

Article

Influence of Sunscreen Composition on the Apparent Radiopacity of Restorative Materials on Digital Dental Radiography: An In Vitro Study

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Abstract

Background and Objectives: The radiographic interpretation of restorative materials may be influenced not only by their intrinsic composition but also by external substances positioned within the X-ray beam path. Mineral-containing sunscreens (MSs) include metal oxides such as zinc oxide, which may attenuate X-rays and alter radiographic image intensity. This in vitro study evaluated the effects of MS and non-mineral sunscreen (NMS) on the mean gray values (MGVs) and aluminum-equivalent radiopacity of restorative materials. **Materials and Methods:** Specimens of glass ionomer cement (GIC), flowable composite resin (FC), and resin composite (RC) were covered with a 5 mm polymethyl methacrylate block for soft-tissue simulation. Sunscreens were applied as standardized 1 mm layers, and each material was radiographed under control, NMS, and MS conditions using identical parameters. An 11-step aluminum wedge was used for calibration. MGVs were measured using ImageJ and converted to millimeters of aluminum (mm Al). **Results:** Restorative material, sunscreen condition, and their interaction significantly affected MGVs (all $p < 0.05$). NMS produced no significant change compared with control. MS significantly increased the MGVs of GIC, FC, and RC from 67.56, 63.89, and 83.56 to 97.56, 90.00, and 104.11, respectively. Corresponding radiopacity values increased from 2.02, 1.78, and 2.79 mm Al to 3.58, 3.12, and 3.98 mm Al. **Conclusions:** Under the conditions of this in vitro study, the tested MS significantly increased the apparent radiopacity of all restorative materials, whereas the tested NMS had no significant effect. These findings indicate that the tested mineral-containing formulation, when positioned within the X-ray beam path, can alter the radiographic appearance of dental restorations. Awareness of this potential superimposition effect may help reduce the risk of misinterpretation during radiographic evaluation.

Keywords: digital dental radiography; restorative dental materials; radiopacity; sunscreen; mean gray value

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1. Introduction

Digital dental radiographs are essential imaging modalities widely used in dentistry for the diagnosis of dental caries, evaluation of periapical pathologies, and follow-up of

restorative treatments [1,2]. Digital imaging systems enable the quantitative assessment of image intensity using the mean gray value (MGV), thereby allowing the radiographic characteristics of different dental materials to be compared [1,3,4].

The radiographic appearance of restorative materials varies depending on their chemical composition, density, and the radiopaque agents they contain. Adequate radiopacity is clinically important for distinguishing restorations from dental tissues, secondary caries, and adjacent anatomical structures. Several studies have also demonstrated that material type and thickness are major determinants of radiopacity [4–6].

The radiopacity of different composite resins, single-shade composites, and flowable composites has been reported to vary according to their material composition. In particular, MGV-based digital analysis methods have been shown to provide reliable results for determining differences in radiopacity among restorative materials [1,3].

Sunscreens are dermocosmetic products used to protect the skin from the harmful effects of solar ultraviolet (UV) radiation [7]. They essentially consist of UV filters incorporated into vehicles suitable for topical application, such as emulsions, gels, aerosols, and sticks [8]. UV filters are active compounds classified as organic or inorganic according to their ability to render UV radiation harmless by converting, dispersing, scattering, and/or absorbing it [9].

The formation of radiographic images is influenced not only by dental materials but also by other substances located along the X-ray beam path. Sunscreens commonly used in daily life can be classified according to their composition as mineral-containing sunscreens (MS) and non-mineral sunscreens (NMS). Mineral-containing sunscreens commonly use zinc oxide (ZnO), titanium dioxide (TiO₂), or both as inorganic UV filters to protect the skin against ultraviolet (UV) radiation [8,10]. In contrast, NMS rely predominantly on organic UV filters such as avobenzone, octocrylene, and octinoxate, which primarily absorb UV radiation and convert it into less harmful energy forms [11].

