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Effect of Photon Radiotherapy on Degree of Conversion and Compressive Strength of Nanohybrid Resin Composite Restoration: An in Vitro Study

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Aim: This study aimed to assess how different photon radiation dosages affected the nanohybrid resin composite's degree of conversion and compressive strength.

Materials and Methods: A total of 30 samples of nanohybrid resin composite (Grandio, VOCO GmbH, Germany), 15 disc shaped and 15 cylindrical shaped, were prepared for testing degree of conversion and compressive strength. The samples were divided into three main groups I-III: control (nonirradiated), 50 Gy, and 70 Gy respectively. The samples were subjected to photon radiotherapy regarding their groups then tested for degree of conversion by FTIR and compressive strength by universal testing machine. After that, a statistical analysis was performed on the data.

Results: The findings indicated that there was no statistically significant variation in the degree of conversion among the groups. However, Group III exhibited the highest statistically significant compressive strength value, while Group I had the lowest.

Conclusion: Within the therapeutic doses, photon radiotherapy did not affect the polymerization of nanohybrid resin composite. It might also improve the resin composite's mechanical properties.

Keywords: Compressive strength, Degree of conversion, FTIR, Nanohybrid Resin composite, Photon Radiotherapy.

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Introduction

Head and neck cancer (HNC) is among the most prevalent cancers. It is ranking as the seventh most prevalent cancer worldwide, with over half a million new cases each year. Radiotherapy is a key treatment for HNC. It utilizes high energy photon beams to damage cancer cell DNA and prevent their growth and division. Depending on the type, stage, and location of the tumor, it is frequently used either as the main treatment or in conjunction with chemotherapy and surgery.[1-3]

Radiotherapy for HNC is usually administered in fractions over several weeks, with total doses ranging from 50 to 70 Gray (Gy). Fractionated doses allow healthy tissues to recover between treatments while maximizing tumor damage. The type of cancer, the size of the tumor, and the patient's general condition all affect the precise dosage and course of treatment. While effective in treating HNC, radiotherapy can cause side effects, including damage to surrounding healthy tissues. These side effects may affect oral and dental health.[1, 4]

Mucositis, xerostomia, dysphagia, and dysgeusia are side effects of HNC radiotherapy that negatively impact the quality of life of a patient. Another serious long-term effect is osteoradionecrosis, which lasts for at least three months, worsens over time, and does not heal spontaneously.[5, 6]

Patients undergoing irradiation often experience damage to their teeth, including the enamel, dentin, and dentin-enamel junction, as well as changes in the dental pulp. Severe cavities, caused by reduced saliva production, bacterial changes, poor oral hygiene and radiation, are common. Radiation also affects the crystalline structure, reduces enamel resistance to acid and alters the hardness and strength of enamel and dentin. Consequently, it is crucial to select the appropriate restorative material accurately, ensuring its properties are not negatively affected by the irradiation.[7, 8]

Besides the harmful effects of radiation on healthy oral tissues, studies have also reported changes in the properties of restorative materials following radiotherapy exposure.[9-11] Resin composites are commonly used in restorative dentistry for their aesthetic qualities and ability to bond with tooth structures.[4] It is usually based on organic matrix of methacrylate and consists of inorganic fillers within a resin matrix, along with initiators and catalysts. Recent advancements in composites have focused on improving the matrix, filler, and initiator systems. Composites are categorized by the type, distribution, and size of the filler particles, which have gradually become smaller over time, evolving from micro-filled and hybrid composites to nano-sized ones, enhancing mechanical and esthetic properties.[12] Nanocomposites, include nano-filled and nanohybrid types. Manufacturers claim that these materials provide enhanced aesthetics, strong mechanical strength, good compatibility with oral tissues, and durable restorations.[12, 13]

A previous study stated that the energy from radiotherapy may break certain chemical bonds in polymerized materials. Simultaneously, this radiation may cause methacrylate monomers to undergo a post-cure reaction, increasing the degree of conversion (DC%) and altering the mechanical characteristics of resin composites.[14]

A different study reported that radiotherapy does not significantly impact the DC% of resin composite restorations. This implies that the resin composite's chemical characteristics are unaffected by radiation.[15]

The impact of radiotherapy on these properties, whether increasing or decreasing them, remains controversial. In this regard, it is essential to understand how radiotherapy affect resin composite properties. Thus, the purpose of this study was to investigate how various radiation dosages affected the DC% and compressive strength (CS) of the nanohybrid resin composite. The null hypothesis of this study was that the DC% and CS of the nanohybrid resin composite were unaffected by photon radiation.

