UNIVERSIDADE FEDERAL DE SANTA CATARINA
CENTRO DE CIÊNCIAS DA SAÚDE
PROGRAMA DE PÓS-GRADUAÇÃO EM ODONTOLOGIA

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Ativação ultrassônica do sistema adesivo aumenta a resistência de união e a penetração intratubular do cimento resinoso à dentina intrarradicular irradiada

Florianópolis
2023

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Dissertação submetida ao Programa de Pós-Graduação em Odontologia, do Centro de Ciências da Saúde da Universidade Federal de Santa Catarina, como requisito para obtenção do título de Mestre. Área de concentração: Endodontia.

Orientador: Prof. Dr. Lucas da Fonseca Roberti Garcia

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Florianópolis

2023

Ficha de identificação da obra elaborada pelo autor,
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Ghidini, Gabriela Pasqualin
Ativação ultrassônica do sistema adesivo aumenta a resistência de união e a penetração intratubular do cimento resinoso à dentina intrarradicular irradiada / Gabriela Pasqualin Ghidini ; orientadora, Lucas da Fonseca Roberti Garcia, coorientadora, Cleonice da Silveira Teixeira, 2023.
51 p.

Dissertação (mestrado) - Universidade Federal de Santa Catarina, Centro de Ciências da Saúde, Programa de Pós Graduação em Odontologia, Florianópolis, 2023.

Inclui referências.

1. Odontologia. 2. Endodontia. I. Garcia, Lucas da Fonseca Roberti . II. Teixeira, Cleonice da Silveira. III. Universidade Federal de Santa Catarina. Programa de Pós Graduação em Odontologia. IV. Título.

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O presente trabalho em nível de Mestrado foi avaliado e aprovado, em 05 de junho de 2023 pela banca examinadora composta pelos seguintes membros:

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Certificamos que esta é a versão original e final do trabalho de conclusão que foi julgado adequado para obtenção do título de mestre em endodontia.

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Prof. Dr. Lucas da Fonseca Roberti Garcia
Orientador

Florianópolis, 2023

AGRADECIMENTOS

Fazer essa pesquisa foi uma grande realização. Trabalhar ativamente para submeter as amostras às diversas etapas, testes e análises foi surpreendentemente divertido. Deixar o consultório clínico para estudar a fundo algo tão delicado foi uma experiência única. Além de que, me senti contribuindo com algo realmente relevante para a sociedade. Portanto, meu mais importante agradecimento vai ao meu orientador Prof. Dr. Lucas da Fonseca Roberti Garcia, que sugeriu o tema, me guiou em todos os caminhos, me atentou a todos os prazos e compromissos e se dedicou juntamente ao desenvolvimento da pesquisa.

Em segundo lugar, agradeço a todas as pessoas que doaram seus dentes para que essa pesquisa pudesse ser realizada. Graças a essas pessoas que muitas pesquisas são realizadas para beneficiar a população. Agradeço a cirurgiã-dentista Mariana Comparotto Minamisako, ao físico Daniel Souza Felipe e ao médico radio-oncologista Paulo Marcelo Rodrigues, do Centro de Pesquisas Oncológicas - CEPON, por se responsabilizarem pela radioterapia realizada nas minhas amostras.

Agradeço a minha coorientadora, Profa. Dra. Cleonice da Silveira Teixeira, que me ensinou a preparar as amostras e a utilizar todos os equipamentos do laboratório, bem como analisou os espécimes no microscópio eletrônico de varredura. O nível de cuidado e detalhamento exigido foi essencial para a qualidade dos resultados obtidos.

Posso dizer que me senti fazendo parte de um time, com todos os alunos da pós-graduação formando uma rede de apoio. Quero agradecer especialmente ao doutorando Luiz Carlos de Lima Dias-Júnior pela ajuda com a parte da estatística, a doutoranda Júlia Savaris com a ajuda na utilização das máquinas do laboratório e a mestranda Bruna Fisher com a ajuda na utilização do estereomicroscópio e outros trabalhos da pós-graduação. Agradeço também ao servidor Lauro por me orientar sempre que havia dúvidas em relação aos equipamentos.

Por fim, mas não menos importante, agradeço ao meu melhor amigo e marido Filipe Gonçalves Teixeira por me acompanhar em vários finais de semanas no laboratório, me ajudar no preparo de amostras, catalogando os espécimes e me ajudando nas análises e nos testes. Seu apoio foi essencial para que eu encontrasse tempo para me dedicar ao mestrado.

