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ORIGINAL ARTICLE

Densitometric Evaluation of Different Pulp Capping Materials using the Prodigy DXA System

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ABSTRACT

Background: The dependence of dental diagnosis on radiographs makes it important for all materials used in the oral cavity to be radiopaque: they can thus be identified and distinguished from dental structures. The objective of the present study was to compare the radiopacity of different pulp capping materials using an experimental densitometric evaluation (Prodigy DXA system).

Materials and methods: Thirty specimens were prepared for each material following manufacturers' instructions. Dentin slices were obtained from freshly extracted premolar teeth. All materials were scanned on a GE healthcare lunar Prodigy and iDXA in routine clinical manner. The assessment of normality was developed by the Shapiro-Wilk test; the Kruskal-Wallis test, and its multiple comparisons, was applied to compare the materials.

Results: Results with $p < 0.05$ were considered to be statistically significant. Major differences were registered between the materials and the dentinal tissue.

Conclusion: Materials containing bismuth oxide showed high densitometric values when compared with resin-based materials and with materials containing zirconium oxide and zinc oxide.

Keywords: Densitometric evaluation, DXA, Pulp capping materials, Radiopacity.

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INTRODUCTION

The radiopacity of restorative materials is listed as one of the basic requirements for the accurate diagnosis and follow-up in restored teeth.[1,2] The commonly-used products to seal communications between the exposed pulp and the oral cavity are calcium hydroxide-based materials and mineral trioxide aggregate.[3] Various methods to rank the radiopacity of restorative materials have been outlined in the literature: McComb and Smith used as a reference the opacity of the metal mold that held their samples while Beyer-Olsen and Ortsavik were the first to introduce, in their radiographs, a reproducible standard for comparison and laid the basis for developing a method that serves as the guideline for radiopacity testing procedures.[4-7] The inclusion of the image of an aluminum stepwedge, which, with a thickness of 1 mm, is referred to have a radiopacity similar to dentin, made it possible to transform readings of light transmission in the radiograph into an equivalent thickness of aluminum.[8-10] However, the indicated values refer to a slightly unconventional method of analysis. In the present study, the radiopacity of pulp capping materials was tested with a densitometric technique in order to avoid the use of the aluminum stepwedge and to directly compare the values obtained. The Prodigy dual energy X-ray absorptiometry (DXA) system provides densitometric analyses based on DXA, that is the absorption and interaction between incident photons and the material. Like traditional radiology, the Prodigy DXA system provides bidimensional images of irradiated surfaces overlapping the changes in density inside the material; however, the inclusion of collimation filters, which allow the emission of a single beam through the material, reduces strayradiation and improves the resolution of the measurements which gain high diagnostic sensibility. The Prodigy DXA system is currently used in several applications in body composition analyses and orthopedics because of the information it offers about bone and soft tissues. This information is expressed as bone mineral content (BMC) and bone mineral density (BMD), thus offering a measurement of density of the material irradiated.

The objective of the present study is to compare the radiopacity of different pulp capping materials using an experimental densitometric evaluation. The null hypothesis is that materials tested present similar values of density to that obtained with dentinal tissue.

