium material has moderate radiopacity. Too much radiopacity has been shown to impede the detection of voids and recurrent caries, thereby decreasing the possibility of diagnostic discrimination in areas covered by the restoration (31).

The radiopacity of other ceramics that contain alumina and zirconia is higher than that of enamel (24, 25, 30). Furthermore, high radiopacity may bring about the Mach effect, which could cause diagnostic misinterpretation (30).

The radiopacity of ceramic materials assists in the radiological detection of the forms (61), contours, and deficiencies of restorations (1-3, 5). The moderate radiopacity of ceramic materials facilitates the diagnosis of secondary caries under the restoration and enables observation of the periodontal effects of the overhangs (2, 18). Moreover, the radiopacity of these materials aids localization following the accidental swallowing of fixed or removable dental prostheses and interim crowns (7).

3.6. Polymethyl Methacrylate (PMMA) and Acrylic-Based Materials

Most of the PMMA and acrylic-based materials do not have enough radiopacity for radiographic discrimination using standard techniques. Computerized tomography and ultrasonography is necessary for the detection of accidentally impacted or ingested acrylic-based materials (8, 29). Triphenyl bismuth and some heavy metal compounds have been used to enhance the radiopacity of PMMA materials (66, 67).

It is desirable to use radiopaque PMMA and acrylic-based materials for rapid localization or removal of any foreign bodies in life-threatening situations (68). Further studies are needed into the addition of radiopacifying agents for the production of clinically acceptable levels of radiopacity without negatively affecting the physical and esthetic properties of these materials.

3.7. Endodontic Root-Canal Sealers

Endodontic materials must be radiopaque in order to discriminate between adjacent anatomical structures, such as teeth and bone, and to check the quality of obturation (69-72), while ISO 6876/200115 states that root-canal sealers must have a minimum radiopacity level equal to 3 mm of aluminum (73).

Despite having been shown to cause dental discoloration (74), bismuth oxide has been widely used as a radiopacifier in endodontic materials. It may also reduce or impair the cement's biocompatibility, as demonstrated in vitro by Gandolfi et al. (75, 76). Zinc oxide (ZnO), zirconium oxide (ZrO_2), titanium dioxide (TiO_2), barium sulphate ($BaSO_4$), iodoform (CHI_3), calcium tungstate ($CaWO_4$), ytterbium trifluoride (YbF_3), tantalum oxide (Ta_2O_5), and niobium oxide (NbO) have also been used as radiopacifiers in endodontic sealers (77, 78). Alternatively, some commercial hydraulic calcium silicate cements have been produced which are free of radiopacifiers, to be used in specific clinical applications such as pulp capping or apicogenesis (79).

In the treatment of endodontic perforations, the materials used should ideally be sufficiently radiopaque in order to determine the filling's quality and distinguish between it and the nearby anatomical structures, and to this end, research into new root filling materials is required.

4. Conclusions

The radiopacity of a dental restorative material should be within the range of that of the tooth or surrounding structures (e.g., dentin, enamel, bone) that are being replaced. In certain situations, a radiopacity slightly greater than that of the replaced tooth structure allows carious-affected or infected tooth structures to be distinguished from the restoration, while at the same time allowing for the homogeneity of the material to be determined. Dental materials, such as bone grafts and endodontic root-canal sealers, need radiopacity levels much higher than that of the neighboring structures in order to better determine the filling accuracy, resorption levels, or the position of the materials. Nevertheless, in cases where metals such as zirconia and amalgam are used, in which the radiopacity is too high, voids or recurrent caries may not be detected, thereby negatively affecting diagnostic discrimination in the area around the restoration.

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