RESUMO

O objetivo deste estudo foi avaliar o efeito da ativação ultrassônica de sistemas adesivos condicionamento ácido total (*etch-and-rinse*) e auto condicionante (*self-etch*) na resistência de união à dentina intrarradicular irradiada. Oitenta dentes anteriores superiores humanos foram distribuídos em 8 grupos (n=10), de acordo com o tipo de sistema adesivo utilizado (*etch-and-rinse* e *self-etch*), a ativação ultrassônica ou não dos sistemas adesivos e a condição da dentina intrarradicular (irradiada ou não irradiada - 70 Gy). O tratamento endodôntico foi realizado seguido de preparo do espaço para pinos de fibra de vidro. Após a cimentação dos pinos de fibra de vidro, as raízes foram seccionadas transversalmente em discos de dentina e submetidas ao teste de resistência de união push out em Máquina Universal de Ensaios (Instron, Modelo 4444 - 0,5 mm/min). Em seguida, os espécimes foram avaliados em estereomicroscópio e Microscópio Eletrônico de Varredura (MEV) para análise do padrão de falha. Um dos discos de dentina foi analisado em MEV para avaliar as características da interface adesiva. Os dados foram comparados estatisticamente (push out - ANOVA e *posthoc* teste de Tukey; padrão de falha - teste exato de Fisher - $\alpha = 0,05$). Os espécimes irradiados apresentaram valores de resistência de união significativamente menores que os não irradiados ($P < 0,0001$). A ativação ultrassônica de ambos os sistemas adesivos aumentou a resistência de união do cimento resinoso à dentina intrarradicular irradiada e não irradiada ($P < 0,0001$). A radioterapia afetou significativamente o padrão de falha nos terços médio ($P = 0,024$) e apical ($P = 0,032$) (falha adesiva). A ativação ultrassônica dos sistemas adesivos não afetou o padrão de falha dos espécimes irradiados e não irradiados ($P > 0,05$). Espécimes não irradiados apresentaram uma interface adesiva mais homogênea. Quando ativados ultrassonicamente, ambos os sistemas adesivos apresentaram maior número de prolongamentos resinosos, independentemente da condição da dentina. A ativação ultrassônica de ambos os sistemas adesivos aumentou a resistência de união do cimento resinoso à dentina intrarradicular irradiada e não irradiada.

Palavras-chave: Radioterapia, Ultrassom, Cimento resinoso, Resistência de união, Interface adesiva.

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1 INTRODUÇÃO

O câncer é um dos principais problemas de saúde pública no mundo (GLOBOCAN, 2021). A incidência vem aumentando gradativamente, em parte devido ao crescimento e envelhecimento populacional (GLOBOCAN, 2021). O número de casos novos de câncer da cavidade oral esperados para o Brasil para cada ano do triênio 2020-2022 será de 11.180 casos em homens e de 4.010 em mulheres. Esses valores correspondem a um risco estimado de 10,69 casos novos a cada 100 mil homens, ocupando a quinta posição. Para as mulheres, corresponde a 3,71 para cada 100 mil mulheres, sendo a décima terceira mais frequente entre todos os tipos de câncer (INCA, 2021).

O tabagismo e o consumo de bebidas alcoólicas são os principais fatores de risco para o desenvolvimento de câncer na cavidade oral (KFOURI et al., 2018). Outros aspectos como infecção por papilomavírus humano, radiação solar e herança genética também fazem parte de sua complexa etiologia (BEZERRA et al., 2018). Além disso, fatores socioeconômicos estão fortemente associados ao risco de câncer na cavidade oral (KFOURI et al., 2018). Em geral, indivíduos com nível socioeconômico mais baixo estão mais expostos a fatores de risco comportamentais (como tabagismo e consumo de álcool) e têm acesso limitado aos serviços de saúde ao longo da vida, o que contribui para menores níveis de prevenção, e altos índices de diagnóstico tardio (FREIRE et al., 2020).

A primeira opção de tratamento para o câncer é a cirurgia/quimioterapia, seguido por radioterapia em casos mais avançados (FONSECA et al., 2019). A radioterapia na região de cabeça e pescoço possui severos efeitos colaterais, sendo os mais comuns a mucosite oral, laringofaríngea e esofagiana, a hiposalivação/xerostomia, perda de paladar, trismo, dificuldade de mastigação e deglutição, cárie relacionada à radiação e a osteorradionecrose (MOLESMI et al., 2016; FONSECA et al., 2019).