Materials and Methods

An approval number 824 was obtained from the Research Ethics Committee of the Faculty of Dentistry at Minia University. The sample size calculation was carried out using G*Power version 3.1.9.4, with α= 0.05 and power = 80%. The effect sizes (f) were found to be 0.98 and 1.06 regarding to previous studies of Taher et al. (2021)[15] and Eltohamy et al. (2020)[10] for degree of conversion and compressive strength respectively. The total sample size was found to be 30, 15 for each test (n=5 per group).

A total of 30 samples of universal nanohybrid resin composite (Grandio, VOCO GmbH, Germany) were prepared following the manufacturer's instructions. The samples were divided into three main groups (n = 5 per group per test) based on the radiation dose. The study design is showed in table (1).

Table (1): Sample Groups, Sample Size, and Tests performed.

	Group I (Control, non-irradiated)	Group II (Radiation dose= 50 Gy.)	Group III (Radiation dose= 70 Gy.)	Total
Degree of conversion	5	5	5	15
Compressive strength	5	5	5	15
Total	10	10	10	30

Samples preparation

For the degree of conversion, 15 disc shaped samples (n=5) were prepared. In accordance with ADA specification number. 27, 15 cylindrical samples (n=5) measuring 6 mm in height and 3 mm in diameter were made for the compressive strength. Both tests' sample were prepared using a split Teflon molds regarding their shapes. The molds were positioned on a glass slab and filled with resin incrementally. Curing was performed using LED light curing unit (RTA MiniS, Guilin Woodpecker Medical Instrument Co.,China, power 1000mW/cm^2) for 20 seconds, following the manufacturer's instructions. At the final increment, to generate a smooth, flat, void-free surface, a second glass slab was placed on top of the sample, and a 500-gram weight was applied for one minute prior to curing. After removing the weight, curing was performed through the glass slab. After that, the samples then were finished and polished regarding the manufacturer's instructions and placed in distilled water for 24 hours.

Radiation exposure:

Samples from groups II and III were removed from distilled water and dried. Then, they were placed in a 4 mm deep cavity within a block made of pink modeling wax (Tenatex eco toughened dental modelling wax, Associated Dental Products Ltd Kemdent Works, Purton, Swindon Wiltshire, SN5 4HT, United Kingdom), measuring 10×10×6 cm³. Another 1.3 cm thick wax layer was applied over the samples to allow for radiation buildup. Small gaps between the samples were filled with water to remove any air from the area. Radiation was then applied using a digital linear accelerator (Elekta Synergy Platform digital linear accelerator, Elekta, Sweden) with an average energy of 6MV, a source-surface distance (SSD) of 98.5 cm at dmax, and a source-axis distance (SAD) of 100 cm. The field size was 10×10 cm². The samples in Groups II and III received a single shot of 50 Gy and 70 Gy, respectively. During the irradiation procedure, group I samples were kept undisturbed.

Degree of conversion test (DC%):

Each sample was crushed into a fine powder. The resin composite powder was then mixed with potassium bromide (KBr) powder (Uvasol Potassium bromide, Sigma Aldrich, Germany) in a 1:10 ratio. This mixture was formed into a pellet using a pellet-making set. A hydraulic press was used to apply a load of 10 tons to compress the powder, creating a pellet with a thickness of 1 mm. The pellet was then analyzed using a Fourier transform infrared spectrometer (FTIR NICOLET IS 10, Thermpscientific, USA.) in absorbance mode with 16 scans, covering the wave number range from 400 to 4000 cm^{-1}, to obtain the spectra for the samples from all three groups. The ratio of the peak area of the aromatic C=C (1608 cm^{-1}) to the aliphatic C=C (1638 cm^{-1}) was used to determine the percentage of C=C, with the aromatic peak acting as the internal standard. The spectrum of the uncured resin composite was also obtained by mixing the resin composite paste with KBr powder in the same ratio, and the percentage of C=C was calculated. Finally, the degree of conversion for each sample was determined using the following equation:

