

RESEARCH PAPER

Evaluation of the Physical and Mechanical Properties of Dental Nanocomposite Filling After Medical X-Ray Exposure

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ABSTRACT

This study aimed to evaluate the physical and mechanical properties of dental nanocomposite filling (Filtek™ Z350 XT) after medical radiographic techniques (OPG, CBCT, CT-Scan) exposure. 32 Samples of Filtek™ Z350 XT (3M ESPE, USA) dental filling material were prepared by placing the filling syringes in a composite heater and raising their temperature to 50°C. The material was then placed in various shaped Teflon molds according to (ISO 4049) specifications. These samples were cured (polymerized) using light curing with a specialized light source for (40 sec). After sample preparation, their dimensions were measured, and they were placed in small, transparent bags, immersed in artificial saliva, and exposed to X-rays emitted from various medical imaging techniques (OPG, CBCT, and CT-Scan). A series of tests was conducted on the samples. Four samples were designated for each test. The FESEM results confirmed that all prepared samples exposed to the medical imaging techniques exhibited positive results. The samples (OPG, CBCT, CT) and those not exposed to radiation, have a nanostructure and fine particles with an average nanoparticle size ranging from (36.478 - 51.08) nm. The best positive radiation effect was observed in the sample exposed to CT radiation, followed by the sample exposed to OPG radiation. Mechanical testing revealed an increase in hardness values and a decrease in compressive strength values for all prepared samples following radiation exposure, compared to the non-irradiated sample; however, the samples demonstrated good compressive strength based on the obtained values. Chemical corrosion testing indicated low values for all prepared samples—despite an increase relative to the non-irradiated sample following radiation exposure—remaining at low levels (five orders of magnitude below zero) that raise no concern. Tests for true density, apparent porosity, and water absorption confirmed an increase in true density values, alongside a decrease in the percentage of apparent porosity and water absorption, across all samples following radiation exposure compared to the non-irradiated sample. Following an evaluation of the restorative material used in this study (3M™ Filtek™ Z350 XT), the material demonstrated high efficiency, exhibiting excellent physical and mechanical properties after medical radiographic techniques exposure—commonly used in dental clinics—which actually enhanced most of its characteristics. Consequently, the researcher recommends using this material for dental restorations, as patients need not fear any structural or property degradation resulting from exposure to medical radiographic techniques (OPG, CBCT, or CT scans).

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INTRODUCTION

Radiation is a natural and fundamental part of the universe and our daily lives; it is energy that travels through space or material media in the form of electromagnetic waves or high-speed particles [1]. Radiation is generally categorized into two main types based on its ability to alter matter. The first is non-ionizing radiation, which possesses enough low energy to move or vibrate atoms but not enough to strip electrons from them. This type surrounds us constantly and is safe under normal conditions. Examples include radio and television waves, microwaves, visible light, and infrared radiation [2]. The second type is ionizing radiation—a high-energy radiation capable of stripping electrons from the atoms it passes through; it is used with great caution in diagnosis and treatment. Examples include medical X-rays, gamma rays, and alpha and beta particles emitted by radioactive materials [3,4].

Radiation technologies have become indispensable in diagnosing many human diseases [5]. X-ray imaging is utilized in various medical fields to diagnose a range of conditions—dentistry being one of them [7]. Oral health is fundamental to dental integrity and functional efficiency; its paramount importance lies in enabling effective chewing, which facilitates digestion and nutrient absorption. Furthermore, oral health plays a pivotal role in clear speech and effective communication, while also providing an appealing appearance that boosts an individual's self-confidence and daily presence [8].

Dental restoration is a key procedure in dentistry. It aims to reconstruct the natural tooth structure so that the treated or restored teeth mimic the nature and function of the original, unaffected teeth [9]. Dental restorative materials vary widely, encompassing four main categories: metals, polymers, ceramics, and composites. These categories comprise a range of options suitable for various therapeutic procedures [10]. Composite filling materials are among the most prominent and widely used restorative options in modern dentistry, with fillers constituting a significant portion of the composite material by volume or weight. The function of the filler is to reinforce the resin matrix, provide the appropriate level of translucency, and control the material's volumetric shrinkage during polymerization [11,12]. In dentistry, composite resin is primarily composed of an organic polymer matrix, inorganic

filler (filler particles), a coupling agent, reaction initiators and accelerators, and coloring pigments [13]. Intraoral resin composites are subjected to continuous thermal fluctuations from hot and cold foods and mechanical stresses, as well as potential exposure to diagnostic radiation—such as X-rays from OPG, CBCT, or CT scans—in certain medical situations [14,15].

Digital panoramic radiography (OPG) is one of the most common and widely used techniques in dental imaging. It produces a comprehensive, expansive X-ray view of both the upper and lower jaws by rotating the X-ray tube and the image receptor in a semicircle around the front of the head, ultimately generating a single, integrated image of the entire mouth. It also offers the advantage of rapid image display, appearing instantly on digital screens [16,17]. Cone-Beam Computed Tomography (CBCT) is a vital diagnostic tool in the medical field, particularly in orthodontics, dental implantology, and oral surgery. The CBCT scanner rotates around the patient's head to gather diagnostic data; it captures a series of two-dimensional images and processes them into three-dimensional, volumetric data. Image accuracy and contrast are influenced by the scan duration—typically ranging from 5 to 20 seconds—and the number of individual images captured, which can reach approximately 600 [18]. Radiation doses in Cone-Beam Computed Tomography (CBCT) systems vary according to the field of view (FOV) options, with the approximate radiation dose range spanning 5–1073 μSv [19]. Computed Tomography (CT) relies on X-ray technology, wherein a series of X-ray beams are directed around a specific area of the body to generate precise, computer-processed cross-sectional images. This technique surpasses conventional X-rays by providing detailed cross-sections free from image overlap or superimposition; this offers a distinct advantage in correlating imaging findings with the patient's clinical status, enabling the highly efficient diagnosis of suspected conditions [20]. The development of dental restorative materials—particularly aesthetic fillings (resin composites)—stands as one of the most significant achievements in combining functionality with aesthetics. The durability of these fillings within the complex oral environment depends on the stability of their physical and mechanical properties over time [21]. However, these materials do not function

in isolation from external influences; they are constantly exposed to various environmental and radiological conditions, both within and outside the dental clinic. X-rays are among the most common forms of radiation energy in dentistry, with widely varying application techniques that encompass routine diagnostic purposes such as digital radiography, panoramic imaging, and cone-beam computed tomography (CBCT) [22]. Exposing dental fillings to these high-energy photons via various irradiation techniques raises fundamental questions regarding the stability of their polymers and chemical networks. X-rays have the capacity to induce ionization or alter the material's molecular bonds, thereby impacting—whether adversely or beneficially—its physical and mechanical properties, such as surface hardness, compressive strength, and others [23].

The research problem lies in the existing discrepancy within the scientific literature regarding the extent to which modern restorative filling materials are affected by radiation doses resulting from various X-ray techniques. Consequently, this research aims to examine and evaluate the behavior of these dental fillings when exposed to X-rays using different techniques, thereby addressing the knowledge gap in this area and providing recommendations to ensure the selection of the safest and most durable materials for patients undergoing radiological examinations.

