Original Article

Effect of Irradiation on the Shear Bond Strength of Self-adhesive Luting Cement in Different Preparation Depths

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ABSTRACT

Objective: The purpose of this study was to evaluate the effects of pre- and post-irradiation application on the shear bond strength of self-adhesive luting cements to dentin and enamel. **Materials and Methods:** Thirty-two extracted human maxillary incisor teeth were used in this study. Teeth were divided into two main groups according to preparation depth (0.5 mm and 1 mm) as Group E and Group D and were divided into four subgroups according to treatment protocol ($n = 12$). Teeth were irradiated and preparation was done after radiation. Adhesive luting cement was placed on the irradiated enamel and dentin surface (Groups E1, D1). Preparation was done before irradiation and resin cement was placed on the irradiated enamel and dentin surface (Groups E2, D2). The resin cement was first placed on their enamel and dentin surfaces and then the specimens were irradiated (Groups E3, D3). Irradiation was done with a total dose of 60 Gy, applied in fractions over 6 weeks for each groups (2-Gy/day fractions, 5 days per week). Nonirradiated groups were determined as controls groups (Groups C1, C2). The shear bond strengths of adhesive luting cement were examined. **Results:** According to the two-way ANOVA results, depth of preparation and treatment protocol and their interactions were significant on shear bond strength of resin cement ($P < 0.05$). **Conclusions:** This study detected significant differences between the irradiated and nonirradiated groups, probably due to the changes in the crystalline structure of dental hard tissues.

KEYWORDS: *Bond strength, irradiation, self-adhesive luting cement*

INTRODUCTION

The patients undergoing radiation therapy for head and neck cancer (HNC) need multidisciplinary approach for dental management because of the side effects of this treatment.[1] Beside the temporary consequences such as loss of taste, sensitive soft tissues, and fungal infections, some side effects are more permanent such as atrophic muscles, change of bacterial microflora and proteins.[2-4] In addition, clinically, a rapid deterioration of the dental hard tissues, which consists of enamel, dentin, and dentinoenamel junction, could be observed as a side effect of radiation therapy.[2,4-6] Some chemical changes in enamel, reduction of microhardness in dentin, and reducing stability of amelodentinal junction could be observed after radiotherapy.[7-9] Radiation caries, which is known as an indirect side effect of radiation therapy, often occur on the cervical region besides occlusal and incisal edges, and besides buccal and oral surfaces.[10-12] In the literature, adhesive restorative techniques were recommended for irradiated patients just because of the reduced life expectancy.[5,11,13]

Preradiotherapy dental management generally include extraction of the untreatable and having suspicious prognosis teeth, preventive dental care, use of fluoride, and education of the patient about the oral hygiene.[14] Thariat *et al*. reported that only 11% of the patients who have HNC did not need preradiotherapy dental care.[15] Furthermore, recently diagnosed with HNC patients have

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high prevalence to dental disease.[16,17] Therefore, it is recommended that simple restorations should be done before radiotherapy.[14] The adhesive resin cements, often used for luting of ceramic restorations, are preferred for their good esthetic and mechanical characteristics such as high flexural, compressive shear, tensile bond strength, and high elastic modulus that prevent the decementation during the function.[18-20] However, resin cements require multiple sensitive clinical steps. Therefore, self-adhesive cements were recently introduced to simplify the luting procedure.[21]

In the literature, only a few studies were focused on the bond strength of adhesive restorative techniques systems that was applied to irradiated dentin,[9,11,22] and there is no report available about the bond strength of adhesive luting cement on irradiated enamel and dentin. Hence, the aim of this study was to evaluate the effects of pre- and post-irradiation application on the bond strength of self-adhesive luting cement onto the enamel and dentin.