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MATERIALS AND METHODS

The materials tested in this study are listed in Table 1. Thirty standardized specimens of each material were prepared in accordance with manufacturers' instructions; in addition, 30 dentin slices (1 mm in thickness and 4 mm in diameter) were obtained from freshly extracted noncarious teeth by using slow-speed diamond disks; these were stored in a 0.1% thymol solution until used. The teeth were all extracted for periodontal reasons in the Department of Clinical-Surgical, Diagnostic and Pediatric Sciences—Section of Dentistry (University of Pavia). The dentin slices were for the purpose of radiographic comparison with the materials. Dycal Ivory (Dentsply Tulsa Dental, Johnson City, TN, USA), Dycal Dentin (Dentsply Tulsa Dental, Johnson City, TN, USA), MTA Angelus (Angelus, Londrina, PR, Brazil), Biodentine (Septodont, Saint-Maur-des-Fosses, France) and Proroot MTA (Dentsply Tulsa Dental, Johnson City, TN, USA) were mixed and placed into silicon molds measuring 1 mm in thickness and 4 mm in internal diameter. The specimens were covered with glass plates on each side to allow for the removal of excessive material. Thirty specimens of Calcimol LC (Voco GmbH, Cuxhaven, Germany) were prepared by condensing the material into silicon molds (1 mm in thickness and 4 mm in internal diameter). The molds were filled with the light-curing material and a glass slide pressed onto each side to extrude any excess material and to form a flat surface. The distal end of the light guide was placed against the surface of the material and positioned concentrically to the cavity in the mold; the material was then light-cured from the top using the Celalux II (Voco, Cuxhaven, Germany) curing light. One, standard, light polymerization mode was used for each material: 1000 mW/cm^2 for 40 seconds. The cordless curing unit was maintained at full charge before use and irradiance was monitored periodically by using a radiometer (SDS Kerr, Orange, CA).

The specimens were kept in a chamber at 37°C and 95% relative humidity for 24 hours. Ten arrays were set by collecting three samples for each material in order to scan them with the Prodigy DXA system (GE Healthcare, Madison, WI).

Dual Energy X-ray Absorptiometry Measurements

All materials were scanned on a GE Healthcare Lunar Prodigy and iDXA in routine clinical manner per manufacturer recommendations. For the Prodigy, Encore software (GE Healthcare, Madison, WI) version 9.2 was used for acquisition and 11.4 for analysis; with iDXA, Encore software version 9.3 was used to acquire scans with version 11.0 used for analyses. The precision assessments were performed in routine clinical manner in accordance with International Society for Clinical Densitometry (ISCD) recommendations.

STATISTICAL ANALYSIS

Data collected were analyzed with R software (version 2.15.3, Development Core Team, 2013) and its package pgirmess.[11,12] The assessment of normality was developed with the Shapiro-Wilk test. The Kruskal-Wallis test, and its multiple comparisons, was applied to compare the materials in order to determine which groups were different (with pairwise comparisons adjusted

Table 1: Characteristics of tested materials

Material	*Composition*	*Lot. No.*	*Manufacturer*
Dycal Ivory	Two-paste system made of a base paste (1,3-butylene glycol disalicylate, zinc oxide, calcium phosphate, calcium tungstate, iron oxide pigments) and a catalyst paste (calcium hydroxide, N-ethyl-o/p-toluene sulphonamide, zinc oxide, titanium oxide, zinc stearate)	120717	Dentsply Tulsa Dental, Johnson City, TN, USA
Dycal Dentin	Two-paste system made of a base paste (1,3-butylene glycol disalicylate, zinc oxide, calcium phosphate, calcium tungstate, iron oxide pigments) and a catalyst paste (calcium hydroxide, N-ethyl-o/p-toluene sulphonamide, zinc oxide, titanium oxide, zinc stearate, iron oxide pigments)	121003	Dentsply Tulsa Dental, Johnson City, TN, USA
Calcimol LC	Light-curing one-component material containing urethanedimethacrylate resin, calcium dihydroxide, 2-dimethylaminoethyl methacrylate	1244494	Voco GmbH, Cuxhaven, Germany
MTA-Angelus	Silicon dioxide, potassium oxide, aluminum oxide, sodium oxide, iron oxide, sulfur trioxide, calcium oxide, bismuth oxide, magnesium oxide, insoluble residues of calcium oxide, potassium sulfate and sodium sulfate	24120	Angelus, Londrina, PR, Brazil
Biodentine	Powder containing tricalcium silicate, calcium carbonate and zirconium oxide. Liquid containing water, calcium chloride (accelerator) and modified polycarboxylate	B06562	Septodont, Saint-Maur-des-Fosses, France
ProRoot MTA	Powder: calcium phosphate, calcium oxide, silica, bismuth oxide, Liquid: distilled water	12001879	Dentsply Tulsa Dental, Johnson City, TN, USA

appropriately).[13] Results with $p < 0.05$ were considered statistically significant.