The composition of the nanocomposite resin material Filtek™ Z350XT (manufactured by 3M/ESPE) consists of an organic phase—comprising UDMA, Bis-GMA, Bis-EMA, and TEGDMA—and an inorganic matrix—comprising silica (20 nm; non-agglomerated/agglomerated), zirconia (4–11 nm; non-agglomerated/agglomerated), and clusters (agglomerated zirconia/silica particles, where 20 nm silica particles are integrated with 4–11 nm zirconia). The abbreviations stand for: Bis-GMA (Bisphenol A-glycidyl methacrylate), UDMA (Urethane dimethacrylate), TEGDMA (Triethylene glycol dimethacrylate), and Bis-EMA (Bisphenol A-ethoxylate dimethacrylate) [24,25].

This restorative material features a true nanocomposite structure that ensures wear resistance and long-lasting luster. It offers a wide color range—available in 36 shades across four levels of translucency (Dentin, Body, Enamel, and Translucent)—to achieve highly natural and aesthetic results. Its handling characteristics make it highly sculptable and resistant to slumping. It is

available in syringes and capsules, color-coded by translucency for quick identification in the dental clinic. Its high radiopacity ensures clear visibility on dental X-rays. It is suitable for direct anterior and posterior restorations, indirect restorations (inlays, onlays, and veneers), core build-ups, and cementation [26,27].

MATERIALS AND METHODS

Materials Used in Sample Preparation

In this study composite restoration material was used 3M Filtek™ Z350XT universal restorative (ENAMEL A2) (3M ESPE, USA) and the Fig. 1 shows the filling syringes used.

This filling is multi-purpose, light-activated nanocomposite material and used in both direct and indirect dental restoration procedures. utilizing advanced nanotechnology, it possesses a truly nanocomposite structure that ensures wear resistance and long-lasting shine, in addition to its high x-ray transparency that makes the material is clearly visible in dental x-ray images. The ease of use of this product makes it highly moldable and resistant to sagging.

Samples Preparation

The samples were prepared according to (ISO 4049) specifications, using dental filling material (3M Filtek™ Z350XT), this material is a paste-like resin packaged in syringes, as shown in Fig. 1. These syringes are placed in a composite heater, the composite heater used is from (3M, USA), designed to raise the temperature of composite resin fillings. It has openings specifically designed for inserting composite syringes or capsules, along with a digital display that allows accurate temperature control. The material syringes are heated to 50°C to reduce viscosity and make the material more flexible and flowable. This facilitates its conformation within the mold and reduces the possibility of voids [28]. A quantity of this resin was injected into a Teflon mold with dimensions of 3 mm in thickness and 2 mm in diameter (according to ISO 4049 specifications) [29], at a temperature of 37°C and under yellow illumination to prevent curing. The bottom layer was pressed into the mold against a glass slab covered with celluloid tape. Once the top layer was in place, its surface was covered with celluloid tape and then with a glass slab to provide a flat, smooth surface and to remove excess material. Transparent.

A (3M™, Elipar Deep Cure-L LED, USA) curing

light was used to cure (polymerize) these samples. This process is essential to ensure the polymerization of the filling and to guarantee its strength, durability, and longevity. The samples were exposed to this light for 40 seconds. The dimensions of the samples were then measured, and they were placed in small, transparent bags and labeled. After preparation, a quantity of artificial saliva was added to cover the sample, ensuring an environment close to that of the mouth. The sample was then exposed to radiation emitted from specialized medical radiography techniques used in dental clinics. Three types of dental radiography techniques were used: OPG, CBCT, and CT-Scan. The type of radiation used in all these techniques is X-rays, but the radiation doses used in each technique vary from one technique to another depending on the function that these techniques perform.

After exposing the samples to the radiation used in these three techniques, the samples are removed from the bags, dried of saliva, and stored for 24 hours after being immersed in distilled water to prevent drying and to simulate the oral environment. After that, they are dried,

placed in other bags, and labeled to be ready for examination. (4) samples were selected to be tested for each radiographic technique. The first sample A represents the prepared dental filling that was immersed in saliva for the same duration as its counterparts but was not exposed to radiation. This sample was then compared with the other samples that were exposed to radiation. The second sample B represents the prepared dental filling that was immersed in saliva and exposed to Orthopantomogram (OPG) radiation. The third sample C represents the prepared dental filling that was immersed in saliva and exposed to cone beam computed tomography (CBCT) radiation. The fourth sample D represents the prepared dental filling that was immersed in saliva and exposed to computed tomography (CT-Scan) radiation. Table 1 shows the codes of the samples prepared in the current study.

Techniques used in exposing samples to radiation *Orthopantomogram Technology (OPG)*

The OPG device (OP 3D, KaVo dental, Biberach, Germany) was used. After operating the device and adjusting the settings with the same settings



Fig. 1. Dental filling (syringes) of 3M Filtek™ Z350XT universal restorative.

Table 1. Sample codes prepared in this study.

Sample Name	Sample Description
A	Dental filling prepared without exposure to any technique (Control sample)
B	Dental filling prepared and exposed to the technique OPG
C	Dental filling prepared and exposed to the technique CBCT
D	Dental filling prepared and exposed to the technique CT-Scan

as the patient's radiographic imaging to capture an OPG image to provide the same conditions, the sample was placed inside small transparent plastic bags and immersed with artificial saliva. The bags were placed in the device's designated area, and the sample was exposed to the X-rays emitted by this technique with an energy of 66 kV, a radiation dose of 62 mGy cm², a current of 7.1 mA, and an exposure time of 9.0 sec.

Cone beam computed tomography technology (CBCT)

The CBCT device (OP 3D, KaVo dental, Biberach, Germany) was used. After operating the device and adjusting the settings with the same radiographic imaging settings to capture a CBCT image of the patient to provide the same conditions, the sample was placed inside transparent plastic bags and immersed in artificial saliva. The bags were placed in the device's designated location, and the sample was exposed to the X-rays emitted by this technology, with an energy of 95 KV, a radiation dose of 662 mGy cm², a current of (8.0 mA), and an exposure time of 3.6 sec.

Computed tomography technology (CT- scan)

A 128-slice CT-Scan device (PHILIPS, Netherlands) was used. After operating the device and adjusting the settings with the same radiographic settings for taking a CT-Scan image of the patient's head to provide the same conditions, the sample was placed inside transparent plastic bags and immersed with artificial saliva. The bags were placed in the device's designated location, and the sample was exposed to the X-rays emitted by this technique, which had an energy of 120 KV, a radiation dose of 1552.5 mGy cm², a current of 120 mA, and an exposure time of 12.3 sec.

Field Emission Scanning Electron Microscopy (FESEM)testing

The FESEM test was performed, and the device used was a MODEL INSPECT F50 from THERMO FISHER SCIENTIFIC.

Hardness Test

A Shore D hardness tester (Check-line DD-100), of U.S. origin, was used.