Previous studies have demonstrated that the radiopacity of restorative materials is influenced by intrinsic material-related factors, including composition, filler characteristics, thickness, and aging-related changes [3–5]. Özdemir and Özdemir [3], for example, reported material-dependent differences in the radiopacity of restorative materials using digital radiography. In a separate line of research, substances positioned within the X-ray beam path have been shown to alter radiographic image characteristics. A recent *in vitro* study demonstrated that facial sunscreens, particularly inorganic formulations, may affect radiographic brightness, image uniformity, and absorbed radiation dose [12]. However, the effect of sunscreen superimposition on the apparent radiopacity of restorative materials has not been specifically investigated. Therefore, the present study combines these two lines of investigation by evaluating whether mineral-containing and non-mineral sunscreens alter the radiographic appearance and aluminum-equivalent radiopacity of restorative materials.

The aim of this study was to evaluate the effects of MS and NMS on the MGVs of different restorative materials and to determine their equivalent radiopacity values based on calibration using an aluminum step wedge. The null hypothesis was that sunscreen application would have no effect on the MGVs of restorative materials and that no difference would exist between the sunscreen types.

2. Materials and Methods

Three different restorative materials were evaluated in this study: a high-viscosity glass ionomer cement (GIC) (EQUIA Forte HT; GC, Tokyo, Japan), a flowable composite resin (FC) (Vittra APS Unique Flow; FGM, Joinville, Brazil), and a conventional composite resin (RC) (G-aenial Posterior, shade A2; GC, Tokyo, Japan) (Table 1). Silicone molds measuring 20 × 20 × 1 mm were used to prepare the specimens. The composite resin

materials were placed into the molds in a single increment. After the molds had been completely filled, a Mylar strip was placed over the material to minimize the formation of the oxygen-inhibited layer and obtain a smooth surface. A glass slide was then placed over the Mylar strip to ensure a flat surface and remove excess material. Polymerization was performed using an LED light-curing unit (Woodpecker Medical Instrument Co., Guilin, China) with an irradiance of 1000 mW/cm². The polymerization duration and application protocol were implemented in accordance with the manufacturers' instructions, and details of the materials used are presented in Table 1. To ensure standardization across all specimens, the light output of the curing unit was verified using a radiometer before each use. The GIC specimens were prepared according to the manufacturer's instructions. All prepared specimens were stored in distilled water under dark conditions for 24 h before measurement. Following polymerization and setting, the thickness of each specimen was verified using a digital caliper (Absolute Digimatic; Mitutoyo Corp., Kawasaki, Japan). A priori power analysis was performed using G*Power version 3.1. Based on the methodology of a previous radiopacity study [3] and assuming a large effect size ($f = 0.50$), an α level of 0.05, and a statistical power of 80%, the minimum required sample size was calculated as nine specimens per material. Accordingly, nine specimens were prepared for each material. To simulate soft tissue, a 5 mm-thick polymethyl methacrylate (PMMA) block was placed over the restorative materials. The sunscreens were applied to the surface of the PMMA block as 1 mm-thick layers using custom-made circular silicone molds. The use of these molds ensured a homogeneous and reproducible sunscreen layer across the specimens and standardized the radiographic measurements (Figure 1). Two commercially available sunscreen formulations with a sun protection factor of 50 or higher were evaluated. The mineral-containing sunscreen (MS) was Minela Care Baby & Kids Mineral Sunscreen SPF 50 (Minela Care, Southbank, Australia). According to the product label, zinc oxide was the principal inorganic UV filter and was listed as the first ingredient. The formulation also contained iron oxide pigments (CI 77499, CI 77491, and CI 77492), whereas titanium dioxide was not listed. The non-mineral sunscreen (NMS) was Avène Eau Thermale Spray SPF 50+ (Pierre Fabre Dermo-Cosmétique, Laval, France). Its labeled UV-filter system included methylene bis-benzotriazolyl tetramethylbutylphenol [nano], bis-ethylhexyloxyphenol methoxyphenyl triazine, diethylhexyl butamido triazone, and butyl methoxydibenzoylmethane; zinc oxide and titanium dioxide were not listed. Quantitative concentrations of the UV filters were not provided on the product labels. For the MS formulation, information regarding zinc oxide particle size, nano/non-nano status, and surface-coating characteristics was also unavailable.

Table 1. Restorative materials evaluated in the study and their manufacturer-reported composition.