Materials and Methods

Thirty-two extracted human maxillary incisor teeth were used in this study. The study was approved by the Research Ethics Committee of Ordu University (2015/2). The teeth were cleaned of debris and stored in phosphate-buffered saline at room temperature for up to 3 months until the experiment. The specimens of test groups (n = 12) are given in Table 1. Teeth in Group E1 and D1 (nonprepared surfaces) were embedded in chemically polymerized acrylic resin (Imicryl, Konya, Turkey) blocks and were irradiated with a total dose of 60 Gy, applied in fractions over 6 weeks (2-Gy/day fractions, 5 days per week). For homogeneity of the irradiation, the teeth were stored in daily renewed saline.

Teeth in Group E1 were prepared by pilot burs at 0.5 mm depth and teeth in Group D1 were prepared by pilot burs at 1 mm depth under constant water cooling. The prepared surface of each tooth was polished with 400- and 600-grit silicon carbide abrasive papers subsequently. Only enamel was etched using K-Etchant Syringe (Kuraray Noritake Dental Inc.,) and then the self-adhesive cements (Panavia SA Cement Plus Automix, Kuraray Noritake Dental Inc., Japan) were luted on the labial surface of teeth with tygon tubes (three tubes on each tooth) that have 7 mm diameter and 1 mm height and light cured for 10 s with a light-emitting diode (LED) curing light (Elipar™ FreeLight 2, 3M ESPE, St. Paul MN, USA) at an intensity of 750 mW/cm^2 [Figure 1].

Teeth in Group E2 were prepared by pilot burs at 0.5 mm depth and teeth in Group D2 were prepared by pilot burs at 1 mm depth under constant water cooling. The prepared surface of each tooth was polished with 400- and 600-grit silicon carbide abrasive papers subsequently. The specimens were embedded in chemically polymerized acrylic resin blocks and prepared surfaces were irradiated by using the same protocol, afterward the resin cement was applied using the same protocol.

Teeth in Group E3 were prepared by pilot burs at 0.5 mm depth and teeth in Group D3 were prepared by pilot burs at 1 mm depth under constant water cooling. The prepared surface of each tooth was polished with 400- and 600-grit silicon carbide abrasive papers and the resin cement was applied to labial surface such as Groups E1, D1, E2, and D2. The specimens were embedded in chemically polymerized acrylic resin blocks. Prepared surfaces and bonded cement were irradiated by using the same protocol.

Teeth in Group C1 were prepared by pilot burs at 0.5 mm depth and teeth in Group C2 were prepared by pilot burs at 1 mm depth under constant water cooling. The resin cement was applied by using the same protocol and teeth were kept as nonirradiated control groups.

Specimens were placed in a universal testing machine (LF Plus, LLOYD, Instrument, Ametek Inc., England). The metal ring was connected with the cross-head and loaded (speed 1 mm/min). Loading was applied to each specimen until the bond between the exposed surface of teeth and resin cement failed. The maximum shear bond strength was recorded from a personal computer as Newton (N) and converted to MegaPascal (MPa). The shear bond strength results (MPa) were analyzed using two-way ANOVA to evaluate the effects of preparation level, treatment protocol, and their interactions. The mean shear bond strength values were then compared using the Tamhane's test. Significance was evaluated at $P < 0.05$ for all tests. All the computational work was performed by means of SPSS 16.0 statistical software (SPSS 16.0; SPSS Inc., Chicago, USA).

To analyze the Fourier transform infrared spectroscopy (FTIR) of the specimens, the self-adhesive cements (Panavia SA Cement Plus Automix Kuraray Noritake Dental Inc., Japan) were placed in a stainless steel mold (5 mm diameter, 2 mm height) and light cured for 10 s with a LED curing light (Elipar™ FreeLight 2, 3M ESPE, St. Paul MN, USA) at an intensity of 750 mW/cm^2. A total of ten specimens were prepared for each group. Half of the specimens were irradiated with a total dose of 60 Gy, applied in fractions over 6 weeks (2-Gy/day fractions, 5 days per week). Specimens were stored in water until FTIR analysis. Thin transparent tablets, which were formed from the control and irradiated adhesive resin cements, were triturationed through KBr (potassium bromide) under the 200 bar. FTIR spectra of the samples were registered by using Unicam Mattson 1000 FTIR spectrometer. (Cambridge, UK).