$$DC\ \% = 1 - \left[\frac{abs(aliphatic\ C=C)/abs(aromatic\ C=C)]cured}{abs(aliphatic\ C=C)/abs(aromatic\ C=C)]uncured}\right] \times 100$$

Compressive strength test (CS):

Each sample from each of the three groups was positioned separately on a universal testing machine's fixture (Instron 3366, USA.). At a crosshead speed of 1 mm/min, a static force was applied to each sample until fracture. After recording the maximum load, the following formula was used to determine the CS:

$$CS = 4P/\pi d^2 \quad (MPa)$$

Where P is the maximum load in Newtons (N) and d is the sample diameter in millimeters (mm).

Statistical analysis:

Data were collected and analyzed using the SPSS software VR. 20.0. The normality was tested and the data were found to be parametric. Mean, standard deviation (SD) and range (minimum "min" and maximum "max") were used to present data. The one way ANOVA (F) was used and for pairwise comparisons, the Post Hoc Tukey test was used. The significance of the results was determined at the $P \leq 0.05$.

Results

Degree of conversion:

The FTIR spectra of the 3 groups were represented in figure 1.

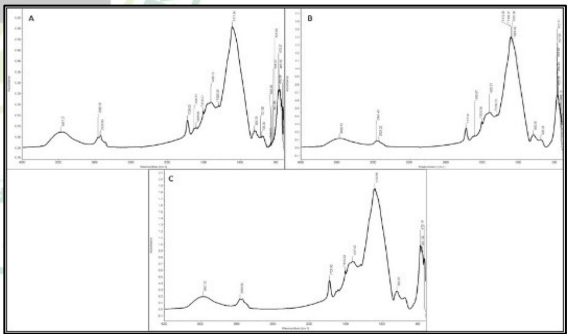

Figure (1): FTIR spectra of different groups (I-III; A, B and C, respectively).

The means of the three groups were statistically non significant where the p value was 0.907. (Table 2, figure 2).

Table (2): Means, SD, min and Max Values, of DC% for the Different Groups.

Groups	Group I (n = 5)	Group II (n = 5)	Group III (n = 5)	F	P values
Mean ± SD.	64.52 ± 6.70	65.67 ± 2.73	65.38 ± 1.46	0.098	0.907ns
Min. – Max.	54.18 – 70.69	62.12 – 69.69	63.64 – 67.53		

Significance level p≤0.05, *significant, ns=nonsignificant.

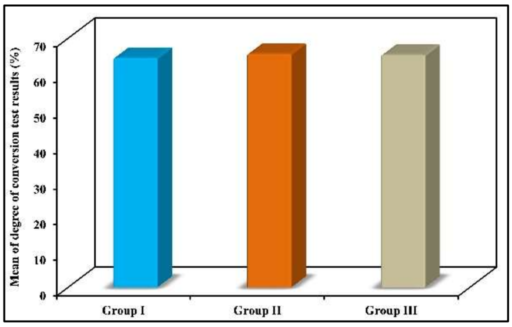

Figure (2): Bar chart illustrates mean DG% of the three groups.

Compressive strength:

The means of groups II and III were statistically significant to group I (control) where the p values were 0.012, 0.003 respectively. However, groups II and III were not significant to each other with p value = 0.708. Group III exhibited the highest CS, while group I had the lowest one. (Table 3, Figure 3)

Table (3): Means, SD, min and max Values of CS for the Different Groups

Groups	Group I (n = 5)	Group II (n = 5)	Group III (n = 5)	F	P
Mean ± SD.	161.6 ± 20.14	218.7 ± 29.68	232.0 ± 27.61	10.257*	0.003*
Min. – Max.	130.7 – 186.3	184.2 – 250.0	191.9 – 268.9		

Significance level p≤0.05, *significant, ns=nonsignificant.