Abbreviation	Material	Manufacturer	Material Type	Composition	Filler Load (wt%/vol%)
RC	G-aenial Posterior (A2)	GC, Tokyo, Japan	Paste-type composite resin	Bis-MEPP, UDMA; 300 nm barium glass filler, 16 nm fumed silica, organic filler	82/65
FC	Vittra APS Unique Flow (VUF)	FGM, Joinville, Brazil	Flowable composite resin	Methacrylate monomer mixture, APS photoinitiator system, co-initiators, stabilizers, silane; barium–aluminum–borosilicate glass and SiO ₂ (1.7–1.9 μ m)	58–62/56–60
GIC	EQUIA Forte HT	GC, Tokyo, Japan	High-viscosity glass ionomer cement	Powder: fluoroaluminosilicate glass, polyacrylic acid, pigment. Liquid: water, polyacrylic acid, carboxylic acid	Not reported

Abbreviations: RC, conventional composite resin; FC, flowable composite resin; GIC, glass ionomer cement; UDMA, urethane dimethacrylate; APS, Advanced Polymerization System; SiO₂, silicon dioxide; wt%, weight percentage; vol%, volume percentage. Material composition and filler-load data were obtained from the manufacturers' product information.

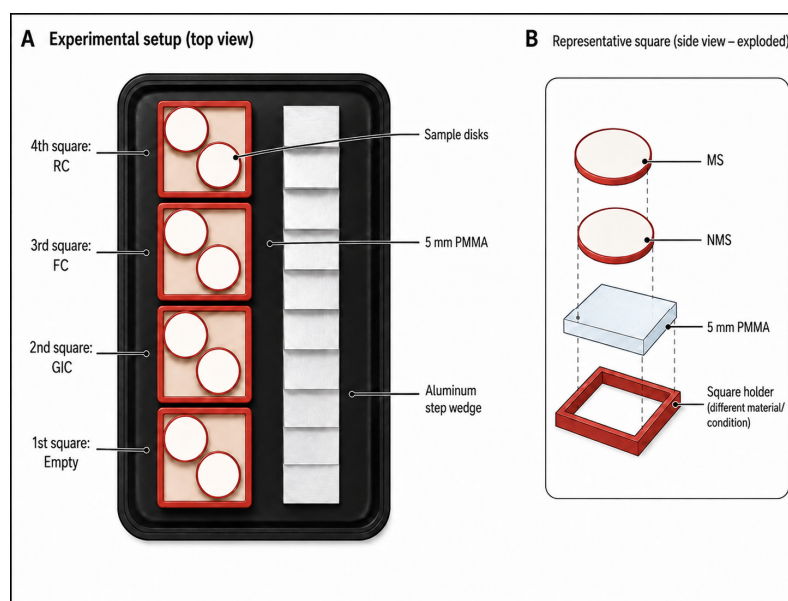


Figure 1. Schematic representation of the experimental setup. (A) Top view showing the 11-step aluminum wedge and the holders containing the glass ionomer cement (GIC), flowable composite (FC), and resin composite (RC) specimens. (B) Exploded side view illustrating the restorative material specimen, the 5 mm polymethyl methacrylate block, and the standardized mineral-containing sunscreen (MS) and non-mineral sunscreen (NMS) application sites.

2.1. Radiographic Imaging and Image Analysis

Digital radiographic images were acquired using a BEST-X-DC dental X-ray unit (New Life Radiology SRL, Grugliasco, Italy). During each radiographic exposure, the restorative material specimens and a custom-made aluminum step wedge (11 steps, 99.5% purity), used as the radiographic reference, were positioned within the same imaging field. The aluminum step wedge was fabricated in accordance with the radiopacity calibration standards used in dental radiographic studies [13].

For the control condition without sunscreen application, the restorative material specimens were imaged together with the PMMA block. For the MS and NMS conditions, the sunscreens were placed within silicone molds measuring 10 mm in diameter and 1 mm in thickness, positioned centrally over the specimens, and the radiographic images were subsequently acquired.