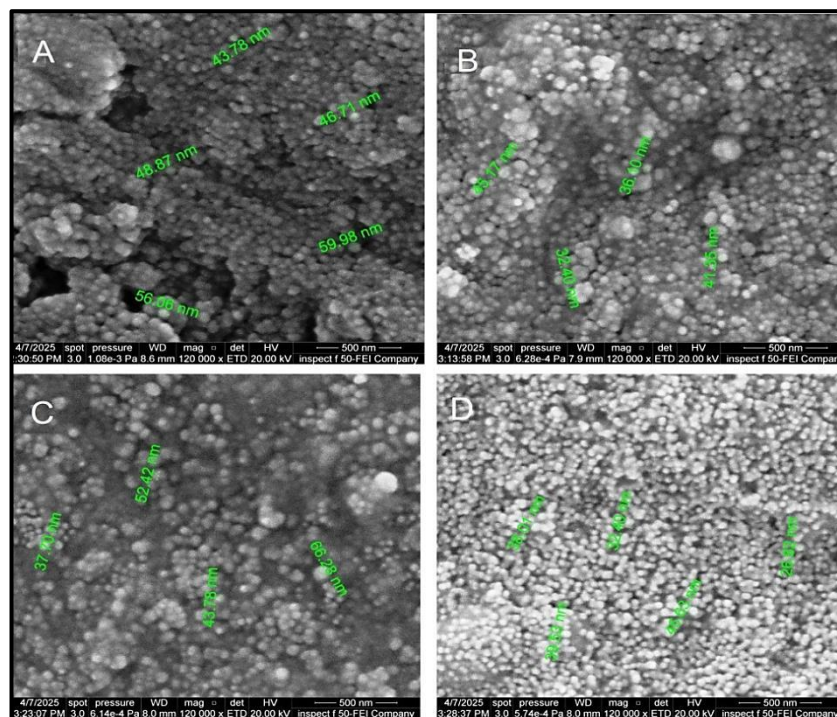


Fig. 2. FESEM images of samples (A, B, C and D).

Compressive strength

A Chinese-made LARYEE device was used for the compressive strength test.

RESULT AND DISCUSSION

Field Emission Scanning Electron Microscopy (FESEM)

Through this technique, the surface shapes of the granular particles comprising the prepared samples were studied. Fig. 2 shows the FESEM analysis of the samples A, B, C, D with measurements of 500nm. Sample A (Control sample) shows a nanostructure with fine grains ranging in size 43.78 - 59.98 nm, with an average nano- grain size of 51.08 nm. This nanoscale size increases the total surface area, which can positively influence chemical properties such as

adhesion and interaction with the oral medium.

Sample B shows the FESEM analysis of sample B exposed to OPG radiation, at 500 nm. It shows the particles with very small and close sizes, with high compactness indicating a relatively regular distribution and fine grains with grain sizes ranging from 32.40 - 45.17 nm and an average nano-grain size of 38.755 nm, which is smaller than the particle size in sample A and more homogeneous. This indicates that exposure to the X-rays emitted from the OPG caused partial recrystallization or stimulation of particle condensation and structural rearrangement or slight dissociation of the material, which reduced the particle size as a result of the energy absorbed from the OPG radiation [30,31].

Sample C shows the FESEM analysis of sample

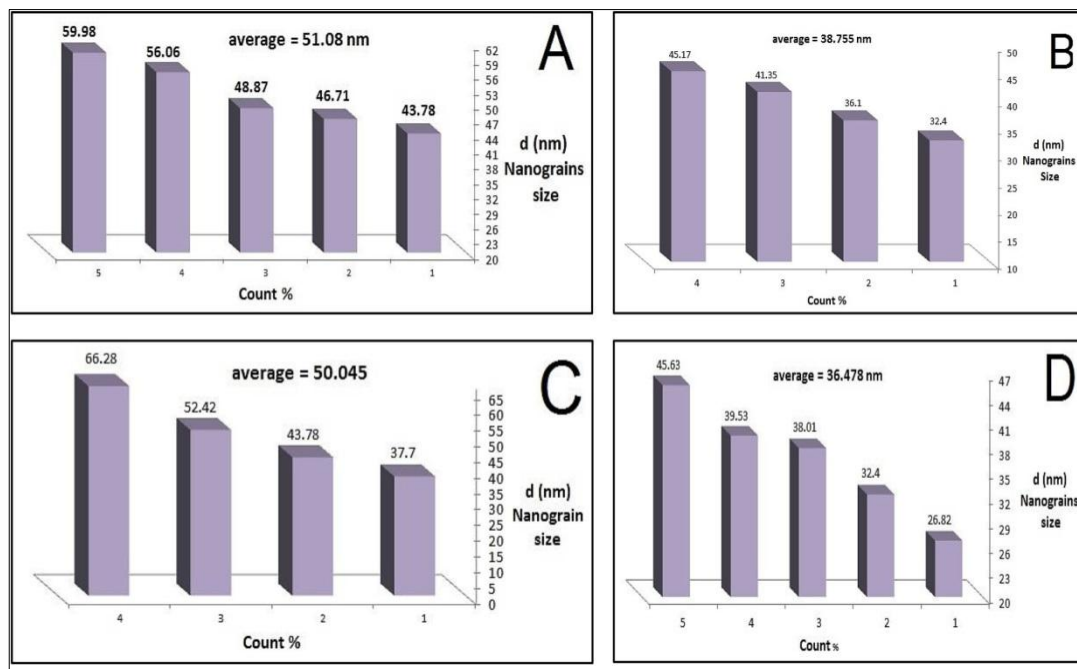


Fig. 3. Nanoscale particle size distribution of the samples (A, B, C and D).

Table 2. Shore D hardness values for the prepared samples.

Sample Name	Average Hardness
A	80.50
B	81.75
C	85.50
D	84.75

C exposed to CBCT radiation at 500 nm. It shows a nanostructure with particle sizes ranging approximately from 37.70 to 66.28 nm and an average grain size of 50.045 nm. The particles exhibit an irregular distribution, appearing coarser compared to control sample A, with some clearly visible clumping. This may indicate changes in surface structure and a significant increase in the size of some particles due to CBCT radiation exposure. CBCT radiation uses a higher radiation dose, a broader energy spectrum, and a longer exposure time than OPG, which increases the effect on the particles (due to the stimulated electromagnetic energy). This caused slight electronic and thermal excitation that affected the filler structure, leading to an increased rate of atomic rearrangement on the surface and the potential for nanoparticle growth or adhesion. This may explain the presence of larger particles. Compared to the control sample A [32,33].

Sample D shows the FESEM analysis of sample

D exposed to CT radiation at 500 nm. It reveals a relatively homogeneous nanostructure with nearly spherical and closely spaced particles, indicating good distribution without significant agglomeration. The particle sizes range from 26.82 to 45.63 nm, with an average particle size of 36.478 nm, which is smaller than the other samples. Since smaller particle size implies a larger surface area, the mechanical properties or tooth adhesion may be improved. CT radiation exposure appears to have smoothed the surface structure and reduced particle size, resulting in a more homogeneous sample compared to the OPG and CBCT samples B and C. This may be due to changes in the chemical composition or the rearrangement of bonds within the material under the influence of radiation. This sample can be considered the best in terms of nanostructure, which may positively impact its clinical performance [34,35]. Fig. 3 shows the nano-scale particle size distribution of the samples A, B, C and D.