O motivo pelo qual a cárie relacionada à radiação se desenvolve nesses pacientes ainda é controverso, e alguns estudos sugerem haver um dano direto da radiação aos tecidos dentais (GUPTA et al., 2015; CAMPOS et al., 2017; FONSECA et al., 2019). Já, outros estudos vincularam esse fenômeno como consequência de efeitos colaterais diversos, como a hiposalivação, alterações da microbiota oral, comprometimento na higiene oral, mau estado da saúde bucal antes e após o tratamento, aumento da ingestão de carboidratos e exposição insuficiente ao flúor, independentemente do efeito direto de radiação nos dentes (KIELBASSA et al., 2006; BRENNAN et al., 2010). A cárie relacionada à radiação é uma lesão rampante, de progressão rápida, acometendo principalmente o terço cervical expondo a raiz do dente (KIELBASSA et al., 2006; BRENNAN et al., 2010).

Considerando todas essas alterações no tecido dentário é razoável assumir que esses indivíduos são mais suscetíveis a desenvolver alterações pulpares, e com maiores chances de necessidade de tratamento endodôntico (MARTINS et al., 2016). Além disso, deve-se levar em consideração que a dentina irradiada pode apresentar diferente comportamento em relação aos materiais obturadores e restauradores, principalmente no que diz respeito à sua adesão (RODRIGUES et al., 2018). A radiação provoca alterações na matriz orgânica da dentina, interferindo no condicionamento ácido e na aplicação de sistemas adesivos, bem como na microdureza e resistência à tração da mesma, tornando-a mais friável (REED et al., 2015; RODRIGUES et al., 2018).

Em pacientes irradiados deve-se evitar ao máximo a realização de procedimentos cirúrgicos, como exodontias, devido ao alto risco de osteorradionecrose (RAGGIO et al., 2018). Por este motivo, a reabilitação de dentes com grande perda coronária em pacientes portadores de câncer de cabeça e pescoço (CCP) tem se tornado realidade e a qualidade da dentina irradiada tem sido amplamente estudada (REED et al., 2015).

Nestes casos, após o tratamento endodôntico, o dente pode ser reabilitado com pinos de fibra de vidro pré-fabricados (VERDUM et al., 2020). Devido ao módulo de elasticidade similar ao da dentina, pinos de fibra de vidro tendem a diminuir a concentração de estresse na interface pino-dentina, reduzindo o risco de fratura radicular em comparação aos pinos metálicos (SANTOS-FILHO et al., 2014; GULDENER et al., 2016).

A adesão do pino de fibra de vidro à dentina intrarradicular é realizada com cimentos resinosos, que são classificados como de múltiplos passos, que podem apresentar polimerização química ou dual e os cimentos autoadesivos, que não necessitam de aplicação prévia de sistemas adesivos (SARKIS-ONOFRE et al., 2014).

Os procedimentos adesivos para fixação do pino de fibra de vidro com cimentos resinosos de múltiplos passos (sistemas adesivos com condicionamento ácido total ou autocondicionantes) tendem a ser mais complexos devido aos inúmeros passos operatórios que devem ser realizados para uma adequada hibridização do substrato dentinário (CHERSONI et al. 2005; D'ARCANGELO et al. 2008). Em contrapartida, os cimentos autoadesivos têm se tornado cada vez mais difundidos devido a menor sensibilidade de sua técnica de aplicação (CHERSONI et al. 2005; D'ARCANGELO et al. 2008; SARKIS-ONOFRE et al. 2014).

Em pacientes portadores de CCP irradiados, há maior dificuldade de adesão do sistema adesivo à dentina intrarradicular devido à degradação dos prolongamentos odontoblásticos, seguido da obliteração dos túbulos dentinários (KIELBASSA et al., 1999; GONÇALVES et al., 2014), além do colapso das fibrilas colágenas presentes da matriz orgânica dentinária (AGGARWAL et al. 2009; DE SIQUEIRA et al., 2014; LOPES et al., 2020). Consequentemente, a retenção de pinos de fibra de vidro é comprometida (AGGARWAL et al. 2009; LOPES et al., 2020). Dessa forma, técnicas para aprimorar essa adesão têm sido avaliadas, como por exemplo, a ativação ultrassônica do sistema adesivo (VERDUM et al., 2020).