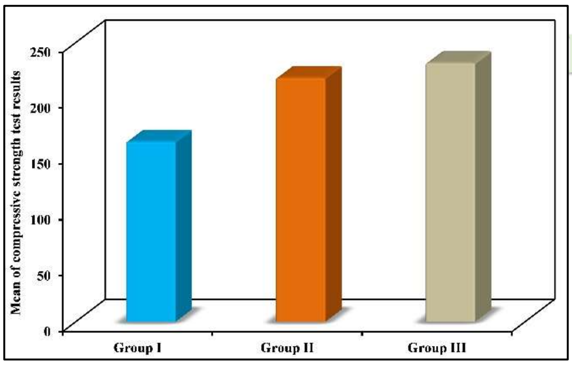

Figure (3): Bar chart illustrate means of CS (MPa) of different groups

Discussion

Head and neck cancer (HNC) has an incidence rate about 13.6%, and it is the seventh most frequent cancer throughout the world. It accounted for 7.6% of all cancer cases. The HNC has a significant effect on global health, causing problems such as difficulty with swallowing, breathing, and speaking, as well as psychosocial challenges for patients.[16, 17]

Radiotherapy is commonly incorporated into primary HNC treatments, improving clinical, structural, and functional outcomes for cancer patients. Nearly 75% of individuals with head and neck squamous cell carcinoma (SCC) benefit from radiotherapy, either as a primary treatment or as an adjunct following surgery. For early stage cancers, radiotherapy can sometimes eliminate the need for surgery. Patients with advanced local cancer may receive chemoradiotherapy or undergo surgery followed by adjuvant radiotherapy. Moreover, radiotherapy is used to preserve organs, such as avoiding laryngectomy through chemoradiotherapy.[1, 18]

Head and neck radiotherapy can cause a range of adverse effects, affecting both oral structures and dental restorations. The severity and development of these complications depend on factors such as the radiation dose, the extent of healthy tissue exposed and the maturity of the affected cells.[19, 20]

Patients undergoing head and neck radiation therapy are generally at a higher risk for dental problems. As a result, selecting appropriate dental restorative materials is critical to prevent adverse interactions between the radiotherapy and the materials' properties. It has been noted that the mechanical properties and clinical longevity of restorative dental materials are significantly affected by photon radiation. For the conventional and resin-modified glass ionomer cements this occurs in an indirect manner by the hyposalivation caused by the damage to the salivary glands by the radiation.[14] As a result, non-metallic and insoluble dental materials are recommended for both pre and post radiation tooth restoration in HNC patients. Composite resins meet these demands and provide superior optical qualities. They also have a modulus of elasticity that is comparable to that of enamel and dentin, which allows for a more even distribution of masticatory forces.[14] Nanohybrid resin composite is claimed to fully meet the functional needs of both anterior and posterior restorations. [12, 13]

This study was therefore conducted to investigate the impact of head and neck photon radiation on the nanohybrid resin composite's degree of conversion (DC%) and compressive strength (CS). Standard radiation therapy is typically administered five days a week in doses of 2 Gray (Gy), for a total dosage of between 50 and 70 Gy. The goal of this treatment regimen is to improve local control while reducing toxicity.[1, 17] For this reason, doses 50 and 70 Gy were selected. The exposure was in a single shot due to absence of living tissues so, there was no need for recovery time between fractions.

A previous study of Campos L. et al. (2015) stated that ionizing radiation is a powerful technique for changing the characteristics of polymeric materials. This radiation's high energy generates a variety of excited molecules and ions along its path, which can initiate processes like degradation, grafting, polymerization, and crosslinking.[21]

The DC% has a vital role in influencing the properties of composite restorations. A high DC% is required to ensure a number of physical characteristics, including strength, dimensional stability, solubility, water absorption, color stability, hardness, and modulus of elasticity.[22-24]

