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Impact of topical fluoride agents on radiation-induced dentin hardness alterations: a laboratory study

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Keywords

Dental caries susceptibility, head and neck neoplasms, fluoride treatment, mechanical tests, preventive dentistry, radiotherapy, radiation oncology, tooth components

Abstract

Radiation therapy for head and neck cancers often leads to radiation-induced caries and microstructural dentin alterations. This laboratory study evaluated the impact of radiation on dentin microhardness and the effectiveness of various topical fluoride treatments in mitigating these effects. One hundred dentin specimens from extracted human teeth were irradiated with a cumulative dose of 60 Gy, simulating therapeutic conditions. Post-irradiation, specimens received weekly applications of silver diamine fluoride (SDF), SDF with potassium iodide, or sodium fluoride varnishes with and without additional compounds. Dentin microhardness was measured using the Knoop hardness test at three key phases: baseline, immediately after reaching a cumulative irradiation dose of 60 Gy, and weekly for five weeks following repeated fluoride applications. At baseline, the average Knoop Hardness Number (KHN) was 57.6 ± 3.9. After irradiation, the average KHN decreased significantly to 41.2 ± 8.1, reflecting an approximate 30% reduction in dentin hardness across all groups ($p < 0.0001$). Five weeks of weekly fluoride treatments led to partial recovery of microhardness, with average KHN values ranging from 42.4 to 54.3, but none of the groups returned to baseline hardness levels. Notably, no significant differences were found among the fluoride treatments in their ability to enhance microhardness. These findings underscore the detrimental effects of radiation therapy on dentin integrity and emphasize the need for targeted dental management strategies. While fluoride applications provide some protective benefit, their limitations highlight the necessity of comprehensive approaches to prevent radiation-related dental deterioration in head and neck cancer patients.

Introduction

Head and neck cancers impose a heavy health burden, accounting for approximately 5.7% of global cancer-related mortalities (1). Treatment modalities for these cancers depend on the specific diagnosis and disease stage, with radiation therapy being a common approach, either alone or combined with chemotherapy, surgical interventions, or both (2, 3).

Despite its effectiveness, radiation therapy is associated with significant toxicity, manifesting as acute and late adverse effects. Long-term adverse effects, emerging months to years post-treatment, include radiation-induced fibrosis and radiation-related caries (4). Notably, radiation-related caries affects about 29% of patients within three months post-treatment (4). This increased susceptibility to caries is largely due to changes in saliva quantity and quality as well as the direct impact of radiation on enamel and dentin (5–8).

Investigations into the direct impact of therapeutic irradiation on tooth substance have elucidated significant changes, particularly within dentin (8, 9). Irradiation impacts the organic dentin matrix, leading to alterations such as increased collagen cross-linking and potential activation of matrix metalloproteases, which could compromise structural integrity (8, 9). Additionally, dentin exhibits a diminished mineral-to-matrix ratio post-irradiation, suggesting a degradation of its inorganic constituents (8, 9). These modifications not only reduce the mechanical properties of dentin, including hardness and elasticity, but also may increase its susceptibility to caries (8, 9). While enamel is also affected, showing decreased hardness and crystallinity, the more pronounced alterations within dentin demand further attention (8, 9).

A laboratory study assessed the impact of various topical fluoride treatments, administered both before and after simulated fractionated radiotherapy, on the microhardness of dentin (10). The study found that silver diamine fluoride (SDF), known for its efficacy in caries prevention and management, notably enhanced the microhardness of dentin prior to irradiation (10). However, exposure to irradiation led to a reduction in microhardness, regardless of any pre-treatment with fluoride agents (10). Subsequent short-term applications of fluoride post-irradiation, irrespective of the agent used, partially recovered the microhardness of dentin, though not to the initial levels (10). These outcomes imply that while pre-irradiation fluoride treatment does not prevent the decline in microhardness due to irradiation, post-irradiation fluoride application may contribute to a gradual restoration of microhardness (10).

However, these findings were based on short-term evaluations conducted within a two-week period post-irradiation. Consequently, the longer-term effects of different fluoride treatments on the recovery of dentin microhardness post-irradiation remain uncertain.

To bridge this gap in knowledge, the current laboratory study was designed to explore the impact of repeated applications of various topical fluoride agents over longer durations. The aim of the study was to examine how these fluoride agents influence the microhardness of dentin specimens exposed to radiation doses comparable to those used in radiation therapy.

Materials and methods

Ethical Approval

The Ethics Committee of Northwest and Central Switzerland approved the use of irreversibly anonymized teeth from donors who had provided informed consent for their extracted teeth to be used in research (EKNZ UBE-15/111). Additionally, the Institutional Review Board of the University of Pennsylvania granted an exemption from oversight, as the study exclusively involved irreversibly anonymized teeth from adult donors with prior consent for research use.