Enamel and dentin structure was examined with a scanning electron microscope (SEM) (Nova Nano SEM 450, FEI Co., USA) for irradiated and nonirradiated teeth. The acceleration voltage of cathode was set to 14 kV. The images were obtained at ×1,000 and ×10,000 magnifications.

Results

According to the two-way ANOVA results, depth of preparation and treatment protocol and their interactions were significant on shear bond strength of resin cement ($P < 0.05$) [Table 2].

The mean shear bond strength values and standard deviations for resin cement, preparation depth, and treatment protocol are shown in Table 3. Tamhane's *post-hoc* comparisons are shown as smallcaps, and values having same letters are not significantly different ($P > 0.05$). For the 0.5 mm depth of preparation, the mean shear bond strengths for the Groups E1, E2, and E3 were significantly lower than the control C1 group ($P < 0.05$). In addition, the mean shear bond strength for the Groups E2 and E3 were significantly lower than E1 group ($P < 0.05$). No significant differences were found between the Groups E2 and E3 ($P > 0.05$). For the 1 mm depth of preparation, the mean shear bond strengths for the Groups D2 and D3 were significantly lower than D1 and C2 groups ($P < 0.05$). No significant differences were found between the Groups D2 and D3 ($P > 0.05$). Figure 2a and b shows the FTIR spectra of the nonirradiated and irradiated self-adhesive luting cement (Panavia SA Cement Plus Automix, Kuraray Noritake Dental Inc., Japan) between 550 and 4000 cm^{-1}. According to FTIR analysis results, there were no differences between the irradiated and nonirradiated self-adhesive luting cement.

The SEM images show that the well-organized prisms which were observed in nonirradiated enamel changed into an amorphous structure after irradiation [Figure 3]. In addition, the well-organized collagen network and dentinal tubes which were observed in nonirradiated dentin were undergone change and degradation [Figure 4].

Figure 1: Preparation process of specimens

Table 1: The specimens of test groups

Groups	Depth of preparation (mm)	Irradiation: Tooth	Irradiation: Resin cement	Time of tooth preparation (treatment protocol)
Group C1 (control 1)	0.5	−	−	No irradiation
Group E1	0.5	+	−	After irradiation
Group E2	0.5	+	−	Before irradiation
Group E3	0.5	+	+	Before irradiation
Group C2 (control 2)	1	−	−	No irradiation
Group D1	1	+	−	After irradiation
Group D2	1	+	−	Before irradiation
Group D3	1	+	+	Before irradiation

Table 2: Two-way analysis of variance results for comparison of shear bond strength values

Source	SS	df	MS	*F*	*P*
Preparation depth (A)	199.822	1	199.822	149.321	<0.001
Treatment protocol (B)	377.014	3	125.671	93.910	<0.001
A × B	24.237	3	8.079	6.037	0.001
Error	117.762	88	1.338		
Total	45812.467	96			

*P<0.05 indicates significant difference. SS=Sum of square; MS=Mean of square

Table 3: Mean, standard deviation, and Tamhane's multiple comparison test results

Preparation depth (mm)	Treat protocol	MPa* Mean±SD*	MPa* Significant**
0.5	C1	26.48±0.73	a
	E1	23.64±1.41	b
	E2	21.14±1.09	c
	E3	21.20±1.26	c
1	C2	22.13±0.81	c
	D1	22.10±1.40	c
	D2	18.15±1.03	d
	D3	18.55±1.30	d

*SD=Standard deviation; [a,b,c,d]The small caps indicates the statistically relation between the test groups; MPa=Megapascal. **Results of Tamhane's multiple comparisons were shown as small caps and values having same letters are not significantly different (P>0.05)