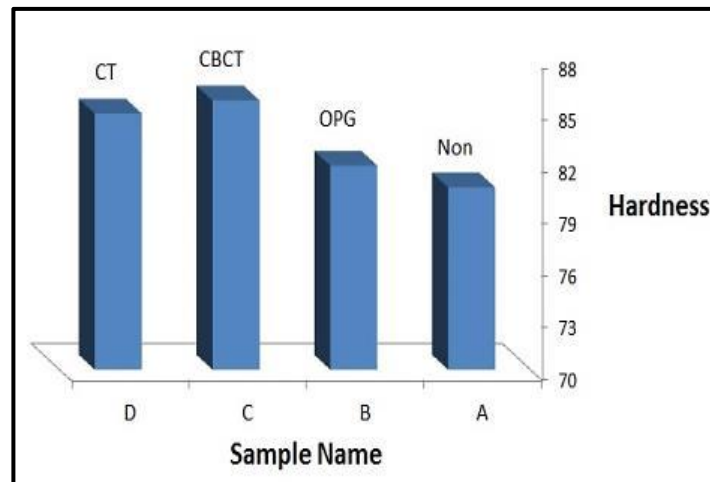


Fig. 4. Plot of hardness values for all the prepared samples.

Table 3. Compressive strength, Young's modulus, maximum stress and strain values for all prepared samples.

Sample	Time sec	Load	Stress(F) N	Strain Fpc	Young's modulus (N/mm ²) (Stress/Strain)	= F/A (Pa)δ or (N/m ²)
A	4.253	2.45	154.088	2.464	62.53	9.691
B	11.641	1.76	107.233	2.322	46.18	6.744
C	11.522	1.29	81.132	1.990	40.76	5.102
D	8.148	1.42	89.308	2.022	44.16	5.616

Mechanical Properties

Hardness

Four standardized samples of the restorative material were prepared for this test, featuring precise circular dimensions 4mm in diameter and 2mm in thickness. Shore D hardness testing was performed on the prepared dental filling samples A, B, C, and D following exposure to various types of radiation (OPG, CBCT, and CT) and compared against a non-irradiated control sample A. Four readings were taken at different locations on the surface of each sample, and the mean value of

these readings was calculated; Table 2 presents the hardness values for the prepared samples. Exposure of samples B, C, and D to radiation from OPG, CBCT, and CT techniques, respectively, resulted in a notable increase in hardness compared to the non-irradiated control sample A. Upon exposure to radiation, the photo-initiators within the resin begin to absorb energy and generate free radicals. These radicals induce the carbon double bonds in the monomers to form single bonds, linking the small molecules together to form long polymer chains. As irradiation

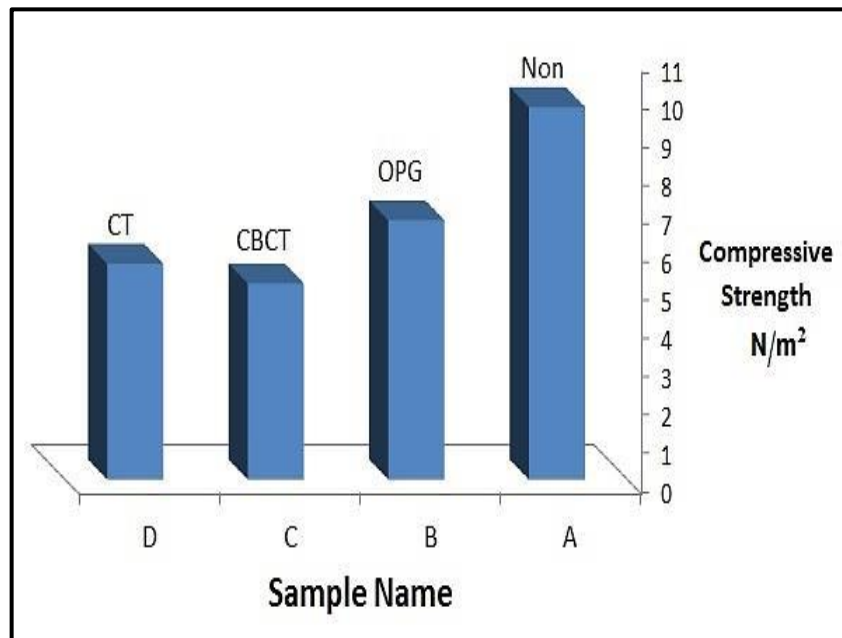


Fig. 5. Plot of compressive strength values for all the prepared samples.

Table 4. Basic values derived from the chemical corrosion test.

Sample name	Potential (V)	Current (Amp/cm ²)	Q(Colum/cm)	Corr. Rate(mm/a)
A	-0.09	-2.7812x10 ⁻⁹	-0.02.888x10 ⁻⁴	0.94 x10 ⁻⁵
B	-0.19306	-11.838x10 ⁻⁹	-0.3038x10 ⁻⁴	6.7x10 ⁻⁵
C	-0.17353	-8.5618x10 ⁻⁹	-5.0877x10 ⁻⁴	115.14X10 ⁻⁵
D	-0.17566	-18.156x10 ⁻⁹	-1.3267x10 ⁻⁴	31.122X10 ⁻⁵

increases up to a certain point, the proportion of monomers that have been converted into polymers increases, making the material more cohesive and rigid. The molecules do not simply form linear chains; radiation exposure also creates cross-links between these chains. These cross-links act as bridges, restricting the movement of the polymer chains. The denser this rigid network is, the greater the material's resistance to penetration or distortion [36,37]. Fig. 4 shows Plot of hardness values for the prepared samples.

Compressive strength

Four uniform samples of the filling material—cylindrical in shape, with a diameter of 4 mm and a height of 9 mm—were prepared for this test. Table 3 shows the values of the compressive strength for the four prepared dental filling samples A, B, C, and

D used in this examination, under the influence of different types of radiation (OPG, CBCT, and CT) which were derived from the data provided by the device after the examination.

Table 3 shows a decrease in compressive strength as the radiation dose increases, compared to the unexposed reference sample. This can be attributed to three factors: initially, radiation increases the density of intermolecular bonds, thereby raising the modulus of elasticity. This renders the material stiffer and more resistant to compression; however, it simultaneously loses ductility and becomes more prone to sudden fracture. This is further supported by the decrease in the load required to cause fracture—as the radiation dose increases—shown in the Table 3 [38].