As part of the medical history questionnaire and informed consent process, all adult donors provided written informed consent before tooth extraction, explicitly permitting the use of their irreversibly anonymized teeth for research. No identifiable patient information was collected or utilized in this study.

Fabrication of dental specimens

Figure 1 provides an overview of the study flow. From a pool of extracted human teeth stored in 0.5% chloramine-T solution in a 100% relative humidity chamber at 37 °C, intact premolars and permanent molars were selected. Specimens were fabricated within 6 months of tooth extraction. Soft tissue remnants were manually removed. The selected teeth, 100 in total, were free of carious lesions, significant tooth wear, and dental restorations. Using molds, the cleaned teeth were embedded in fast-curing orthodontic acrylic resin (Jet Liquid, Great Lakes Dental Technologies, Tonawanda, NY, USA).

To expose the dentin and enamel, the embedded teeth were ground at 300 revolutions per minute (rpm) with 400, 800, and 1200 grit silicon carbide pressure sensitive grinding papers (Extec Corporation, Enfield, CT, USA) on a grinding/polishing machine (Struers, Ballerup, Denmark). After grinding, the teeth were polished at 150 rpm on the same grinding/polishing machine using an alcohol-based lubricant and 3 µm poly-crystalline diamond suspension (Extec Corporation, Enfield, CT, USA). The surface of the specimens was regularly monitored after each grinding and polishing step under a light microscope at a magnification of 50 × (Olympus BH-2, Evident, Hamburg, Germany). After the surface was free of visible scratches at this magnification, the specimens were cleaned in deionized water in an ultrasonic cleaner (1510, Branson, Brookfield, CT, USA).

The 100 specimens were randomly divided into five equal groups using a randomized allocation scheme created by free online software (www.randomizer.org). In order to simulate the conditions of the oral cavity, the specimens were stored in a chamber with 100% relative humidity at a temperature of 37°C when they were not under examination or treatment.

Figure 1. Schematic representation of the experimental study flow.

Knoop hardness assessment

Blinded investigators performed Knoop hardness (KHN) measurements at three key phases, totaling seven time points: at baseline; after accumulating a cumulative irradiation dose of 60 Gy; and weekly for five weeks following repeated fluoride applications. Before KHN evaluation, specimens underwent cleaning in an ultrasonic cleaner with water and were then dried using compressed air. KHN was assessed at locations 2 mm into the dentin at cusp tips. To ensure the consistency of the measurements at each evaluation, KHN was determined in duplicate for each specimen, with only values displaying less than a 10% discrepancy being considered valid. The KHN assessments were performed with a microhardness tester (Falcon 450, Innovatest, Maastricht, The Netherlands), employing a Knoop indenter, a main load of 200 gram-force, and a dwell time of 15 s. KHN values were automatically determined from the long diagonal of the residual indent using the tester's 10× objective lens and Impressions digital image analysis software (Innovatest, Maastricht, The Netherlands). Figure 2 presents representative optical microscope images of Knoop hardness indentations in specimens after reaching the total irradiation dose.

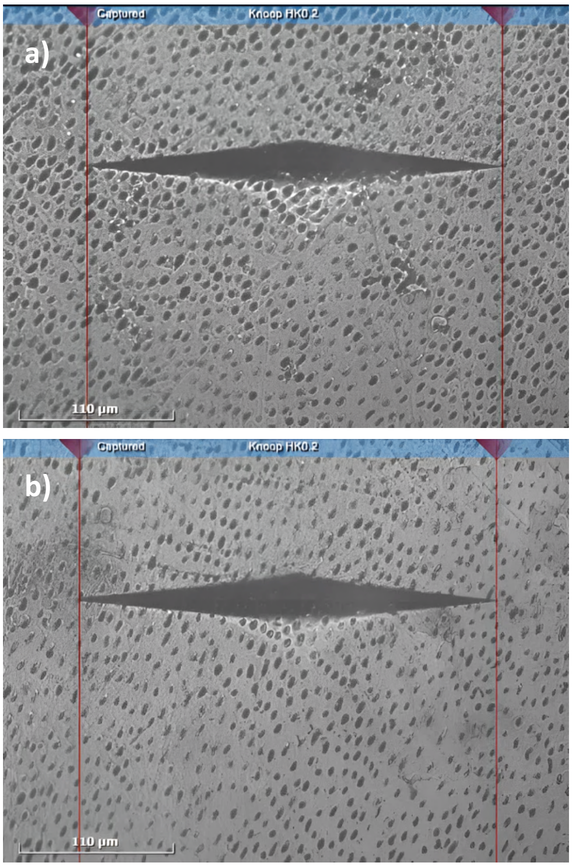

Figure 2. Optical microscope images of dentin specimens taken at 10× magnification following irradiation. The hardness measurement was 32.7 KHN for the specimen in the left panel **(a)** and 32.5 KHN for the specimen in the right panel **(b)**.