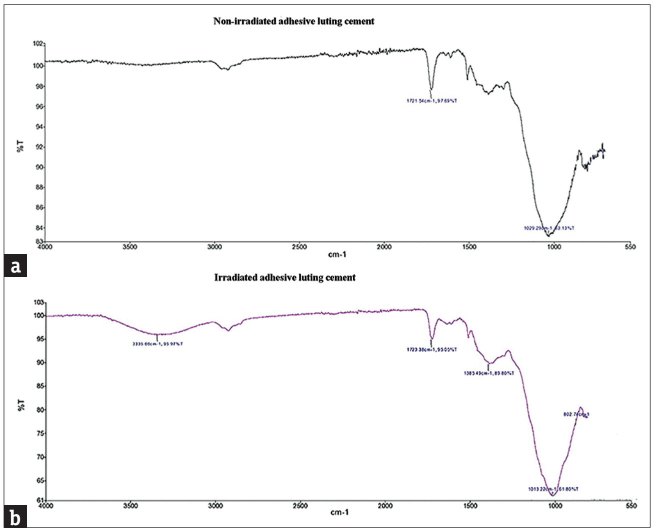

Figure 2: (a and b) Fourier transform infrared spectra of both irradiated and nonirradiated adhesive luting cement. Strong broadband at about 1020 cm^{-1} C—O—C diglycidylmethacrylate and triethylene glycol dimethacrylate. Absorption at about 1700 cm^{-1} showed the C—O stretching band of the carboxylate salts of the polyacid. 3000–3500 cm^{-1} band in spectra was showed to the water band, meant that O—H (or—COOH) group probably did not react

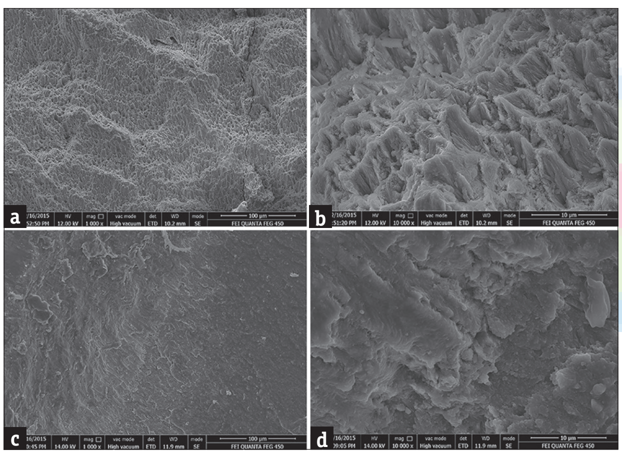

Figure 3: Scanning electron micrograph of the enamel. The images were obtained by scanning electron microscopy at ×1,000 (a and c) and ×10,000 (b and d). (a and b) nonirradiated enamel, (c and d) irradiated enamel

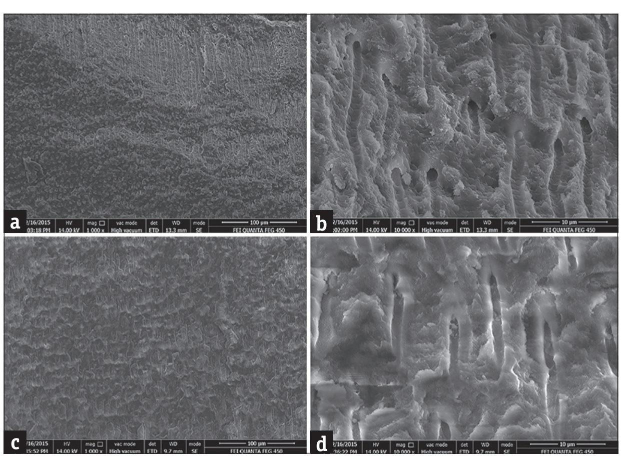

Figure 4: Scanning electron micrograph of the dentin. The images were obtained by scanning electron microscopy at ×1,000 (a and c) and ×10,000 (b and d). (a and b) nonirradiated dentin, (c and d) irradiated dentin