A second reason is that compressive strength

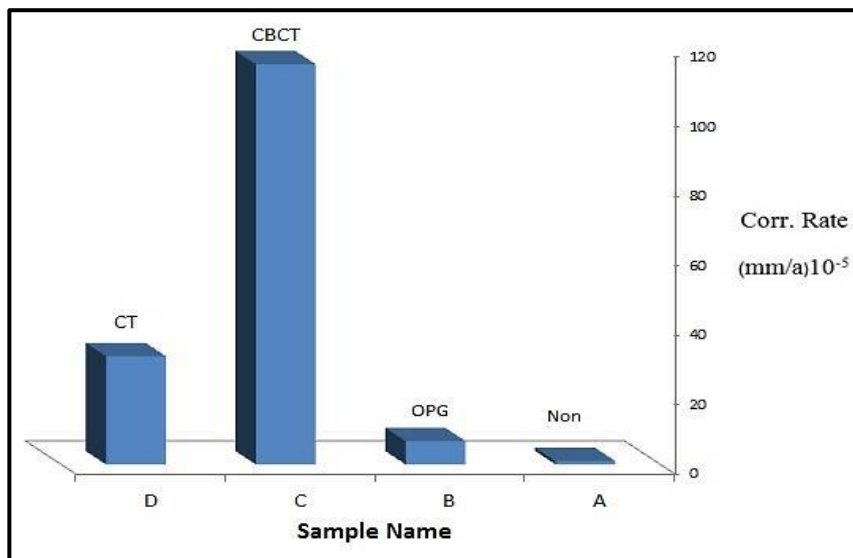


Fig. 6. Plot of corrosion rate values for all the prepared samples.

Table 5. True density values of the prepared samples.

Sample Name	W1 gm	W2 gm	W3 gm	Density (g/cm ³) ($\rho = \frac{W_1}{W_3 - W_2} * D$)
A	0.079	0.018	0.082	1.234
B	0.082	0.040	0.084	1.863
C	0.081	0.030	0.083	1.528
D	0.079	0.023	0.080	1.385

depends primarily on the efficiency of load transfer from the matrix to the fillers. Radiation can specifically target this interface, initiate the breakdown of chemical bonds and causing the onset of microscopic separation between the resin and the solid components; consequently, even if the fillers remain strong, the failure of the bond causes the material to collapse under lower pressure, as the components no longer function as a unified mass. This is further supported by the data in the Table 3, which shows a decrease in the load required to cause failure as the radiation dose increases [39].

The third reason is that the presence of the material in a moist environment (saliva) during radiation exposure accelerates the hydrolysis process; as the radiation dose increases, compressive strength decreases significantly [40]. Fig. 5 presents a plot of the compressive strength values for all prepared samples. Despite

the reduction in compressive strength values associated with increased radiation doses, the samples exhibit good compressive strength relative to the values obtained in Table 3, there was no significant deterioration in the values, but rather a decrease within normal limits.

Chemical Corrosion Resistance

Chemical corrosion testing was conducted in accordance with ASTM standards. This test evaluates the sample's resistance to chemical corrosion, reflecting its behavior within the laboratory medium (artificial saliva) in which it was placed. Table 4 presents the key data derived from the chemical corrosion analysis, detailing the results for the four prepared dental filling samples A, B, C, and D under exposure to various types of radiation (OPG, CBCT, and CT). Sample A ranks first (performing the best overall), as it exhibits the highest corrosion potential (the least negative

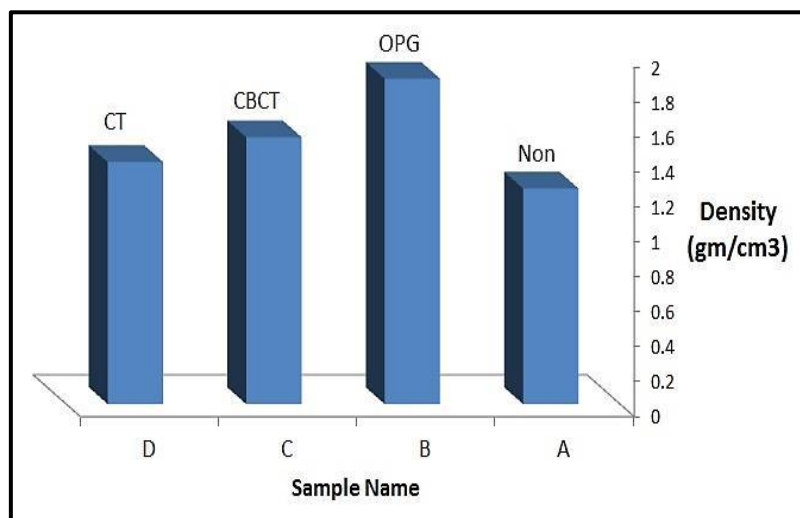


Fig. 7. Plot of true density values for the prepared samples (A, B, C and D).

Table 6. Apparent porosity percentages for the prepared samples (A, B, C, D).

Sample name	W1 gm	W2 gm	W3 gm	(A.P)%
A	0.079	0.018	0.082	4.68 %
B	0.082	0.040	0.084	4.54 %
C	0.081	0.030	0.083	3.77 %
D	0.079	0.023	0.080	1.75 %

value), the lowest corrosion current density, and the lowest charge density and corrosion rate. This indicates that Sample A is the most chemically stable and demonstrates excellent protective behavior compared to the other samples. Sample B ranks second; although it has the most negative corrosion potential, its corrosion current and corrosion rate remained notably low compared to Samples C and D, placing it second in terms of actual corrosion resistance [41].

The general behavior of the sample indicates that OPG radiation affected the surface structure or chemical bonds, thereby increasing surface activity and resulting in a slight rise in chemical corrosion activity compared to Sample A. Sample D ranks third, exhibiting a relatively moderate corrosion

rate and corrosion current—indicating moderate corrosion resistance—which places it in a better state than Sample C but inferior to Samples A and B. The sample rapidly evolved toward a stable state (passivation); the absence of sharp oscillations or significant voltage fluctuations indicates the formation of a stable surface layer that inhibits or reduces corrosion. Although conventional CT involves a relatively high radiation dose, it utilizes a fan-shaped beam that rotates around the sample, capturing images as slices; the scanner requires multiple rotations to cover the area of interest. This explains the superior corrosion resistance of Sample D compared to Sample C, which was exposed to CBCT radiation. Sample C ranks fourth and exhibits the lowest corrosion

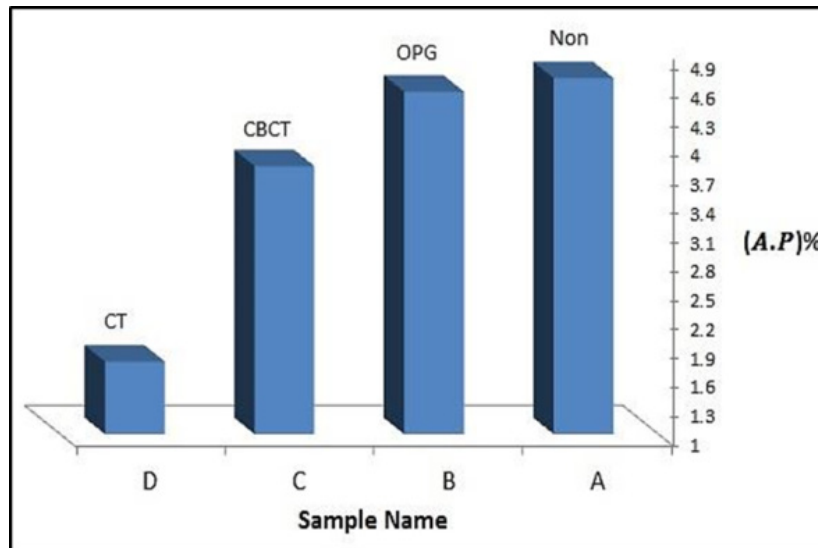


Fig. 8. Chart of apparent porosity percentages for the prepared samples (A, B, C, D).