Specimen irridation

To simulate radiation therapy administered to patients with head and neck cancer, blinded investigators exposed the specimens to a daily dose of 2 Gy of radiation five consecutive days per week over a span of six weeks. Irradiation was conducted using a cabinet X-ray irradiator set to 320.0 KV and 12.5 mA (X-Rad 320ix, Precision X-Ray, Madison, CT, USA). The irradiator operated at a dose rate of approximately 0.92 Gy/min, requiring a daily exposure time of 130.5 seconds to deliver the prescribed 2 Gy dose. The system was equipped with real-time dosimetry, ensuring that irradiation times were adjusted as needed to maintain consistent daily radiation fractions. Outside of treatment or testing periods, the specimens were stored in a fluoride-free mouthwash solution (Biotène Dry Mouth Oral Rinse, GlaxoSmithKline, Mississauga, Canada) in an incubator maintaining 100% relative humidity at a temperature of 37°C.

Fluoride treatment

Following the post-irradiation KHN assessment, the specimens were subjected to various topical fluoride treatments: Group 1 received silver diamine fluoride (SDF) (Riva Star, SDI, Itasca, IL, USA). Group 2 was treated with both SDF and a potassium iodide (KI) solution (Riva Star, SDI, Itasca, IL, USA). Group 3 underwent application of a varnish containing 5% sodium fluoride (NaF), casein phosphopeptides (CPP), and amorphous calcium phosphate (ACP) (MI Varnish, GC America, Alsip, IL, USA). Group 4 was treated with a 5% NaF varnish (Acclean, Henry Schein, Palatine, IL, USA). Group 5 acted as the control and did not receive any fluoride treatment. Table 1 outlines the specifics of the fluoride agents used, including their method of application. These treatments were administered weekly for a total duration of five weeks. A fresh unit-dose container was used for each application. The investigators performing the treatments were unblinded.

Table 1. Overview of topical fluoride agents used and their application methods.

Group	Fluoride agent	Product	Application
1	SDF (~44,800 ppm fluoride)	Riva Star, SDI, Itasca, IL, USA	Using a microtip applicator, SDF solution was carefully applied to the dry dentin surface. The solution was allowed to sit for 60 s before being gently blotted dry.
2	SDF and KI (~44,800 ppm fluoride)	Riva Star, SDI, Itasca, IL, USA	Using a microtip applicator, SDF solution was carefully applied to the dry dentin surface. Immediately after, using a fresh microtip applicator, a generous amount of KI solution was applied to the same area, turning the site initially creamy white. The application of KI solution continued until the treated surface turned clear. The agents were allowed to sit for 60 s before being gently blotted dry.
3	Varnish containing 5% NaF, CPP, and ACP (~22,600 ppm fluoride)	MI Varnish, GC America, Alsip, IL, USA	The varnish was stirred with a disposable brush in the unit-dose container until thoroughly mixed. The dry dentin surface was then coated with a thin, uniform layer of the varnish. It remained undisturbed until the next measurement required cleaning.
4	Varnish containing 5% NaF (~22,600 ppm fluoride)	Acclean, Henry Schein, Palatine, IL, USA	The varnish was stirred with a disposable brush in the unit-dose container until thoroughly mixed. The dry dentin surface was then coated with a thin, uniform layer of the varnish. It remained undisturbed until the next measurement required cleaning.
5	None	N/A	N/A

Abbreviations: ACP, amorphous calcium phosphate; CPP, casein phosphopeptides; KI, potassium iodide; N/A, not applicable; NaF, sodium fluoride; ppm, parts per million; SDF, silver diamine fluoride.

Statistical analysis

Data were expressed as mean and the corresponding standard deviation (SD). The Kruskal-Wallis one-way analysis of variance (ANOVA) test was used to assess differences between different groups. Dunn's method was employed to conduct pairwise multiple comparisons. Statistical analyses were performed by an unblinded investigator using statistical software (Microsoft Excel 16.60 [22041000], Microsoft, Redmond, WA, USA). The significance level was set at $\alpha = 0.05$. The dataset generated and analyzed in this study is available from the corresponding author on request.

Results

Results are reported in detail in Table 2. At baseline, the average KHN of the untreated dentin groups ranged from 49.6 to 66.6, with an average KHN of 57.6 and SD of 3.9 ($n = 100$). Across the groups, there was no significant difference in KHN values at baseline. Following irradiation, the average hardness was recorded at 41.2 with a SD of 8.1 ($n = 100$). The KHN values post-irradiation showed a significant decrease from the baseline, with an average reduction in hardness of about 30% across all groups ($p < 0.0001$). After five weeks of weekly fluoride treatments post-irradiation, there was no significant difference in KHN values among the four experimental groups. While there was an increase in KHN for the groups that received repeated fluoride treatments, these values did not return to the baseline levels (Figure 3).