RESULTS

For dentin, and for each pulp capping material, descriptive statistics of BMD are shown in Table 2 and represented (by boxplots) in Figure 1. The null-hypothesis that the distributions in groups were modeled as a Gaussian random variable was not confirmed by the Shapiro-Wilk test ($p < 0.05$). The results obtained by the Kruskal-Wallis test, and its multiple comparisons, is reported in Table 3. The Kruskal-Wallis test returned a significant result ($p < 0.001$); this indicates that at least one of the groups is different from at least one of the others. Concerning multiple comparisons, all the materials, except Dycal Ivory, showed densitometric values significantly higher than dentinal tissue ($p < 0.05$). ProRoot MTA and MTA Angelus showed the highest values of density when compared with the other materials ($p < 0.05$). Significant differences were also noted between Calcimol LC and Dycal Ivory ($p < 0.05$).

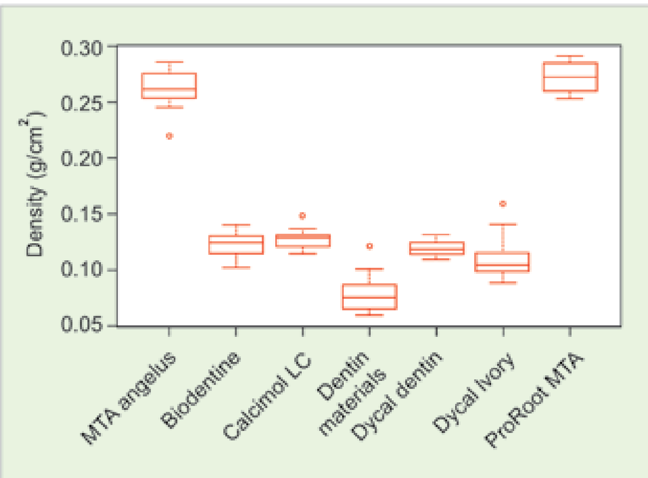

Fig. 1: Box plot of densitometric values for each material tested. The bold horizontal line shows the median value. The top and bottom of the box show the 25th and 75th percentiles, respectively. The vertical dashed lines are called the 'whiskers', they show 1.5 times the interquartile range of the data (i.e. the difference in the third and first quartiles of the observed index). Points more than 1.5 times the interquartile range above the third quartile and points less than 1.5 times the interquartile range are defined as outliers and are plotted individually

DISCUSSION

The dependence of dental diagnosis on radiographs makes it important for all materials used in the oral cavity to be radiopaque: they can thus be identified and distinguished from dental structures. This property is even more important for pulp capping materials, which are used in contact with pulp tissue. The use of materials less radiopaque than dentin below restorative materials could be radiographically mistaken for decalcified or carious dentin.[14] Moderately, radiopaque materials are preferable to those with a high degree of radiopacity since the latter may obscure caries-adjacent restorations.[15-17] It is desirable that restorative materials have radiopacity values similar to that of enamel for better performance.[15,18] Duarte et al evaluated the radiopacity of Portland cement with different radiopacifying agents; they were added because the original formulation of Portland cement had a low radiopacity, making impossible to distinguish it from bone and dentinal tissues.[19,20] It was observed that this association is more radiopaque when the following radiopacifying agents were added in decreasing order: bismuth oxide, zirconium oxide, calcium tungstate, barium sulfate and zinc oxide. Therefore, it could be