Discussion

The cumulative doses of ionizing radiation to the head and neck region range from 50 to 70 Gy delivered over 5–7 weeks and causes comprehensive side effects.[23] In the present study, specimens were irradiated with 60 Gy, fractionally applied over a period of 6 weeks, which corresponded to standard clinical procedures.[7] It was reported that the storage medium of extracted teeth affects the result of the bond strength studies.[24] In the current study, buffered saline was used as storage medium.[22,25]

It is recommended that HNC patients' restorative procedures should be kept simple to provide esthetic and function.[13] Although some authors offer adhesive restorative techniques for irradiated patients and avoid the extensive treatment,[13,26] general objectives of dental care of the HNC patients, which include having function and esthetic dentition, have no difference from normal ones.[14] Clinically, HNC patients could already have cemented indirect restorations or restorations could be decemented during the radiotherapy or could have needed cemented indirect restorations after radiotherapy. That is the reason why we have designated four groups for each preparation depth.

Adhesive systems require technical precision during operation, such as the need for a separate set of adhesive application stage.[18] In recent years, self-adhesive resin cements have been developed to eliminate technical errors and also to decrease the chair time.[21,22] In the present study, self-adhesive resin cement was used because of having advantages which was stated above. Self-adhesion mechanism could continue for weeks or even months.[27] As the timeframe of irradiation sequences was set as 6 weeks, all specimens were stored in water during the period of 6 weeks, until the shear bond test.

There is no study in the literature about the direct effect of irradiation on adhesive luting cement. Studies dealing with irradiation effects on dental materials focused mainly adhesive restorative techniques.[11,22,28] Gernhardt *et al*. investigated the tensile bond strength of dentin adhesives on irradiated and nonirradiated dentin and found no differences between the groups.[11] As similar, Bulucu *et al*. found no differences between the control and preirradiated groups.[22] In addition, it was reported that the mechanical properties of dentin seemed to be less affected by irradiation than the enamel.[29] In the present study, significant differences were observed between the Groups (preirradiated) C1 and E1 whereas no significant differences were observed between the Groups C2 and D1.

The current study was planned to find out the effect of irradiation on the restored tooth and to appraise the effects of X-ray irradiation on the interfaces between the tooth and the restoration. Therefore, their radiation also was done after restoration in test Groups E3 and D3. Yesilyurt *et al*.[9] investigated the effect of irradiation on glass ionomer cements and found that postirradiated group was shown lower bond strength than control groups and they claimed that irradiation might break the chemical bond between glass ionomer cements and dentin. In the present study, postirradiated Groups (E3, D3) had significant lower bond strength than control (C1, C2) and preirradiated (E1, D1) groups, but there were no significant differences found between the Groups of E2–E3 and D2–D3. Taken together, FTIR spectra of irradiated and nonirradiated luting cements were not different from each other. Moreover, no significant differences between the Groups of E2–E3 and D2–D3 were found. This could not be explained by broken chemical bonds.[30] The common feature of Groups E2, E3 and D2, D3 was surface property of teeth during the radiotherapy. Surface of the teeth in this groups was already prepared before the irradiation, had no sound enamel and dentin, and damaged surface was exposed to irradiation. The effects of irradiation on the structural changes of enamel and dentin are controversial.[7,8,29,31,32] Although enamel composition is mainly inorganic, irradiation affects the organic portion of enamel initially.[33] However, de Siqueira Mellara *et al*. reported that irradiation may affect both organic and inorganic compounds in the enamel.[32] Hence, the mechanical properties and integrity of the enamel could be affected.[29] In contrast to some authors,[34,35] it was reported that irradiation could break down the dentinal collagen matrix[36] or could change crystalline structure of dentin,[37,38] hence could affect the mechanical stiffness of dentin.[7] This study detected significant differences between the irradiated and nonirradiated groups. This situation is also supported by the SEM images. The changes in the crystalline structure of dental hard tissues after irradiation[7,37,38] seemed to affect the bond strength of adhesive luting cement.