Table 2. Average KHN values of dentin specimens. An asterisk indicates a statistically significant reduction in KHN from the pre-irradiation to the post-irradiation measurements ($p < 0.0001$). The data are presented as mean with the corresponding SD.

Group	KHN pre-irradiation	KHN immediately post-irradiation	% change immediately post-irradiation	KHN 5 weeks post-irradiation	% change 5 weeks post-irradiation
1	58.2 ± 3.3	39.0 ± 8.4*	-33.0%	44.6 ± 10.5	-23.4%
2	58.5 ± 3.1	42.5 ± 6.1*	-27.4%	42.5 ± 12.7	-27.4%
3	56.3 ± 3.8	37.4 ± 7.9*	-33.6%	42.4 ± 13.5	-24.7%
4	56.8 ± 2.8	37.7 ± 5.2*	-33.6%	42.4 ± 12.8	-25.4%
5	58.0 ± 5.8	49.7 ± 5.5*	-14.3%	54.3 ± 11.8	-6.4%

Abbreviation: KHN, Knoop hardness.

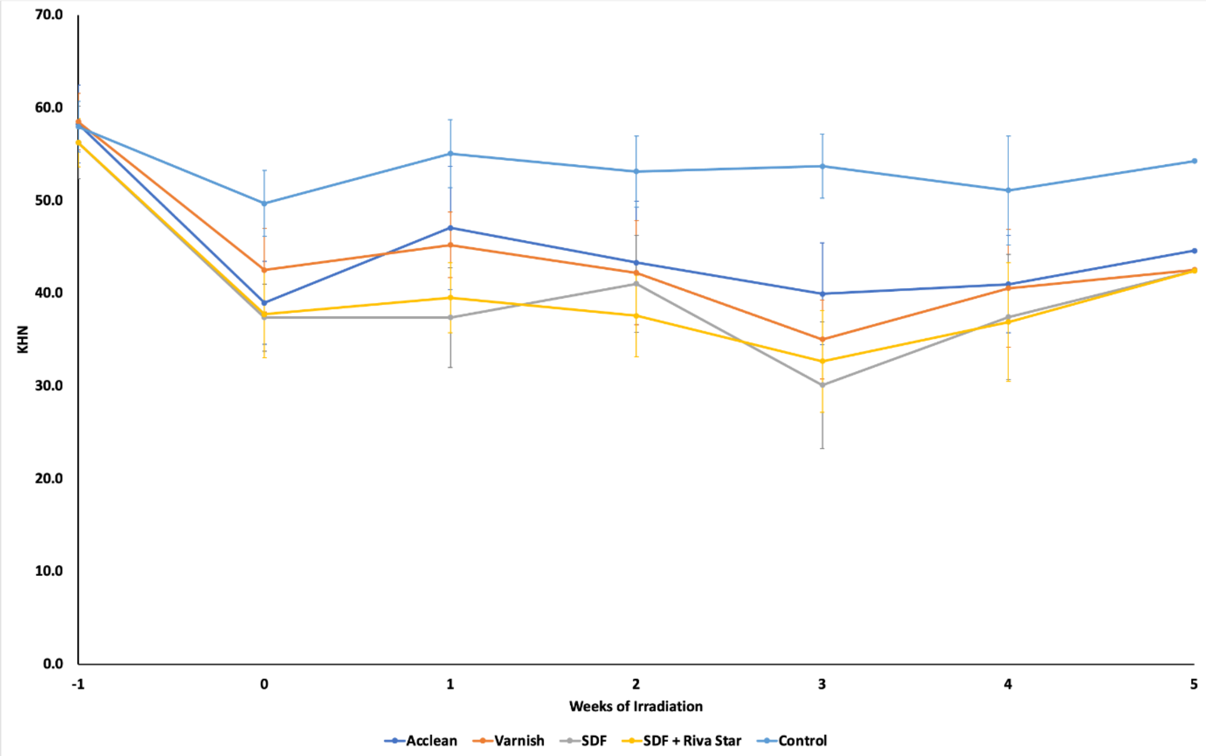

Figure 3. KHN values for dentin specimens at seven time points: at baseline (1 week prior to irradiation, denoted as week –1), immediately post-irradiation (week 0), and at weekly intervals over a five-week period following fluoride treatment. Data are presented for all experimental groups as mean values, with standard deviations shown as error bars (n = 20 per group).

Discussion

The objective of this laboratory investigation was to evaluate the impact of multiple applications of diverse topical fluoride agents on the microhardness of dentin exposed to radiation levels analogous to those employed in radiotherapy for head and neck cancers. In line with previous studies, results indicated a reduction in the microhardness of dentin following irradiation (8, 9). Though subsequent applications of fluoride agents caused a modest increase in microhardness, the values did not reach the baseline levels observed prior to irradiation. Comparative analysis among the different fluoride treatments revealed no significant disparities, implying that no single agent demonstrates a distinct superiority in restoring post-irradiation dentin microhardness.

