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Effect of radiation therapy on the dislocation resistance for different root canal sealers to root dentine: An *in vitro* study

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Abstract:
Radiotherapy may alter dentinal structure and compromise the bonding performance of root canal sealers. Therefore, it is of interest to evaluate the effect of 60 Gy irradiation on the dislocation resistance of resin-based, calcium silicate–based and bioactive glass–based sealers using push-out bond strength testing. In non-irradiated teeth, resin-based sealer exhibited the highest dislocation resistance, followed by calcium silicate–based and bioactive glass–based sealers. Irradiation significantly reduced dislocation resistance for all sealers, while calcium silicate–based sealer showed significantly higher bond strength than the other sealers in irradiated dentine ($p < 0.05$). Thus, data shows that calcium silicate–based sealer may offer a bonding advantage in irradiated dentine.

Keywords: Bioactive glass, bioceramic sealer, calcium-silicate, dislocation resistance, radiotherapy, root canal sealers, root dentine, resin-based sealer

Background:
Head and neck cancers (HNC) represent a substantial global health burden and are among the most prevalent malignancies worldwide, with approximately half a million new cases diagnosed annually **[1]**. Their management typically involves surgery, chemotherapy and radiotherapy, either alone or in combination **[2]**. Radiotherapy remains a cornerstone of treatment due to its targeted action on malignant cells through ionizing radiation; however, this therapeutic benefit is frequently accompanied by significant oral and dental adverse effects **[3]**. Patients undergoing head and neck radiotherapy are particularly prone to developing oral complications such as xerostomia, taste alterations, mucositis, periodontal breakdown, trismus, microvascular changes, soft tissue necrosis, osteoradionecrosis and an increased risk of dental caries **[4]**. Among these, radiation-related dental caries is one of the most significant complications, with a multifactorial pathogenesis involving salivary hypofunction, ecological shifts in oral microbiota, impaired oral hygiene and cariogenic dietary patterns **[5]**. Additionally, radiation induces direct structural and chemical alterations in dental hard tissues, including changes in enamel and dentin microstructure, reduced microhardness, disruption of the dentinoenamel junction and increased enamel solubility. These effects collectively accelerate tooth structure loss and may predispose to early pulpal involvement, often necessitating endodontic treatment **[6]**. The outcome of endodontic therapy depends on effective microbial elimination and the establishment of a durable hermetic seal that prevents reinfection **[7]**. Although gutta-percha remains the most widely used core material, its inability to bond to dentin necessitates the use of endodontic sealers to improve adaptation and adhesion between the obturation material and root dentin. A wide variety of endodontic sealers have been introduced, including resin-based, calcium silicate–based bioceramic and more recently, bioactive glass–based sealers. Epoxy resin–based sealers are widely used due to their favorable mechanical properties, dentinal tubule penetration, dimensional stability and strong adhesion to dentin. However, concerns remain regarding polymerization stress and potential monomer release affecting long-term stability. Calcium silicate–based bioceramic sealers exhibit bioactivity by forming hydroxyapatite at the sealer–dentin interface, resulting in chemical bonding, enhanced biocompatibility and improved interfacial stability **[8]**. Therefore, it is of interest to assess the influence of radiotherapy on the dislocation resistance of a resin-based sealer, a calcium silicate–based bioceramic sealer and a recently introduced bioactive glass–based sealer to root dentin.

Methodology:
60 freshly extracted mandibular premolar teeth with fully formed apices, single canals and straight roots were selected. Teeth with cracks, caries, restorations, resorption, or previous endodontic treatment were excluded. Soft tissue remnants were cleaned from the teeth and subsequently kept in distilled water until use. Teeth were sectioned at the cementoenamel junction with a diamond disc under water cooling to obtain a standardized root length of 14 mm. All canals were instrumented sequentially with the ProTaper Gold rotary system up to size F3, with 3% sodium hypochlorite used as the irrigant throughout the procedure. Following completion of canal preparation, a final irrigation protocol was carried out using 17% EDTA to eliminate the smear layer, followed by final rinse with 3 ml normal saline.