All radiographs were acquired using standardized exposure parameters (60 kV, 7 mA, and 0.16 s). The focal spot-to-object distance was fixed at 30 cm for all exposures. Images were obtained using a size 4 PSP plate (5.7 × 7.5 cm; Dürr Dental, Bietigheim-Bissingen, Germany) and digitized after exposure using a PSP scanner (VistaScan Mini Plus; Dürr Dental, Bietigheim-Bissingen, Germany) (Figure 2). Radiographic image analysis was performed using ImageJ software version 1.54g (National Institutes of Health, Bethesda, MD, USA). All ImageJ measurements and manual ROI selections were performed by a single examiner who was blinded to the experimental conditions (Control, NMS, and MS) during image analysis. Standardized regions of interest (ROIs) were selected over the restorative materials and the aluminum step wedge, and the corresponding MGVs were recorded. Three separate ROIs, each measuring 1 mm², were defined for each structure, and the mean MGv was calculated for each image. To assess intra-observer reliability, all radiographic images were re-evaluated by the same examiner after a four-week interval.

MGVs of the restorative material specimens were converted into aluminum-equivalent radiopacity values, expressed as millimeters of aluminum (mm Al), using the interpolation method described by Lachowski et al. [14]. The aluminum step wedge

consisted of 11 steps with 1 mm thickness increments. For each radiographic image, standardized regions of interest were placed on the restorative material specimens and on each step of the aluminum wedge. The two adjacent aluminum steps whose MGVs bracketed the specimen MGV were identified. The aluminum-equivalent radiopacity of each specimen was then calculated using the following equation:

$$\text{mmAl}_x = t_{\text{low}} + ((\text{MGV}_x - \text{MGV}_{\text{low}})/(\text{MGV}_{\text{high}} - \text{MGV}_{\text{low}})) \times (t_{\text{high}} - t_{\text{low}})$$

where mm Al_x represents the calculated aluminum-equivalent radiopacity of the tested specimen; MGV_x represents the mean gray value of the specimen; MGV_{low} represents the mean gray value of the aluminum step immediately below the specimen MGV; and MGV_{high} represents the mean gray value of the aluminum step immediately above the specimen MGV. The terms *t*_{low} and *t*_{high} represent the known thicknesses, expressed in millimeters of aluminum, of the corresponding lower and upper aluminum steps, respectively. The term (*t*_{high} − *t*_{low}) represents the thickness interval between the two adjacent aluminum steps. Because the aluminum step wedge used in the present study had 1 mm thickness increments, this interval was equal to 1 mm.

The calculation was performed separately for each radiographic image using the MGVs of the aluminum step wedge recorded on the same image.

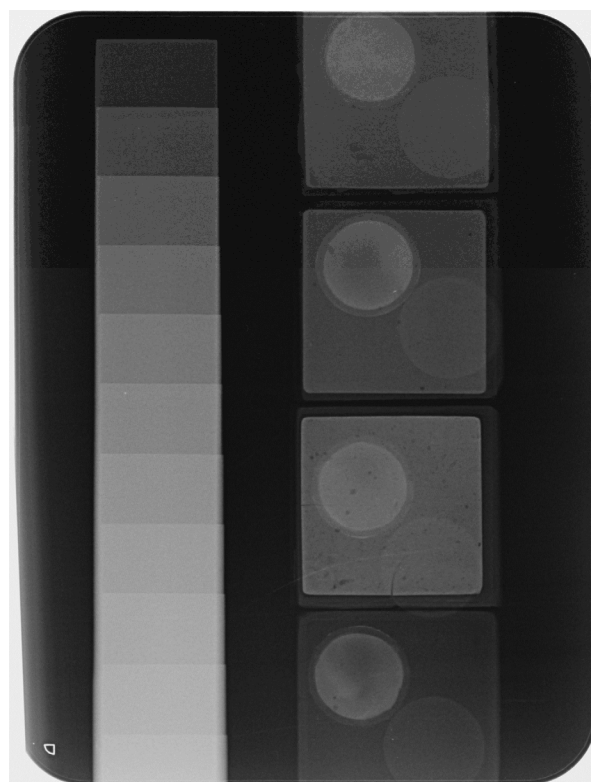


Figure 2. Digital radiograph of the experimental setup.

2.2. Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics for Windows, version 26.0 (IBM Corp., Armonk, NY, USA) [15]. Data were expressed as mean ± standard deviation. Intra-observer reliability was assessed using the intraclass correlation coefficient (ICC) with 95% confidence intervals. The effects of restorative material type, sunscreen condition, and their interaction on MGV were evaluated using two-way analysis of variance (ANOVA). Multiple comparisons were performed using Tukey's honestly significant difference test. Statistical significance was set at *p* < 0.05.