The fluoride agents assessed in this investigation were on par in terms of their effect on dentin microhardness post-irradiation. This finding corroborates the results of a previous in vitro study that assessed different fluoride agents on dentin subjected to irradiation, with the observation period ending within two weeks post-irradiation (10). This indicates that extending the duration of post-irradiation fluoride application does not result in noticeably different effects on dentin microhardness among the fluoride agents.

However, it is critical to note that this equivalence does not translate to equal effectiveness in clinical settings for patients receiving radiation therapy. The scope of this study did not encompass conditions simulating demineralization akin to cariogenic or erosive environments. This was a deliberate choice to isolate and evaluate the specific structural changes induced irradiation alone and minimize confounding factors. However, by using sound dentin rather than dentin affected by caries or demineralization, the study cannot address how these fluoride agents perform under clinically relevant demineralization challenges (11, 12). Further investigations are necessary to explore the performance of different fluoride treatments on irradiated dentin in models that incorporate such conditions. Given the known variance in fluoride agents' effectiveness in preventing and managing root caries, it is plausible that their preventative or therapeutic utility may differ among patients undergoing radiation therapy (13, 14). Consequently, one should draw no conclusion from this study regarding the suitability of different fluoride agents in this complex patient cohort.

The findings of the present study underscore the impact of radiation on dentin microhardness, corroborating the broader body of evidence highlighting the detrimental effects of radiation therapy on dental hard tissues, particularly dentin (8, 9). Consistent with prior research, this study observed a marked reduction in dentin microhardness post-irradiation, aligning with observations of increased collagen cross-linking and potential alterations in the organic dentin matrix owing to radiation exposure (8, 9).

While the study revealed a modest recovery in microhardness with repeated fluoride applications, these treatments failed to revert it to pre-irradiation levels. This finding suggests a persistent vulnerability of irradiated dentin to structural compromise and resonates with existing literature that emphasized the complex interplay between irradiation effects and the limited reparative capacity of fluoride treatments on irradiated dentin (10). Moreover, the lack of significant differences between the effects of various fluoride agents on post-irradiation dentin microhardness further supports the notion that the primary factor influencing the response of dentin post-radiation is the radiation itself, rather than the subsequent therapeutic interventions. These findings underscore the importance of developing treatment protocols that not only aim to reduce dental exposure to radiation but also effectively address any ensuing structural alterations in both enamel and dentin.

One potential reason fluoride agents cannot fully restore the hardness of dentin post-irradiation lies in the complex nature of radiation-induced damage. Radiation therapy extensively alters the microstructure of dentin, affecting both its organic components and apatite crystal structure. These alterations include increased collagen cross-linking, activation of matrix metalloproteases, and a decrease in the mineral-to-matrix ratio, all of which compromise the structural integrity of dentin (7, 8). While fluoride treatments are effective in remineralizing sound dentin and partially restoring hardness of irradiated dentin, they may not reverse these deep-seated structural changes.

SDF, a potent fluoride agent, enhances sound dentin hardness through multiple mechanisms. Upon application of SDF on enamel and dentin, silver and fluoride interact synergistically to form fluorapatite, significantly increasing surface microhardness (15). SDF also promotes calcium absorption and inhibits its dissolution from enamel and dentin, resulting in a highly remineralized zone rich in calcium and phosphate (15). Additionally, SDF inhibits the enzymatic activities of matrix metalloproteases and cysteine cathepsins, preventing collagen degradation and preserving the organic matrix of dentin (15). Collectively, these actions not only arrest carious lesion progression but also enhance the structural integrity and hardness of dentin (16).

However, the findings of the present study suggest that fluoride agents, including SDF, cannot fully repair the microstructural damage inflicted by radiation. This limitation may be due to the impeded formation of fluorapatite and silver incorporation in radiation-damaged dentin and the compromised structural integrity of the collagen matrix. Further research into alternative or adjunctive treatments that address both surface and subsurface dentin integrity is necessary to mitigate the effects of radiation on dental tissues more effectively.

An important observation is the convergence of microhardness values between fluoride-treated and control groups around the five-week mark. This trend suggests that a time-dependent hardness recovery process may be occurring independently of fluoride application. Similar delayed recovery phenomena have been reported in irradiated bone tissue, supporting the hypothesis that irradiated hard tissues may undergo gradual structural recovery over time (17, 18). To further explore this trajectory, future studies should incorporate extended follow-up periods.

KHN assessment was selected over Vickers hardness owing to its enhanced sensitivity to surface-level microstructural changes, which are relevant in the evaluation of radiation-induced damage in dentin. The elongated Knoop indentation allows for precise, shallow measurements—ideal for hard tissues such as dentin. Additionally, the lower applied load and anisotropic indent geometry reduce the risk of cracking and interference with neighboring features, making KHN suitable for repeated, localized measurements across multiple time points.