Fourier Transform Infrared (FTIR) spectroscopy and Raman spectroscopy are popular used approaches for accurately evaluating the DC% using spectroscopic techniques.[22] FTIR is the most frequently used method to assess the conversion of monomers in resin materials, because it can directly identify C=C stretching vibrations both before and after the materials are cured.[25, 26]

The most commonly used method for FTIR sample preparation involves using KBr as the matrix material. Although other materials like sodium chloride, magnesium fluoride, and zinc selenide can also be used. KBr is preferred because it is transparent in the mid-infrared region. In addition, it has low absorption in the region where most samples absorb, making it ideal for FTIR analysis. Its widespread use is also due to its low cost, easy availability, chemical stability, and lack of reactivity with most samples, making it a safe and convenient choice for this purpose.[27]

According to this study's findings, there was no statistically significant variation in the DC% of resin composite before and after irradiation. This result aligns with the study of Brandeburski SBN et al. (2018), who observed similar FTIR spectra before and after 70.2 Gy irradiation, with the resin composite's main spectral bands remaining unchanged.[28]

Taher RM et al. (2021) also reported findings consistent with this study, noting that the DC% of different resin composites were not statistically affected by 60 Gy radiation exposure. They explained that photon radiation penetrates the organic resin matrix of composites, causing excitation and ionization that generate reactive species. But because of the restricted molecular mobility in the network of polymerized resin, these species mainly form new bonds with nearby groups, affecting other mechanical properties but not increasing the DC%.[15]

Turjanski S et al. (2023) reported similar results, attributing the effects of radiotherapy on DC% to both destructive processes and constructive processes. The destructive process is like chain scission. The constructive process might be such as increased crosslinking. The variations in effects are likely due to differences in the degree of these opposing processes. These variations make it difficult to predict the dominant effect as both processes are expressed at the same time.[29]

In contrast, Campos L. et al. (2015) disagreed with this study findings, showing that ionizing radiation caused a post-cure response and modifications in irradiated resin composites that had previously undergone photopolymerization at doses between 0.25 and 2 kGy.[21] This discrepancy may be partly due to differences in resin composite formulations and the higher radiation doses used.

Compressive strength is considered the primary factor for ensuring success in the use of restorative materials in dental procedures. A compression test is conducted to assess a material's resistance to crushing and its ability to withstand compressive forces under different loads. Since chewing primarily involves compressive forces, it is essential to examine materials in these conditions.[17, 30]
For optimal results, the cylinder sample of CS should have a length that is twice its diameter. If the sample is too short, the force distribution becomes more complex. Conversely, if the sample is too long, it may experience bending rather than compression.[31]

The study's CS results revealed that the irradiated group was significantly higher than the control group. This finding comes in agreement with Sivavong P. et al. (2024), who observed an improvement in the compressive strength of resin composite after irradiation. They clarified that photon radiation might have gone through the resin matrix since it was absorbed by both radiosensitive chemical groups and inorganic filler particles. This process causes the matrix to be excited and ionized, generating reactive species that result in increased crosslinking of the polymer chains. Over time, these radicals also contribute to the conversion of double bonds, enhancing the DC% and improving CS.[32]

Although in the present study the compressive strength increased after irradiation, the DC% did not show significant change. This can be explained by the findings of Taher RM et al. (2021). Photon radiation interacts with the composite's organic resin, causing excitation and ionization that produce reactive species. Due to the restricted molecular mobility in the hardened resin, these reactive species primarily form new bonds with nearby groups, potentially improving mechanical properties without increasing the DC%.[15]

Regarding to this study's finding, the null hypothesis was accepted for the DC%. However, it was rejected for the CS since the differences between the groups were statistically significant.

Conclusion

Photon radiation, within the therapeutic doses, has no effect on the polymerization of nanohybrid resin composites, revealing that radiation exposure may not have an impact on the material's curing efficiency. It, however, enhances the compressive strength of the resin composite through the formation of new bonds with nearby groups or other structural changes within the material.

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Data availability

All data generated or analyzed during this study are included in this published article.

Ethics approval and consent to participate

An ethical approval number 824 was obtained from the Research Ethics Committee of the Faculty of Dentistry at Minia University.

Competing interests

The authors declare no competing interests

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