Grouping of samples:
The prepared samples were randomly allocated into two main groups according to radiation exposure:
Group 1: Non-irradiated group
Group 2: Irradiated group
Each primary group was further subdivided into three subgroups based on the type of root canal sealer used:

Control group: Non irradiated (n=30):
[1] Group 1A(n=10) - Resin-based sealer

[2] Group 1B(n=10) - Calcium silicate-based bioceramic sealer
[3] Group 1C(n=10) - Bioactive glass-based bioceramic sealer

Experimental group: Irradiated (n=30):
[1] Group 2A(n=10)- Resin-based sealer
[2] Group 2B(n=10)- Calcium silicate-based bioceramic sealer
[3] Group 2C(n=10)- Bioactive glass-based bioceramic sealer

Samples in the irradiated group were exposed to a cumulative radiation dose of 60 Gy using a medical linear accelerator. The radiation was delivered in fractions of 2 Gy per day, five days per week, with a latency period of two days over a period of six weeks, simulating a conventional head and neck radiotherapy regimen. During radiation exposure, the access cavities were sealed with a temporary restorative material and the specimens were mounted in modeling wax and stored in distilled water to prevent dehydration. Following radiation exposure, obturation was performed in all samples using the warm vertical compaction technique with gutta-percha in combination with the assigned sealer for each subgroup. The sealers were mixed and applied in accordance with the manufacturers' guidelines. Following obturation, the access cavities were sealed and the specimens were incubated at 37 °C with 100% humidity for 48 hours to ensure complete setting of the sealers. After setting, roots were sectioned in transverse direction, 5 mm from the apex to obtain a 2mm thick dentine section using a low-speed, water-cooled diamond disc fixed to a straight handpiece. The 2 mm sections were embedded in acrylic resin and dislocation resistance was evaluated using a universal testing machine. A compressive force was applied in an apico-coronal direction, with the plunger tip positioned at the sealer–dentin interface, at a crosshead speed of 1 mm/min. The readings for dislocation resistance were tabulated by the sudden drop of resistance on graph. The maximum force required to dislodge the filling material was recorded and expressed in megapascals (MPa).

Statistical analysis:
The collected data were tabulated and statistically analyzed using the Statistical Package for Social Sciences (SPSS) version 22. Mean and standard deviation were calculated for each group. One-way ANOVA was applied to compare dislocation resistance among the groups, followed by Tukey's post hoc test for pairwise comparisons, with the level of significance set at $P < 0.05$.

Results:
The mean bond strength (*i.e.* dislocation resistance) of all three sealers, Group A (AH plus), Group B (Ceraseal) and Group C (GuttaFlow Bioseal), was higher in non-irradiated teeth than irradiated teeth. In non-irradiated teeth, AH Plus exhibited the highest bond strength (482.33 ± 50.92 MPa), followed by Ceraseal (369.96 ± 46.36 MPa), while GuttaFlow Bioseal showed the lowest values (75.06 ± 17.57 MPa). Intergroup comparison using Tukey's post-hoc test revealed statistically significant differences among all three sealers ($P < 0.001$). In irradiated teeth, the highest mean bond strength was observed with Ceraseal (270.47 ± 44.78 MPa), followed by AH Plus (136.30 ± 13.39 MPa), while GuttaFlow Bioseal again demonstrated the lowest bond strength (42.88 ± 7.45 MPa) **(Table 1 and Figure 1).** Tukey's test showed statistically significant differences among all sealers ($P < 0.001$).

Table 1: For each subgroups, comparison of difference in mean bond strength (MPa) between two groups by Tukey test

Subgroup/	Group (teeth)		Mean difference	P-value
Sealer	Non radiated (n=10)	Irradiated (n=10)		
AH plus	482.33 ± 50.92	136.30 ± 13.39	346.03	< 0.001
Ceraseal	369.96 ± 46.36	270.47 ± 44.78	99.49	< 0.001
GuttaFlow Bioseal	75.06 ± 17.57	42.88 ± 7.45	32.18	0.321

P < 0.001- as compared to AH plus. The bond strength of two groups and three subgroups were summarised in Mean ± SD and compared by Tukey test.