It is important to consider the inherent limitations of this laboratory study. First, dentin exhibits anisotropic characteristics owing to its unique microstructural composition. As a result, its physical properties, including hardness, can vary depending on the direction in which they are measured (19). These variations primarily stem from the orientation of dentinal tubules, which, despite adherence to established hardness measurement protocols, may have influenced the recorded values.

It is, therefore, important to consider the distribution of dentinal tubules alignment on the polished surface of the specimens as a potential source of variability in our measurements. It remains unclear whether this distribution was consistent across all specimens, and tubule orientation at the indentation sites was not explicitly controlled. This introduces the possibility that alignment variability contributed to measurement uncertainty. If substantial, this uncertainty may have obscured a modest recovery in hardness, a limitation of this study that must be recognized. However, the same variability also applies to the observed reduction in hardness following irradiation. If measurement uncertainty is significant enough to mask a potential recovery, it must also be considered when interpreting the initial hardness loss. Future studies should quantify this uncertainty and assess whether standardizing tubule alignment at measurement sites could enhance the reliability of hardness assessments.

Second, the specimens were exposed to a total radiation dose of 60 Gy, delivered in daily 2 Gy fractions over six weeks—a protocol widely used in laboratory studies to model head and neck radiotherapy (20). While this regimen reflects clinical fractionation schedules, it does not fully replicate the complex radiation exposure experienced by dental tissues in patients. Specifically, irradiation was performed using a cabinet X-ray system, which differs from clinical linear accelerators in beam quality and depth-dose characteristics. Moreover, the use of X-rays, as opposed to advanced modalities such as proton beam therapy, introduces differences in tissue interaction and dose distribution. These distinctions should be considered when interpreting the translational relevance of the findings.

Third, the age and history of fluoride exposure of teeth used to fabricate dentin specimens were not documented. While the randomized allocation of specimens to the different groups was intended to minimize the influence of pre-existing variances, it is important to note that potential biases stemming from these unknown factors cannot be discounted. Notably, the control group exhibited higher surface hardness values post-irradiation compared with the fluoride-treated groups. While no statistical comparison was conducted at baseline, this discrepancy raises concerns about the comparability of groups. The lack of clear differentiation between control and treated groups, including evidence of surface rehardening in the control group, suggests that partial structural recovery may occur independently of fluoride treatment. This phenomenon, while complicating interpretation, may reflect an intrinsic time-dependent recovery process in irradiated dentin (20). These issues underscore the limitations of the current experimental setup and highlight the need for future studies to enhance baseline matching of specimens.

Fourth, while a fluoride-free mouthwash, specifically formulated as a saliva substitute for dry mouth, was selected to prevent unintended fluoride exposure and thus avoid confounding the effects of the experimental treatments, it must be recognized that artificial saliva would have more accurately replicated physiological oral conditions—with the caveat that patients post-irradiation commonly suffer from severe xerostomia. Therefore, future studies should consider artificial saliva with salivary protein analogs for more accurate simulation.

Fifth, the Knoop hardness testing methodology employed in this study provided a robust and well-established assessment of dentin's mechanical properties. However, the addition of scanning electron microscopy could have offered complementary insights into the microstructural alterations induced by irradiation and subsequent fluoride treatments. Future studies should incorporate scanning electron microscopy to further elucidate the complex interactions between radiation and fluoride treatments.

Sixth, though fluoride treatments led to an increase in dentin microhardness, the formation of fluorohydroxyapatite—a potential contributing factor—was not directly confirmed. Future research should incorporate methods such as attenuated total reflectance-Fourier transform infrared spectroscopy to identify specific vibrational bands, providing definitive evidence of fluorohydroxyapatite formation and enhancing the understanding of fluoride-mediated dentin remineralization. Additionally, the inherent limitations of laboratory studies must be recognized—specifically, the absence of critical oral components such as saliva, acquired pellicle, and biofilm, which can influence fluoride interaction and dental hard tissue remineralization.

Lastly, while this study focused on microhardness, it did not investigate other outcomes, such as specimen discoloration, which is a relevant concern. Notably, SDF, an effective and equitable agent for caries prevention and control, is known to cause dark staining of tooth substance, representing a significant adverse effect (16, 21, 22). The use of KI, applied immediately following SDF application, has been shown to mitigate this staining (23, 24). The investigators in the present study observed no visible specimen discoloration immediately post-irradiation. However, discoloration was noted in specimens treated with SDF, and, to a lesser extent and inconsistently across specimens, in those treated with both SDF and KI. It is important to highlight that no standardized color measurements, such as spectrophotometric assessments, were conducted. Further research is essential to fully understand the adverse effects, including discoloration, associated with repeated applications of topical fluorides. These adverse effects could affect patient acceptance and limit the widespread use of some fluoride agents by dental professionals.