The limitation of this *in vitro* study is that only one type of luting cement was used. Therefore, different types of adhesive resins should be evaluated under the same experimental conditions. In addition, the further investigations that assess the *in vivo* conditions should be made.

Conclusions

Within the limitations of this study, the following conclusions can be drawn:

- Dentin seemed to be less affected by irradiation than the enamel
- Time of irradiation (before or after preparation) has significant effect on shear bond strength of adhesive luting cement
- Irradiation has no effect on the chemical bonds of adhesive luting cement.

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Conflicts of interest

There are no conflicts of interest.

References

1. Andrews N, Griffiths C. Dental complications of head and neck radiotherapy: Part 1. Aust Dent J 2001;46:88-94.
2. Jham BC, da Silva Freire AR. Oral complications of radiotherapy in the head and neck. Braz J Otorhinolaryngol 2006;72:704-8.
3. Kielbassa AM, Hinkelbein W, Hellwig E, Meyer-Lückel H. Radiation-related damage to dentition. Lancet Oncol 2006;7:326-35.
4. Lieshout HF, Bots CP. The effect of radiotherapy on dental hard tissue – A systematic review. Clin Oral Investig 2014;18:17-24.
5. Wöstmann B, Rasche KR. The influence of radiotherapy on survival time of teeth and restorations. A study on patients with maxillofacial defects. Zahnärztl Welt 1995;104:627-33.
6. Knychalska-Karwan Z, Pawlicki R, Karwan T. Structural and microanalytical changes in dentition after radiotherapy applied in cases of tumour in the oral cavity region. Folia Histochem Cytobiol 1988;26:25-32.
7. Kielbassa AM, Beetz I, Schendera A, Hellwig E. Irradiation effects on microhardness of fluoridated and non-fluoridated bovine dentin. Eur J Oral Sci 1997;105(5 Pt 1):444-7.
8. Pioch T, Golfels D, Staehle HJ. An experimental study of the stability of irradiated teeth in the region of the dentinoenamel junction. Endod Dent Traumatol 1992;8:241-4.
9. Yesilyurt C, Bulucu B, Sezen O, Bulut G, Celik D. Bond strengths of two conventional glass-ionomer cements to irradiated and non-irradiated dentin. Dent Mater J 2008;27:695-701.
10. Jongebloed WL, Gravenmade EJ, Retief DH. Radiation caries. A review and SEM study. Am J Dent 1988;1:139-46.
11. Gernhardt CR, Kielbassa AM, Hahn P, Schaller HG. Tensile bond strengths of four different dentin adhesives on irradiated and non-irradiated human dentin *in vitro*. J Oral Rehabil 2001;28:814-20.
12. Kielbassa AM, Munz I, Bruggmoser G, Schulte-Mönting J. Effect of demineralization and remineralization on microhardness of irradiated dentin. J Clin Dent 2002;13:104-10.
13. Odlum O. Preventive resins in the management of radiation-induced xerostomia complications. J Esthet Dent 1991;3:227-9.
14. Beech N, Robinson S, Porceddu S, Batstone M. Dental management of patients irradiated for head and neck cancer. Aust Dent J 2014;59:20-8.
15. Thariat J, De Mones E, Darcourt V, Poissonnet G, Dassonville O, Savoldelli C, *et al.* Teeth and irradiation in head and neck cancer. Cancer Radiother 2010;14:128-36.
16. Jham BC, Reis PM, Miranda EL, Lopes RC, Carvalho AL, Scheper MA, *et al.* Oral health status of 207 head and neck cancer patients before, during and after radiotherapy. Clin Oral Investig 2008;12:19-24.