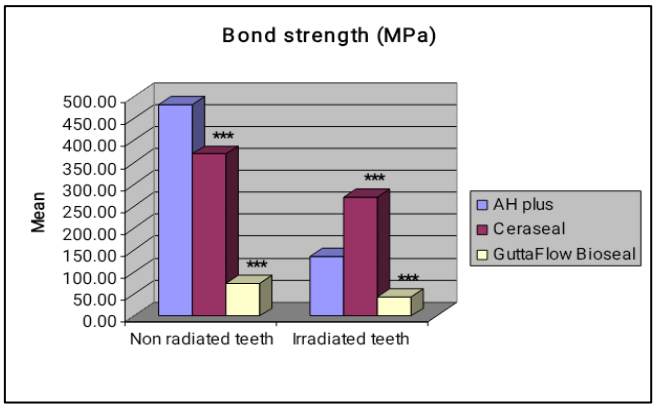


Figure 1: For each group, comparisons of difference in mean bond strength among three subgroups

Discussion:

Radiation therapy constitutes a cornerstone in the management of head and neck malignancies and achieves tumor control through ionizing energy–mediated DNA disruption and reactive oxygen species generation **[9, 10]**. Radiotherapy for head and neck malignancies may cause several oral complications, including xerostomia, mucositis, candidiasis, trismus, osteoradionecrosis and radiation caries, particularly when the oral cavity and salivary glands are exposed to radiation **[11, 12]**. Among these complications, radiation caries and structural alterations of dental tissues are important long-term concerns in patients undergoing head and neck radiotherapy **[12, 13]**. Radiation can alter the chemical composition and mechanical properties of dental tissues, including the protein-to-mineral ratio and structural characteristics of dentin. These radiation-associated alterations may affect dentin's mechanical behavior and its interaction with restorative and endodontic materials, although the specific mechanisms influencing adhesion require further investigation **[14, 15]**. Radiation-associated changes in