Conclusions

Within the constraints of this laboratory study, the following conclusions were drawn:

- Radiation therapy significantly reduced dentin microhardness, underscoring its detrimental impact on dental hard tissues.
- Repeated topical fluoride applications modestly improved microhardness but did not restore it to baseline, indicating a persistent vulnerability of dentin to structural damage post-radiation.
- No significant differences were observed among fluoride agents, suggesting that radiation exposure itself is the dominant factor affecting dentin integrity.
- These findings reinforce the need to minimize dental radiation exposure and to develop targeted strategies to preserve dentin structure during and after therapy.
- Despite limited structural recovery, fluoride agents remain essential in caries prevention and control and must be integrated into oral care protocols for head and neck cancer patients.

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Zusammenfassung

Einleitung

Kopf-Hals-Tumoren erfordern häufig eine Strahlentherapie, die trotz ihrer Wirksamkeit mit langfristigen Nebenwirkungen wie strahlenbedingter Karies verbunden ist. Strahlenbedingte Karies betrifft bis zu 29 % der Patienten innerhalb von drei Monaten nach der Strahlentherapie und steht im Zusammenhang mit Hyposalivation sowie direkten, strahleninduzierten Veränderungen der Zahnhartsubstanzen, insbesondere des Dentins. Frühere Studien zeigten, dass Bestrahlung den Mineralgehalt und die Mikrohärte des Dentins reduziert und so dessen strukturelle Integrität beeinträchtigt. Kurzzeituntersuchungen deuten darauf hin, dass topische Fluoridbehandlungen — insbesondere Silberdiaminfluorid (SDF) — die Mikrohärte nach der Bestrahlung teilweise wiederherstellen können. Es ist allerdings unklar, wie sich Fluoridbehandlungen über mehrere Wochen auf die Mikrohärte des Dentins auswirken. Das Ziel dieser Studie war es daher, den Einfluss wiederholter Fluoridanwendungen über einen längeren Zeitraum auf bestrahltes Dentin zu untersuchen, um Strategien zur Reduktion strahlenbedingter Zahnschäden besser zu verstehen.

Material und Methoden

In dieser In-vitro-Studie wurden 100 extrahierte, kariesfreie menschliche Zähne präpariert, poliert und randomisiert fünf Behandlungsgruppen zugeteilt. Die Proben wurden schrittweise bis zu einer Gesamtdosis von 60 Gy bestrahlt, um die klinischen Bedingungen einer Strahlentherapie nachzuahmen. Nach der Bestrahlung erhielten die Proben über fünf Wochen wöchentliche Fluoridanwendungen, darunter SDF, SDF kombiniert mit Kaliumiodid (KI), zwei unterschiedliche natriumfluoridhaltige Lacke oder keine Behandlung (Kontrollgruppe). Die Knoop-Härte der Dentinoberflächen wurde vor, während und nach der Behandlung gemessen, um den Einfluss der Fluoridapplikationen auf die mechanische Stabilität bestrahlten Dentins zu bewerten. Die Datenanalyse erfolgte mittels Kruskal-Wallis-Test und Dunn's Post-hoc-Vergleich bei einem Signifikanzniveau von $\alpha = 0.05$.

Resultate

Zu Beginn zeigten alle Gruppen vergleichbare Knoop-Härtewerte (KHN) des Dentins (Durchschnitt: 57.6 ± 3.9). Nach Bestrahlung fiel die KHN signifikant auf durchschnittlich 41.2 ± 8.1 ab, was einer Reduktion von rund 30 % entspricht ($p < 0.0001$). Im Anschluss an fünf Wochen wöchentlicher Fluoridbehandlungen stieg die Härte der behandelten Proben im Vergleich zu den Werten, die unmittelbar nach der Bestrahlung gemessen wurden, leicht an, erreichte jedoch in keiner Gruppe wieder das Ausgangsniveau. Zwischen den behandelten Gruppen zeigten sich nach fünf Wochen keine signifikanten Unterschiede.

Diskussion

In dieser In-vitro-Studie wurde der Einfluss wiederholter Applikationen verschiedener topischer Fluoridpräparate auf die Mikrohärte von bestrahltem Dentin untersucht. Die Ergebnisse bestätigten, dass die Bestrahlung die Mikrohärte von Dentin signifikant reduziert, was mit früheren Studien übereinstimmt. Zwar zeigten Fluoridbehandlungen eine moderate Erhöhung der Härte, jedoch wurde das Ausgangsniveau nicht erreicht. Zwischen den getesteten Fluoridpräparaten ergaben sich keine signifikanten Unterschiede, was nahelegt, dass die Strukturschädigung primär durch die Bestrahlung verursacht wird und durch Fluorid nur begrenzt reversibel ist.

Die Studie weist einige Limitationen auf: mögliche Variabilität durch die Orientierung von Dentintubuli, Unterschiede im Alter und Vorbehandlung der Probenzähne, der Einsatz von künstlicher Speichelersatzlösung anstelle physiologischer Bedingungen sowie die ausschliessliche Betrachtung der Mikrohärte ohne ergänzende strukturelle Analysen. Darüber hinaus wurde die Bildung von fluoridhaltigen Mineralphasen nicht direkt nachgewiesen.