Table 7. Water absorption percentages for all the prepared samples.

Sample Name	W1 gm	W2 gm	W3 gm	(W. P)%
A	0.079	0.018	0.082	3.7974
B	0.082	0.040	0.084	2.4390
C	0.081	0.030	0.083	2.4691
D	0.079	0.023	0.080	1.2658

resistance, showing the highest corrosion rate compared to the other samples. Although the corrosion potential indicates a moderate tendency for corrosion, the corrosion current density and charge loss density are higher than those of the other samples. The relatively high corrosion rate demonstrates that the material was adversely affected by irradiation; this is attributed to the fact that exposure to CBCT radiation altered the chemical or microstructural composition of the filling such as the breaking of polymer bonds or an increase in surface impurities, thereby relatively impairing the sample's corrosion resistance [42, 43].

This reduction in chemical stability increases the interaction between the filling and the surrounding medium (saliva), thereby increasing corrosion. Although this sample exhibited the highest corrosion rate compared to the others, the value 0.0011514 mm/a remains low and is not a cause for concern, given that the corrosion rate is measured in millimeters per year. Fig. 6 Plot of corrosion rate values for the prepared samples.

True Density

The true density was calculated based on Eq. 1.

$$\rho_t = \frac{W_1}{W_3 - W_2} \times D \quad (1)$$

where: ρ_t = True density g/cm^3 , D = Density of distilled water g/cm^3 , W_1 = weight of the dry sample g, W_2 = weight of the sample when immersed in water g, W_3 = weight of the sample after water saturation g [44].

Four samples of the filling material were systematically prepared with precise circular dimensions: a diameter of 3 mm and a thickness of 2 mm. Table 5 The true density values of the samples. It can be observed from the table that the true density of the samples increases with the radiation dose. This is explained by the fact that the dental filling material consists of composite resins; upon exposure to radiation, the absorbed energy breaks residual double bonds that did not react during the initial light-curing process. This leads to the formation of additional cross-links between polymer chains and a reduction in intermolecular spacing, resulting in a more compact structure and, consequently, an increase in the sample's density [45,46]. Fig. 7 Plot of true density values for the prepared samples A, B, C and D.

However, this explanation applies only up to a certain radiation dosage; if the material is exposed to higher doses—beyond its optimal limits—high-energy photons collide with its long molecular chains, causing covalent bonds to break. Microscopic voids or micro-cracks may form within the material's internal structure, thereby increasing porosity, reducing shrinkage, and

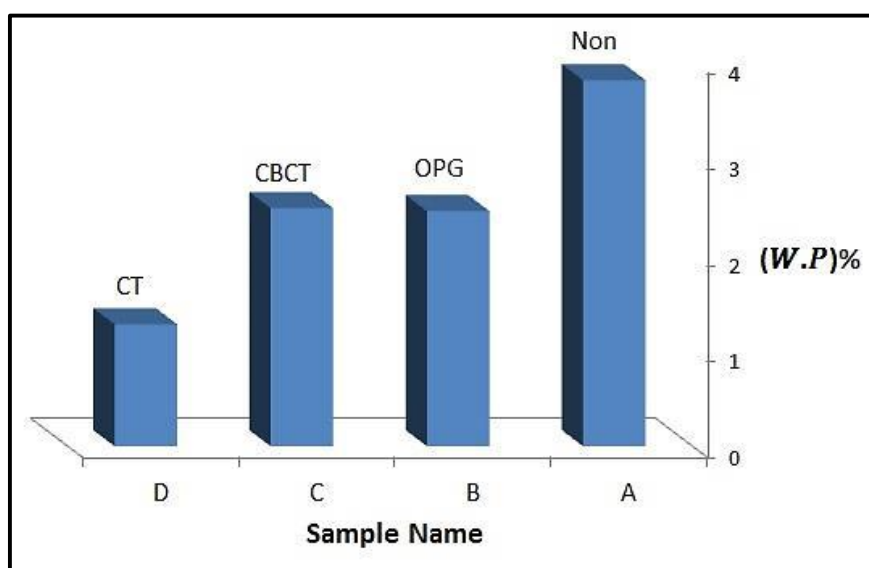


Fig. 9. Plot of water absorption percentages for all the prepared samples.

lowering density. This accounts for the observed decrease in density as radiation exposure increases in CBCT and CT samples compared to OPG samples. Fig. 6 Plot of true density values for the prepared samples A, B, C, D

Apparent Porosity (A.P)

The Apparent Porosity was calculated based on Eq. 2.

$$(A.P) \% = \frac{W_3 - W_1}{W_3 - W_2} \times 100\% \quad (2)$$

where: A.P = Apparent Porosity, W1 = weight of the dry sample g, W2 = weight of the sample when immersed in water g, W3 = weight of the sample after water saturation g [47].

Four samples of the filling material were prepared with precise circular dimensions—3 mm in diameter and 2 mm in thickness. The Table 6 shows that the percentage of pores within the samples decreases as the irradiation dose increases, relative to the reference sample A. This is attributed to the fact that irradiating polymeric materials or composite resins causes the breaking of weak chemical bonds and the formation of active free radicals. These radicals subsequently form new covalent bonds between molecular chains—a process known as cross-linking. This cross-linking causes the chains to draw closer together and reduces interstitial voids (pores), thereby rendering the material's internal structure more compact and denser. Furthermore, increasing the irradiation dose leads to an overall shrinkage in the material's volume—a result of heightened attractive forces between the cross-linked molecules. Since apparent porosity is determined by the ratio of void volume to total volume, the reduction of these voids due to the new bonding forces inevitably leads to a decrease in the porosity percentage. This can also be explained in terms of density and mass: increasing the radiation dose within the material's optimal limits raises its true density. Given the inverse relationship between density and porosity, a decrease in porosity is the natural outcome, a finding that corroborates the results obtained from true density testing. It should be noted that this relationship holds true only up to a certain point (the optimal dose). If the radiation dose exceeds this limit, material degradation may occur, leading to chain scission and the formation of new pores or cracks as a

result of radiation damage [48,49]. Fig. 8 is a plot showing the apparent porosity percentages for the prepared samples A, B, C and D.

Water Absorbance (W.A%)

The Water Absorbance was calculated based on Eq. 3.

$$(W.A) \% = \frac{W_3 - W_1}{W_1} \times 100\% \quad (3)$$

where: W.A = Water Absorbance, W1 = weight of the dry sample g, W2 = weight of the sample when immersed in water g, W3 = weight of the sample after water saturation g [50].