dental tissue morphology and mechanical properties may compromise tooth integrity and contribute to subsequent dental complications **[14]**. Because the adhesion and sealing ability of root canal sealers depend partly on their interaction with radicular dentin, radiation-induced alterations in the dentinal substrate may influence sealer bonding performance **[16]**. Therefore, understanding the effect of radiotherapy on the interaction between dentin and root canal sealers becomes clinically significant, particularly in patients who have received head and neck cancer treatment. The study demonstrated significantly lower dislocation resistance in irradiated teeth compared with non-irradiated teeth irrespective of sealer type, indicating that therapeutic radiation adversely affects bonding performance. This reduction in dislocation resistance may be associated with radiation-induced alterations in dentin morphology and mechanical properties. De Siqueira Mellara *et al.* (2014) reported progressive morphological disruption of dentin following irradiation, while Reed *et al.* (2015) showed changes in its chemical composition **[14, 15].** These findings are consistent with the study by Calik *et al.*, which reported reduced dentinal tubule penetration and push-out bond strength when radiotherapy was administered after obturation, although the effects varied according to the sealer type and root canal level **[16].** Yaduka *et al.* similarly reported significantly reduced dislocation resistance for AH Plus following irradiation, whereas BioRoot RCS showed no statistically significant reduction, highlighting the possibility of material-specific responses to radiotherapy **[17].** In non-irradiated teeth, the resin-based sealer, Group 1A (AH Plus) exhibited the highest dislocation resistance, followed by calcium silicate–based sealer, Group 1B (Ceraseal) and bioactive glass–based sealer, Group 1C (GuttaFlow Bioseal) **[18]**. The higher dislocation resistance observed with AH Plus in non-irradiated teeth may be related to its established interaction with the organic phase of dentin and its favorable bonding properties. Maharti *et al.* showed that dentin conditioning influenced the push-out bond strength and sealing ability of AH Plus, supporting the importance of dentinal substrate characteristics in its bonding performance **[19]**. Calcium silicate-based sealers are hydraulic materials whose setting reactions depend on moisture, and they demonstrate bioactive properties that may promote interactions with dentinal tissues. However, the extent to which mineralization-related processes and tubule penetration contribute to Ceraseal's dislocation resistance requires further investigation **[20, 21]**. Additionally, the hydrophilic nature and small particle size of Ceraseal facilitate penetration into dentinal tubules and improve adaptation to canal walls **[20]**. On the other hand, bioactive glass–based sealer (GuttaFlow Bioseal) exhibited the lowest dislocation resistance among the sealers tested in the non-irradiated group. The lower dislocation resistance observed with GuttaFlow Bioseal may be related to its material composition and interaction with the dentinal substrate. Ozlek *et al.* (2020) showed that dentin moisture conditions significantly influenced the dislocation resistance of GuttaFlow Bioseal, highlighting the importance of substrate conditions in its bonding performance **[22].** In a related investigation, Magoga *et al.* found that irradiation reduced the bond strength of AH Plus Jet and BioRoot RCS, whereas the effect on the zinc oxide-based sealer Endofill varied by root level, further suggesting that radiation-associated changes in dislocation resistance depend on the sealer and experimental conditions **[23].** Interestingly, in irradiated teeth, the pattern of dislocation resistance differed from the non-irradiated group. Calcium silicate–based sealer (Ceraseal) exhibited the highest dislocation resistance, followed by resin-based sealer (AH Plus), while GuttaFlow Bioseal continued to demonstrate the lowest bond strength **[21]**. In contrast, Malik *et al.* found that AH Plus exhibited the highest push-out bond strength among the four sealers evaluated, with no statistically significant differences attributable to irradiation or treatment timing within individual sealer groups **[24].** The higher dislocation resistance of Ceraseal in irradiated teeth may reflect differences in the interaction of calcium silicate-based materials with the altered dentinal substrate. Their hydration-dependent setting and bioactive properties provide plausible explanations; however, these mechanisms were not directly evaluated in the present study. Reed *et al.* (2015) reported a radiation-associated decrease in the protein-to-mineral ratio at most of the dentin and enamel sites examined, together with changes in other compositional parameters **[15]**. Because AH Plus interacts with the organic phase of dentin, radiation-associated changes in dentin composition may influence its bonding performance. This may partly explain the lower dislocation resistance observed for AH Plus in irradiated teeth, although the specific mechanism was not directly investigated in the present study **[19, 25].** In contrast, the bioactive properties of calcium silicate-based sealers may favor interactions with dentin under altered substrate conditions. Whether these properties compensate for radiation-associated changes in the organic matrix and account for Ceraseal's higher dislocation resistance remains uncertain **[20].** GuttaFlow Bioseal continued to demonstrate the lowest dislocation resistance in irradiated teeth. Although its bioactive components may contribute to interactions with dentin, the present findings indicate that these properties did not translate into higher dislocation resistance under the experimental conditions. The specific effects of radiation-induced changes in dentin composition, morphology and moisture-related properties on GuttaFlow Bioseal adhesion require further investigation **[22]**. Although bioactive glass particles promote apatite formation, this reaction appears insufficient to significantly enhance bonding in irradiated dentin.

Conclusion:

Radiation therapy was found to adversely affect the dislocation resistance of all tested root canal sealers to root dentine. The findings of this study highlight the clinical importance of careful sealer selection in patients undergoing or having undergone head and neck radiotherapy. Radiation-induced alterations in dentin can compromise bonding effectiveness; therefore, the use of materials capable of adapting to such changes is essential.

Advancement to knowledge:

Despite irradiation-related reductions in dislocation resistance, calcium silicate–based sealer retained significantly higher bond strength than resin-based and bioactive glass–based sealers, highlighting its potential relevance for endodontic treatment in irradiated teeth.

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