Zusammenfassend verdeutlichen die Ergebnisse die anhaltende Anfälligkeit von bestrahltem Dentin für strukturelle Schwächungen und unterstreichen die Bedeutung von Strahlenschutzstrategien sowie von weiterführender Forschung zu ergänzenden oder kombinierten Therapien, um Zahnschäden durch Bestrahlung wirksam zu mindern.

Résumé

Introduction

Les tumeurs de la tête et du cou nécessitent fréquemment une radiothérapie, laquelle, malgré son efficacité, est associée à des effets secondaires à long terme, tels que la carie radio-induite. Cette pathologie touche jusqu'à 29 % des patients dans les trois mois suivant la radiothérapie et est corrélée à une hyposialie ainsi qu'à des altérations directes des tissus dentaires d'origine radiogénique, en particulier au niveau de la dentine. Des travaux antérieurs ont montré que l'irradiation réduit la teneur minérale et la microdureté de la dentine, compromettant ainsi son intégrité structurelle. Des études à court terme suggèrent que les applications topiques de fluor — en particulier le fluorure diamine d'argent (SDF) — peuvent partiellement restaurer la microdureté de la dentine après irradiation. Cependant, l'effet de traitements fluorés prolongés sur la microdureté du tissu dentinaire irradié reste incertain. L'objectif de cette étude était d'évaluer l'influence d'applications répétées de fluor sur une période prolongée sur la dentine irradiée, en vue d'améliorer la compréhension des stratégies de prévention des dommages dentaires liés à la radiothérapie.

Matériels et méthodes

Dans cette étude in vitro, 100 dents humaines extraites, saines et sans carie, ont été préparées, polies puis aléatoirement réparties en cinq groupes expérimentaux. Les échantillons ont été irradiés par fractions successives jusqu'à atteindre une dose cumulative de 60 Gy, simulant ainsi les conditions cliniques d'un protocole de radiothérapie. Après irradiation, les échantillons ont reçu, sur une période de cinq semaines, des applications hebdomadaires de fluor, incluant du SDF, du SDF combiné à de l'iodure de potassium (KI), deux vernis fluorés à base de fluorure de sodium, ou aucune application (groupe témoin). La microdureté des surfaces dentinaires a été mesurée à l'aide du test de dureté Knoop avant irradiation, après irradiation, et à la fin du protocole fluoré, afin d'évaluer l'effet des traitements sur la stabilité mécanique de la dentine irradiée. L'analyse statistique a été réalisée au moyen du test de Kruskal-Wallis et du test post hoc de Dunn, avec un seuil de signification fixé à $\alpha = 0,05$.

Résultats

Au début de l'expérimentation, les échantillons présentaient des valeurs de microdureté Knoop (KHN) homogènes (moyenne : $57,6 \pm 3,9$). Après irradiation, une diminution significative de la dureté a été observée, les valeurs chutant en moyenne à $41,2 \pm 8,1$, correspondant à une réduction d'environ 30 % ($p < 0,0001$). Après cinq semaines de traitements fluorés hebdomadaires, une légère augmentation de la microdureté a été notée dans les groupes traités, comparée aux valeurs mesurées immédiatement après irradiation, sans toutefois retrouver les niveaux initiaux. Aucune différence statistiquement significative n'a été observée entre les différents agents fluorés après cinq semaines de traitement.

Discussion

Cette étude in vitro visait à examiner l'impact d'applications répétées de divers agents fluorés topiques sur la microdureté de la dentine irradiée. Les résultats confirment que l'irradiation induit une réduction marquée de la microdureté dentinaire, corroborant ainsi les observations antérieures. Bien que les traitements fluorés aient permis une récupération partielle de la dureté, celle-ci est restée inférieure aux valeurs initiales. L'absence de différences significatives entre les divers agents fluorés suggère que les altérations structurales sont principalement dues à l'exposition aux rayonnements et que la capacité de réparation via les fluorures est limitée.

Cette étude présente certaines limites, notamment la variabilité potentielle liée à l'orientation des tubules dentinaires, les différences d'âge et d'exposition préalable au fluor des dents utilisées, l'usage d'une solution de substitution salivaire non physiologique, ainsi que l'évaluation restreinte à la microdureté sans analyses structurelles complémentaires. Par ailleurs, la formation de phases minérales fluorées n'a pas été directement confirmée.

En conclusion, ces résultats soulignent la vulnérabilité persistante de la dentine irradiée face aux altérations structurales et mettent en évidence l'importance d'adopter des stratégies de radioprotection dentaire, ainsi que la nécessité de recherches complémentaires sur des approches thérapeutiques combinées afin d'atténuer les effets délétères de la radiothérapie sur les tissus dentaires.

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