3. Results

The MGVs of the restorative materials under the three experimental conditions are presented in Table 2. For interpretation of the superscript notation in Table 2, lowercase letters indicate comparisons among sunscreen conditions within the same restorative material, whereas uppercase letters indicate comparisons among restorative materials within the same sunscreen condition. Values sharing the same letter are not significantly different, whereas different letters indicate statistically significant differences. Within-material comparisons revealed significant differences among the sunscreen conditions for all three restorative materials ($p < 0.001$; Table 2). However, post hoc analysis showed no significant difference between the Control and NMS groups. The significant overall result was mainly driven by the higher MGVs observed in the MS group. In the GIC group, the MGV increased from 67.56 ± 4.57 under the control condition without sunscreen to 70.33 ± 3.46 following NMS application; however, this increase was not statistically significant. In contrast, MS application increased the MGV to 97.56 ± 4.61 , resulting in a value significantly higher than those observed under both the control and NMS conditions ($p < 0.05$). The same pattern was observed in the FC and RC groups: NMS application produced only a limited, non-significant increase, whereas MS application significantly increased the MGV of both materials.

Table 2. Mean gray values of the restorative materials under different sunscreen conditions.

Restorative Material	Control	NMS	MS	<i>p</i> Value *
GIC	67.56 ± 4.57 ^{aA}	70.33 ± 3.46 ^{aA}	97.56 ± 4.61 ^{bB}	<0.001
FC	63.89 ± 5.22 ^{aA}	68.33 ± 3.28 ^{aA}	90.00 ± 5.87 ^{bA}	<0.001
RC	83.56 ± 3.88 ^{aB}	87.56 ± 3.81 ^{aB}	104.11 ± 6.72 ^{bc}	<0.001
<i>p</i> value [†]	<0.001	<0.001	<0.001	

Data are presented as mean $\pm$ standard deviation. Different lowercase superscript letters within the same row indicate statistically significant differences among sunscreen conditions for the same restorative material. Different uppercase superscript letters within the same column indicate statistically significant differences among restorative materials under the same sunscreen condition. * *p* values for comparisons among sunscreen conditions within each restorative material. [†] *p* values for comparisons among restorative materials within each sunscreen condition. GIC, glass ionomer cement; FC, flowable composite; RC, resin composite; NMS, non-mineral sunscreen; MS, mineral-containing sunscreen.

Two-way analysis of variance demonstrated significant effects of both restorative material type and sunscreen condition on MGV, as well as a significant interaction between these factors (Table 3). This interaction indicates that the effect of sunscreen application on MGV varied according to the restorative material evaluated.

Table 3. Results of the two-way analysis of variance for MGV.

Source	F	<i>p</i> Value
Restorative material	109.68	<0.001
Sunscreen condition	247.10	<0.001
Restorative material $\times$ sunscreen condition	3.73	0.008

The apparent aluminum-equivalent radiopacity values of the restorative materials under the three experimental conditions are presented in Table 4. For all materials, no significant difference was observed between the control and NMS conditions, whereas MS application resulted in significantly higher mm Al values than both the control and NMS conditions ($p < 0.05$).

Table 4. Apparent aluminum-equivalent radiopacity values of the restorative materials under different sunscreen conditions.

Material	Control	NMS	MS	<i>p</i> Value
GIC	2.02 ± 0.22 ^a	2.15 ± 0.18 ^a	3.58 ± 0.27 ^b	<0.05 *
FC	1.78 ± 0.26 ^a	2.06 ± 0.15 ^a	3.12 ± 0.31 ^b	<0.05 *
RC	2.79 ± 0.19 ^a	2.98 ± 0.16 ^a	3.98 ± 0.36 ^b	<0.05 *

Values are presented as mean ± standard deviation and expressed as millimeters of aluminum equivalence (mm Al). Different lowercase superscript letters within the same row indicate statistically significant differences among sunscreen conditions, whereas identical letters indicate no statistically significant difference (Tukey HSD test). * $p < 0.05$. GIC, glass ionomer cement; FC, flowable composite resin; RC, conventional composite resin; NMS, non-mineral sunscreen; MS, mineral-containing sunscreen.