Four samples of the filling material were prepared with precise circular dimensions—3 mm in diameter and 2 mm in thickness. The Table 7 shows that the percentage of water absorption in the samples decreases as the irradiation dose increases, compared to the control sample A. This is attributed to the fact that irradiation acts as a catalyst for the chemical reaction in materials that cure via polymerization such as resin-based fillings; increasing the dose raises the proportion of monomers converted into polymers. Since unreacted monomers are typically hydrophilic, reducing their content necessarily leads to lower water absorption. The table also shows a close similarity in the percentage of water absorption between the OPG and CBCT samples; this may be attributed to the fact that the exposure time for the CBCT sample is significantly shorter than that for the OPG sample, in addition to differences in the beam geometry of the two techniques [51,52]. Fig. 9 is a chart illustrating the water absorption percentages for the prepared samples A, B, C and D.

Recommendation

Based on the evaluation of the restorative material used in this study 3M™ Filtek™ Z350 XT Universal, the results demonstrate its high efficiency and excellent physical and mechanical properties following exposure to medical radiographic techniques—commonly used in dental clinics. In fact, this exposure actually enhanced most of the material's properties, as it did not compromise the material's structural integrity. Consequently, the researcher recommends using this restorative material for dental restorations, assuring patients that there

is no need for concern regarding structural failure or property degradation following exposure to medical radiographic techniques (OPG, CBCT, CT-Scan) exposure.

CONCLUSION

This study demonstrates that exposure of Filtek™ Z350XT nanocomposite resin to diagnostic X-ray modalities produces measurable microstructural and physicochemical changes that depend on irradiation type and dose. FESEM findings showed that OPG and CT exposure generally reduced particle size and improved surface homogeneity, whereas CBCT produced a comparatively coarser and more irregular surface. Mechanically, irradiation increased Shore D hardness, indicating enhanced post-curing and greater cross-link density within the resin matrix. In contrast, compressive strength showed a gradual decrease with increasing radiation dose, suggesting that although the material became stiffer, it also became relatively less tolerant to fracture due to interfacial weakening and reduced ductility. Corrosion analysis confirmed that the non-irradiated control remained the most chemically stable, while irradiated groups still exhibited low corrosion rates overall, with CBCT showing the greatest susceptibility. In addition, true density increased and both apparent porosity and water absorption decreased after irradiation, reflecting a more compact internal structure and reduced hydrophilicity. Collectively, these findings indicate that routine diagnostic radiation does not cause catastrophic degradation of Filtek™ Z350XT, but rather induces a balance of beneficial and adverse effects. Clinically, the material appears to retain acceptable performance after radiographic exposure, although higher-dose techniques may slightly compromise some properties. Further studies are recommended to evaluate long-term aging behavior under repeated clinical irradiation conditions.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this manuscript.

REFERENCES

1. Danyo EK, Ivantsova M, Selezneva I. Ionizing radiation effects on microorganisms and its applications in the food industry. *Foods and Raw Materials*. 2023;12(1):1-12.
2. Nanda K, Kazi MM, Farhana I, Md. Marjanul H, Md R, Mollah

- MZI, et al. Fundamental characteristics and application of radiation. *GSC Advanced Research and Reviews*. 2021;7(1):064-072.
3. Bhatnagar P, Gururani P, Bisht B, Kumar V, Kumar N, Joshi R, et al. Impact of irradiation on physico-chemical and nutritional properties of fruits and vegetables: A mini review. *Heliyon*. 2022;8(10):e10918.
4. Russ E, Davis CM, Slaven JE, Bradfield DT, Selwyn RG, Day RM. Comparison of the Medical Uses and Cellular Effects of High and Low Linear Energy Transfer Radiation. *Toxics*. 2022;10(10):628.
5. Al-Janabi AHS, Ai-Baghdadi MH. Evaluation of biological effects of X-radiography and computed tomography scan on oral microflora. *International Journal of Oral Health Sciences*. 2019;9(1):20.
6. Author index and Subject index. *Clin Tech Small Anim Pract*. 1998;13(4):238-244.
7. Sadeghi S, Saeidi N, Salehi A, Attari K, Irani MAI, Aryanezhad SS, et al. Advances in Radiation Protection in Oral and Dental Radiology: Pragmatic Approaches and Recent Innovations. *Frontiers in Biomedical Technologies*. 2025.
8. Caiafa A, Visser L. *Restorative Dentistry*. Wiggins's Veterinary Dentistry: Wiley; 2018. p. 357-386.
9. Reza Rezaie H, Beigi Rizi H, Rezaei Khamseh MM, Öchsner A. *Dental Restorative Materials*. Advanced Structured Materials: Springer International Publishing; 2020. p. 47-171.
10. Paryani M, Bhojwani PR, Ikhar A, Reche A, Paul P. *Evolution of Biomimetic Approaches for Regenerative and Restorative Dentistry*. Cureus. 2023.
11. ElBatal FH, Marzouk MA, Abdelghany AM. UV-visible and infrared absorption spectra of gamma irradiated V2O5-doped in sodium phosphate, lead phosphate, zinc phosphate glasses: A comparative study. *Journal of Non-Crystalline Solids*. 2011;357(3):1027-1036.
12. Miletic V. *Development of Dental Composites*. Dental Composite Materials for Direct Restorations: Springer International Publishing; 2017. p. 3-9.
13. Schricker SR. Composite resin polymerization and relevant parameters. *Orthodontic Applications of Biomaterials*: Elsevier; 2017. p. 153-170.
14. Suryawanshi A, Behera N. Dental composite resin: a review of major mechanical properties, measurements and its influencing factors. *Materialwiss Werkstofftech*. 2022;53(5):617-635.
15. Süsgün Yıldırım Z, Eyiler E, Bek Kürklü ZG. Effect of thickness on the degree of conversion, monomer elution, depth of cure and cytotoxicity of bulk-fill composites. *J Oral Sci*. 2023;65(2):121-126.
16. Yengopal V, Harnekar SY, Patel N, Siegfried N. Dental fillings for the treatment of caries in the primary dentition. *Cochrane Database of Systematic Reviews*: John Wiley & Sons, Ltd; 2009.
17. Direct and indirect restorative materials. *The Journal of the American Dental Association*. 2003;134(4):463-472.
18. Alshomrani F. Cone-Beam Computed Tomography (CBCT)-Based Diagnosis of Dental Bone Defects. *Diagnostics*. 2024;14(13):1404.
19. Hupe M. StatPearls. *Journal of Electronic Resources in Medical Libraries*. 2024;21(3):147-152.
20. Gonzalez SM. *Introduction to Cone Beam Computed Tomography*. Interpretation Basics of Cone Beam Computed Tomography: Wiley; 2013. p. 1-23.
21. Cassuto D, Bellia G, Schiraldi C. An Overview of Soft Tissue Fillers for Cosmetic Dermatology: From Filling to Regenerative Medicine. *Clin Cosmet Invest Dermatol*. 2021;Volume