17. Rosales AC, Esteves SC, Jorge J, Almeida OP, Lopes MA. Dental needs in Brazilian patients subjected to head and neck radiotherapy. Braz Dent J 2009;20:74-7.
18. Rosenstiel SF, Land MF, Crispin BJ. Dental luting agents: A review of the current literature. J Prosthet Dent 1998;80:280-301.
19. Hill EE, Lott J. A clinically focused discussion of luting materials. Aust Dent J 2011;56 Suppl 1:67-76.
20. Shiozawa M, Takahashi H, Asakawa Y, Iwasaki N. Color stability of adhesive resin cements after immersion in coffee. Clin Oral Investig 2015;19:309-17.
21. Radovic I, Monticelli F, Goracci C, Vulicevic ZR, Ferrari M. Self-adhesive resin cements: A literature review. J Adhes Dent 2008;10:251-8.
22. Bulucu B, Avsar A, Demiryürek EO, Yesilyurt C. Effect of radiotherapy on the microleakage of adhesive systems. J Adhes Dent 2009;11:305-9.
23. Nauntofte B, Reibel J, Reichart PA, Sciubba JJ, Zakrzewska J. Radiation therapy and the dental management team. Oral Biosci Med 2004;1:149-50.
24. Retief DH. Standardizing laboratory adhesion tests. Am J Dent 1991;4:231-6.
25. Yip HK, Tay FR, Ngo HC, Smales RJ, Pashley DH. Bonding of contemporary glass ionomer cements to dentin. Dent Mater 2001;17:456-70.
26. Geursten W. Ästhetische Restaurationen von anterioren Zahnhartsubstanzdefekten bei Tumorpatienten – Ein Fallbericht. Jahrbuch der Psychologie und Psychosomatik in der Zahnheilkunde. 1991. p. 207.
27. Mount GJ. Glass ionomer cements and future research. Am J Dent 1994;7:286-92.
28. De Moor RJ, Stassen IG, van 't Veldt Y, Torbeyns D, Hommez GM. Two-year clinical performance of glass ionomer and resin composite restorations in xerostomic head- and neck-irradiated cancer patients. Clin Oral Investig 2011;15:31-8.
29. al-Nawas B, Grötz KA, Rose E, Duschner H, Kann P, Wagner W. Using ultrasound transmission velocity to analyse the mechanical properties of teeth after *in vitro*, *in situ*, and *in vivo* irradiation. Clin Oral Investig 2000;4:168-72.
30. Cheung DT, Perelman N, Tong D, Nimni ME. The effect of gamma-irradiation on collagen molecules, isolated alpha-chains, and crosslinked native fibers. J Biomed Mater Res 1990;24:581-9.
31. Jansma J, Buskes JA, Vissink A, Mehta DM, Gravenmade EJ. The effect of X-ray irradiation on the demineralization of bovine dental enamel. A constant composition study. Caries Res 1988;22:199-203.
32. de Siqueira Mellara T, Palma-Dibb RG, de Oliveira HF, Garcia Paula-Silva FW, Nelson-Filho P, da Silva RA, *et al.* The effect of radiation therapy on the mechanical and morphological properties of the enamel and dentin of deciduous teeth – An *in vitro* study. Radiat Oncol 2014;9:30.
33. Joyston-Bechal S. The effect of X-radiation on the susceptibility of enamel to an artificial caries-like attack *in vitro*. J Dent 1985;13:41-4.
34. Zach GA. X-ray diffraction and calcium-phosphorous analysis of irradiated human teeth. J Dent Res 1976;55:907-9.
35. White JM, Goodis HE, Marshall SJ, Marshall GW. Sterilization of teeth by gamma radiation. J Dent Res 1994;73:1560-7.
36. Fisher BV, Morgan RE, Phillips GO, Wardale HW. Radiation damage in calcium phosphates and collagen: An interpretation of ESR spectra. Radiat Res 1971;46:229-35.
37. Jervoe P. X-ray diffraction investigation on the effect of experimental and *in situ* radiation on mature human teeth. A preliminary report. Acta Odontol Scand 1970;28:623-31.
38. Ostrowski K, Dziedzic-Goclawska A, Stachowicz W, Michalik J. Application of electron spin resonance in research on mineralized tissues. Clin Orthop Relat Res 1973;97:213-24.