Repeated measurements demonstrated excellent intra-observer reliability (ICC = 0.987; 95% CI: 0.972–0.994).

4. Discussion

The present study evaluated the effects of MS and NMS on the radiographic appearance of different restorative materials. The principal finding was that MS application significantly increased both the MGV and aluminum-equivalent radiopacity of all restorative materials tested. In contrast, no statistically significant difference was observed between the NMS and control conditions. Furthermore, the significant interaction between restorative material type and sunscreen condition indicated that the radiographic effect of MS was not uniform across all restorative materials. Accordingly, the null hypothesis was rejected.

The differentiation of restorative materials on dental radiographs largely depends on their radiopacity. Adequate radiopacity is clinically important for distinguishing restorations from dental tissues, secondary caries, marginal discrepancies, and adjacent anatomical structures [4,5]. Previous studies have reported that the radiopacity of restorative materials varies according to their chemical composition, filler type, filler content, thickness, and incorporated radiopaque agents [1,3,5]. Consistent with the findings of Özdemir and Özdemir [3], the present study also demonstrated material-dependent differences in baseline radiopacity, with RC exhibiting the highest and FC the lowest values under the control condition. However, while previous studies primarily focused on intrinsic material-related determinants of radiopacity, the present study extends these observations by demonstrating that an external substance positioned within the X-ray beam path can also modify the apparent radiopacity of restorative materials.

MS application markedly increased the MGVs of all restorative materials. TiO₂ and ZnO are commonly used as UV-protective agents in MS formulations [8–10]. In the MS tested in the present study, ZnO was the principal inorganic UV filter listed by the manufacturer, whereas TiO₂ was not listed. The formulation also contained iron oxide pigments, which may have contributed to the observed X-ray attenuation. Metal oxide particles can interact with X-ray beams and thereby alter image intensity. Previous studies have shown that ZnO particles can be detected using X-ray-based imaging systems and can modify image contrast [16]. The present findings are also consistent with those of Nejaim et al. [12], who reported that inorganic facial sunscreen significantly increased radiographic image brightness, whereas organic sunscreen did not produce a comparable effect. Similarly, in the present study, MS significantly increased both MGV and aluminum-equivalent radiopacity, while NMS did not differ significantly from the control condition. This agreement supports the interpretation that inorganic sunscreen components can produce

measurable X-ray attenuation. However, the studies differ in their primary outcomes: Nejaim et al. evaluated general image-quality parameters and absorbed radiation dose, whereas the present study quantified the effect of sunscreen superimposition on the apparent radiopacity of individual restorative materials. Thus, our findings extend previous observations by demonstrating that the effect is not limited to overall image brightness but may also modify the radiographic appearance of restorative materials.

No significant difference was observed between the NMS and control groups. This finding may be explained by the lower X-ray attenuation of organic UV filters compared with that of metal oxide particles. Organic filters primarily consist of compounds that absorb or convert UV radiation; however, their interaction with the X-ray energies used in dental radiography is less pronounced than that of mineral filters [8,9]. Therefore, the limited effect of NMS on the radiographic appearance of restorative materials is consistent with the available literature.

In this study, the mm Al equivalents derived using the aluminum step wedge supported the MGTV findings. The use of an aluminum step wedge is a widely accepted approach for evaluating the radiopacity of dental materials [13]. International standards specify that the radiopacity of dental restorative materials should not be lower than that of an equivalent thickness of aluminum [17]. Under the control condition, the radiopacity values of the materials ranged from 1.78 to 2.79 mm Al, whereas these values increased to 3.12–3.98 mm Al following MS application. This increase did not result from the intrinsic structural radiopacity of the materials but rather reflected the additional attenuation caused by the MS positioned within the X-ray beam path. Therefore, MS may cause restorative materials to appear more radiopaque than they actually are. In addition to raw MGTV measurements, aluminum-equivalent radiopacity values were calculated using an aluminum step wedge. This approach provides an important methodological advantage because MGTVs are inherently device- and exposure-dependent. Digital gray values may vary according to exposure parameters, detector type, scanning protocol, image-processing algorithm, bit depth, and software settings. Therefore, raw MGTVs obtained from a digital radiographic system cannot be directly compared across studies or even across different imaging systems without calibration. The use of an aluminum step wedge allows gray values to be converted into a physically interpretable reference scale, expressed as millimeters of aluminum. Because the step wedge and the test specimens were imaged simultaneously under identical exposure and detector conditions, this calibration minimizes the influence of minor variations in exposure, scanning, and image acquisition. Moreover, aluminum-equivalent radiopacity is widely used in dental materials research and provides a more standardized basis for comparing the radiopacity of restorative materials with previous studies and international radiopacity standards.