- 14:1857-1866.
22. Wiklander L, Cederlund A, Kadesjö N, Näsman P, Tranaeus S, Naimi-Akbar A. Negative health effects of dental X-rays: A systematic review. *PLoS One*. 2025;20(5):e0323808.
23. Ahmed H, Ashour NI, Hani MY, Dheyab MA, Jameel MS. Absorbed Dose and Image Quality of X-Ray Diagnostics in Composite and Amalgam Dental Restorations. *Journal of Medical Physics*. 2025;50(2):407-414.
24. da Rosa GM, da Silva LM, de Menezes M, do Vale HF, Regalado DF, Pontes DG. Effect of whitening dentifrices on the surface roughness of a nanohybrid composite resin. *European Journal of Dentistry*. 2016;10(02):170-175.
25. Botrel BJ, Condi ML, Turssi CP, Gomes-França FM, Vieira-Junior WF, Basting RT. Physical and Mechanical Properties of Bulk-fill Resin Composites Submitted to Additional Polymerization for Use in Semi-direct Restorations. *Oper Dent*. 2025;50(1):44-58.
26. Ibrahim MS, AlKhalefah AS, Alsaghirat AA, Alburayh RA, Alabdullah NA. Comparison between Different Bulk-Fill and Incremental Composite Materials Used for Class II Restorations in Primary and Permanent Teeth: In Vitro Assessments. *Materials*. 2023;16(20):6674.
27. Abuelenain D, Abou Neel E, Al-Dharrah A. Surface characterization and mechanical behavior of bulk fill versus incremental dental composites. *Tanta Dental Journal*. 2017;14(2):56.
28. Elkaffass A, Eltoukhy R, Elnegoly S, Mahmoud S. Influence of preheating on mechanical and surface properties of nanofilled resin composites. *Journal of Clinical and Experimental Dentistry*. 2020:e494-e500.
29. Par M, Gotovac L, Horvat S, Marovic D, Tarle Z, Tauböck TT, et al. Comparing ISO 4049 and Fourier-transform infrared spectroscopy for assessing ambient light sensitivity in dental resin composites. *Sci Rep*. 2025;15(1).
30. Latoui R, Bouzid D, Boyron O. Dental composites: a comprehensive review on formulation, properties and recent developments. *Polym Int*. 2026;75(5):365-386.
31. Rashid SN, Jasim AS, Aadimb KA. Influence of Number of Pulses on Characterization of Nanoparticles of Copper and its Oxides Synthesized by Nd: YAG Laser Ablation Technique and its Antibacterial Activity. *Neuroquantology*. 2022;20(3):150-159.
32. Rashid A, Feinberg L, Fan K. The Application of Cone Beam Computed Tomography (CBCT) on the Diagnosis and Management of Maxillofacial Trauma. *Diagnostics*. 2024;14(4):373.
33. Makhlof O, Khadraoui M, Aissat A, Sahraoui K, Miloua R. Structural, optical and electrical properties of mixed PbS – SnS thin films deposited by spray pyrolysis. *Materials Today Communications*. 2025;46:112923.
34. Al-Hamdan RS, Almutairi B, Kattan HF, Alresayes S, Abduljabbar T, Vohra F. Assessment of Hydroxyapatite Nanospheres Incorporated Dentin Adhesive. A SEM/EDX, Micro-Raman, Microtensile and Micro-Indentation Study. *Coatings*. 2020;10(12):1181.
35. Nagpal D, Singh A, Kumar A, Budhraj V. Comprehensive characterization techniques for nanostructured thin films. *Nanostructured Thin Film Deposition by Sputtering*: Elsevier; 2025. p. 143-168.
36. de Amorim DMG, Veríssimo AH, Ribeiro AKC, de Assunção e Souza RO, de Assunção IV, Caldas MRGR, et al. Effects of ionizing radiation on surface properties of current restorative dental materials. *J Mater Sci Mater Med*. 2021;32(6).
37. Zaharescu T, Mariş M. Irradiation Effects in Polymer Composites for Their Conversion into Hybrids. *Journal of Composites Science*. 2022;6(4):109.
38. Nouh SA, El-Nabarawy HA, Abutalib MM, Bahareth RA. Effect of X-ray irradiation on the structure, thermal and mechanical properties of polyester. *The European Physical Journal Applied Physics*. 2013;62(3):30201.
39. Prabhu S, Bubbly SG, Gudennavar SB. X-Ray and γ-Ray Shielding Efficiency of Polymer Composites: Choice of Fillers, Effect of Loading and Filler Size, Photon Energy and Multifunctionality. *Polymer Reviews*. 2022;63(1):246-288.
40. E Lima RW, De Vasconcelos L, Pontual M, Meireles S, Maciel Andrade A, Duarte R. Effect of ionizing radiation on the properties of restorative materials. *Indian J Dent Res*. 2019;30(3):408.
41. Dannenberg EM. The Effects of Surface Chemical Interactions on the Properties of Filler-Reinforced Rubbers. *Rubber Chem Technol*. 1975;48(3):410-444.
42. Ochoa Suarez KA, Chamba-León D, Bravo Torres WD, Astudillo-Rubio D. Diagnostic accuracy of artificial intelligence models for detecting interproximal caries on bitewing radiographs using ICCMS as reference standard: a systematic review. *INPLASY - International Platform of Registered Systematic Review and Meta-analysis Protocols*; 2026 2026/03/01.
43. Dionysopoulos D, Koliniotou-Koumpia E. Effect of Acidulated Phosphate Fluoride Gel on the Surface of Dental Nanocomposite Restorative Materials. *Journal of Nano Research*. 2018;51:1-12.
44. Xambó Sedó A. Thor Magnusson, *Sonic Writing: Technologies of Material, Symbolic, and Signal Inscriptions*. New York: Bloomsbury Academic, 2019. ISBN: 9781501313851.
45. Moberg M, Brewster J, Nicholson J, Roberts H. Physical property investigation of contemporary glass ionomer and resin-modified glass ionomer restorative materials. *Clin Oral Invest*. 2018;23(3):1295-1308.
46. Landi S, de Carvalho TM, de Souza AD. An Instructive Apparatus for Determining the Density of Liquids Based on Archimedes' Principle. *The Physics Teacher*. 2024;62(2):114-115.
47. Westphal E, Seitz H. Porosity and density measurement of additively manufactured components: A comparative analysis of measurement methods across processes and materials. *Materials Science in Additive Manufacturing*. 2025;4(2):025090010.
48. Luo X, Zhou S, Zhou S, Zhou X, Huang J, Liu Y, et al. Functionalized Modification of Conjugated Porous Polymers for Full Reaction Photosynthesis of H₂O₂. *Adv Funct Mater*. 2024;35(7).
49. Salek MF, Beckingham LE. Effect of X-Ray Computed Tomography Imaging Parameters on Quantification of Petrophysical Properties. *Earth and Space Science*. 2023;10(10).
50. Maslinda AB, Abdul Majid MS, Ridzuan MJM, Afendi M, Gibson AG. Effect of water absorption on the mechanical properties of hybrid interwoven cellulosic-cellulosic fibre reinforced epoxy composites. *Compos Struct*. 2017;167:227-237.
51. Zhou Y, Ma Y, Samad A, Wang Z, Gu Z, Shi J, et al. Effects of irradiation sterilization on the physicochemical and functional properties of commercial biomedical hydrogels. *Biomaterials Science*. 2025;13(22):6270-6284.
52. Li D, Wan Y, Zhang J, Zhang Y, He R, Sang S, et al. Effect of electron beam irradiation on edible quality maintenance of high moisture rice grains. *Journal of Cereal Science*. 2025;121:104104.