Table 2: Descriptive statistics for each material tested

Materials	*Obs*	*Mean*	*Median*	*Std. Dev.*	*Min.*	*Max.*
Dentin	30	0.0804	0.0755	0.0183	0.0590	0.1220
Dycal Ivory	30	0.1132	0.1050	0.0203	0.0890	0.1600
Dycal Dentin	30	0.1208	0.1190	0.0068	0.1100	0.1320
Calcimol LC	30	0.1293	0.1295	0.0090	0.1150	0.1490
MTA Angelus	30	0.2637	0.2630	0.0180	0.2210	288
Biodentine	30	0.1248	0.1250	0.0120	0.1020	0.1410
ProRoot MTA	30	0.2730	0.2740	0.0134	0.2550	0.2930

Table 3: Adjusted p-values and Kruskal-Wallis values (in brackets) obtained for each pairwise comparison between the materials $p < 0.05$ corresponded to values of comparison (>47.67) statistically significant

	Dentin	*Dycal Ivory*	*Dycal dentin*	*Calcimol LC*	*MTA-Angelus*	*Biodentine*	*ProRoot MTA*
Dentin		>0.05 (40.72)	<0.05* (61.90)	<0.05* (89.20)	<0.05* (153.42)	<0.05* (74.02)	<0.05* (162.92)
Dycal Ivory			>0.05 (21.18)	<0.05* (48.48)	<0.05* (112.70)	>0.05 (33.30)	<0.05* (122.20)
Dycal Dentin				>0.05 (27.3)	<0.05* (91.52)	>0.05 (12.12)	<0.05* (101.02)
Calcimol LC					<0.05* (64.22)	>0.05 (15.18)	<0.05* (73.72)
MTA Angelus						<0.05* (79.40)	>0.05 (9.50)
Biodentine							<0.05* (88.90)

* Significant values

inferred that, depending on the amount and proportion of each radiopacifying agent, more or less radiopaque cement might be obtained.[21] The comparison derived from the present study highlighted the different influences of the components of each material, largely respecting the information provided in Duarte et al.[19] Indeed, MTA-Angelus and ProRoot MTA showed the highest values in experimental densitometric evaluation, confirming the key role of bismuth oxide-which represents the 20% of both products.[22] However, all materials tested showed a significant difference in the densitometric evaluation with BMD against dentin, thus sharing an important property. As reported above, the components which resulted in a higher density to materials when they were scanned with the GE healthcare Lunar Prodigy and iDXA were zinc oxide, contained in Dycal Dentin and Dycal Ivory, and zirconium oxide, contained in Biodentin. Zinc oxide is a well-known radiopacifying agent previously used in restorative and endodontic materials, such as zinc-oxide-eugenol based cements.[23] Zirconium oxide, unlike bismuth oxide which has a high intrinsic radiopacity, imparts a lower radiopacity even though it seems to guarantee the clinical requests for this type of dental material. Due to this fact, the high percentage of bismuth oxide contained in MTA-Angelus and ProRoot MTA does not appear to be completely justified; in fact bismuth oxide is not inert but slows the setting time and is a known catalyst for the oxidation of various organic compounds. Moreover, Chan et al have added that a moderate degree of radiopacity is preferable to a high degree.[24] Very high radiopacity, like that of amalgam, does not provide the best condition for detecting radiolucent areas, such as recurrent caries adjacent to restorations. Calcimol LC is the only resin-based material tested in this study, however it maintains acceptable degrees of radiopacity providing significant differences with dentin tissue.

The main limit of the present study is the low number of dentin samples which do not represent all the individual variations of density and mineral content. The randomized method used when the operator did the extractions should prevent from further limitations and bias.

The strength of the densitometric evaluation provided by the Prodigy DXA System is the ability to minimize measurement errors. Differently from the radiographic evaluation which shows how a material appears in a bidimensional format, BMD values show which is the material density.

CONCLUSION

The null-hypothesis that all materials present similar values of density to that obtained with dentinal tissue has been rejected because of the significant differences the materials showed when evaluated with the experimental method based on a GE Healthcare Lunar Prodigy and iDXA. Thanks to this method, the values obtained could be directly analyzed without employing the aluminum stepwedge, thus reducing the risk of error.[25]

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