From a clinical perspective, the observed increase in MGTV following MS application may alter the radiographic appearance of restorative materials. Such alterations have the potential to influence image interpretation, particularly in situations where subtle radiographic density differences are important, such as the assessment of restoration margins or the detection of early secondary caries. However, the present study did not evaluate diagnostic accuracy, and therefore these potential clinical implications should be interpreted with caution.

The originality of the present study lies in evaluating the radiographic superimposition of sunscreens on restorative materials rather than their effects on general radiographic image characteristics alone. To the best of our knowledge, this is the first study to demonstrate and quantify material-dependent changes in both MGTV and aluminum-equivalent radiopacity caused by mineral-containing sunscreen. These findings identify the radiographic superimposition of mineral-containing topical products as a previously unrecognized factor that may alter the apparent radiopacity of restorative materials.

The sunscreens were applied as a standardized 1 mm-thick layer to ensure homogeneous and reproducible application across all specimens. This thickness was selected not to replicate the exact amount used clinically, but to ensure a homogeneous and reproducible application across all specimens and thereby improve intergroup comparability. In dermatological sunscreen efficacy testing, products are generally applied at a dose of 2 mg/cm². However, under real-life conditions, the amount and frequency of sunscreen application, its distribution over the skin, and its drying time vary considerably among individuals [18]. Therefore, although the present experimental model does not fully reproduce clinical conditions, it enabled the relative radiographic effects of MS and NMS to be evaluated under controlled conditions.

This study has several limitations. First, it was conducted *in vitro*; therefore, the findings cannot be directly generalized to clinical conditions. Second, only one MS and one NMS formulation were evaluated. Moreover, although zinc oxide was identified as the principal inorganic UV filter in the tested mineral sunscreen, quantitative information regarding its concentration, particle size, nano/non-nano status, and surface-coating characteristics was not available. The formulation also contained iron oxide pigments, which may represent an additional compositional factor potentially contributing to X-ray attenuation. Therefore, the present findings should be interpreted specifically in the context of the tested formulations and should not be generalized to all mineral-containing or non-mineral sunscreens. Third, only a PSP-based digital imaging system was used. The results may differ when complementary metal-oxide-semiconductor sensors or alternative imaging protocols are used. Fourth, the study evaluated only MG and mm Al equivalence and did not investigate diagnostic accuracy parameters, such as caries detectability, assessment of restoration margins, or observer performance.

Taken together, the absence of a significant difference between the Control and NMS conditions, the consistent increase observed with MS across all three restorative materials, and the corresponding increase in aluminum-equivalent radiopacity indicate that the observed effect was primarily associated with the mineral-containing formulation rather than sunscreen application itself. This pattern, together with previous evidence that inorganic sunscreens can increase radiographic brightness [12], supports the conclusion that mineral-containing topical products within the X-ray beam path may alter the apparent radiopacity of restorative materials.

Future studies should investigate the effects of different cosmetic products on dental radiographic images, particularly MS, foundations, face powders, lipsticks containing metallic pigments, and skin-care products. The effects of these products on the detectability of proximal caries, secondary caries, and restoration defects should also be evaluated using different product thicknesses, sensor systems, and clinical simulation models. Observer-based diagnostic accuracy studies are essential to determine whether the radiographic superimposition of mineral-containing cosmetic products meaningfully affects diagnostic decision-making.

5. Conclusions

Mineral-containing sunscreen significantly increased the mean gray values and aluminum-equivalent radiopacity of all restorative materials evaluated, whereas non-mineral sunscreen produced no significant change compared with the control condition. These findings indicate that the tested mineral-containing sunscreen, when positioned within the X-ray beam path, can alter the apparent radiopacity of restorative materials. Although the present study did not assess diagnostic accuracy, awareness of this potential superimposition effect may help prevent misinterpretation of dental radiographs.

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