Insertos ultrassônicos são amplamente utilizados na endodontia em diversas situações clínicas, como para a remoção de retentores intrarradiculares, material obturador e cirurgias parendodônticas (VERDUM et al., 2020). Entretanto, sua principal aplicação atualmente tem sido na ativação ultrassônica de soluções irrigantes para otimizar a sanificação e limpeza do sistema de canais radiculares (BAGIS 2008; VERDUM et al. 2020) e, mais recentemente, a de cimentos obturadores, para aumentar sua capacidade de selamento (DE BEM et al. 2020). A ativação ultrassônica permite que a solução irrigante atinja áreas anatômicas complexas intocadas pela instrumentação, e melhora o selamento endodôntico, pois permite que o cimento penetre mais profundamente na dentina intertubular (BAGIS et al., 2008; VERDUM et al. 2020; DE BEM et al. 2020).

Recentemente, Verdum et al. (2020) demonstraram que a ativação ultrassônica do sistema adesivo auto condicionante foi capaz de aumentar sua penetração nos túbulos dentinários, melhorando significativamente a retenção de pinos de fibra de vidro. Por outro lado, não se sabe ainda se a ativação ultrassônica de sistemas adesivos auto condicionantes e de condicionamento ácido total podem aumentar a sua resistência de união à dentina intrarradicular irradiada.

2 OBJETIVOS E HIPÓTESE

2.1 OBJETIVO GERAL

- Avaliar o efeito da ativação ultrassônica de sistemas adesivos na resistência de união do cimento resinoso à dentina intrarradicular de dentes submetidos a radiação ionizante.

2.2 OBJETIVOS ESPECÍFICOS

- Avaliar o efeito ativação ultrassônica de sistema adesivo de condicionamento ácido total (*etch-and-rinse*) na resistência de união à dentina intrarradicular de dentes submetidos ou não à radiação ionizante.
- Avaliar o efeito ativação ultrassônica de sistema adesivo auto condicionante (*self-etch*) na resistência de união à dentina intrarradicular de dentes submetidos ou não à radiação ionizante.

2.3 HIPÓTESE

A ativação ultrassônica dos sistemas adesivos de condicionamento ácido total (*etch-and-rinse*) e auto condicionante (*self-etch*) afetará a resistência de união do cimento resinoso à dentina intrarradicular irradiada?

3 ARTIGO CIENTÍFICO

Este estudo foi preparado e escrito na forma de artigo científico de acordo com as normas para submissão no periódico *Journal of the Mechanical Behavior of Biomedical Materials* (Qualis A1, Fator de Impacto 4.042).

Ultrasonic activation of adhesive systems increases the bond strength and intratubular penetration of resin cement to irradiated root dentin

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ABSTRACT

This study aimed to evaluate the effect of ultrasonic activation of etch-and-rinse and self-etch adhesive systems on the bond strength of a resin cement to irradiated intraradicular dentin. Eighty human maxillary anterior teeth were distributed into 8 groups (n = 10), according to the type of adhesive system used (etch-and-rinse and self-etch), the ultrasonic activation of the adhesive systems, and the dentin condition (irradiated or non-irradiated - 70 Gy). Endodontic treatment was performed followed by fiberglass post-space preparation. After fiberglass posts' luting, the roots were transversely sectioned on dentin discs and submitted to the push-out bond strength test in a Universal Testing Machine (0.5 mm/min). The fractured specimens were analyzed under a stereomicroscope and Scanning Electron Microscope (SEM) for failure mode classification. One of the dentin discs was analyzed under SEM to evaluate the characteristics of the adhesive interface. Data were statistically compared (push-out - ANOVA and Tukey's post hoc test; failure mode - Fisher's exact test - $\alpha = 0.05$). Irradiated specimens had lower bond strength than non-irradiated specimens ($P < 0.0001$). Ultrasonic activation of both adhesive systems increased the bond strength of the resin cement to irradiated and non-irradiated dentin ($P < 0.0001$). Radiotherapy significantly affected the failure mode in the middle ($P = 0.024$) and apical thirds ($P = 0.032$) (adhesive failure). Ultrasonic activation of adhesive systems did not affect the failure mode of irradiated and non-irradiated specimens ($P > 0.05$). Non-irradiated specimens had a more homogeneous adhesive interface. When ultrasonically activated, both adhesive systems showed a greater number of resinous tags, regardless of the dentin condition. Ultrasonic activation of both adhesive systems increased the bond strength of the resin cement to irradiated and non-irradiated intraradicular dentin.

Keywords: Radiotherapy, Ultrasonics, Resin cement, Bond strength, Adhesive interface.

1. Introduction

Cancer is one of the main public health problems worldwide (Globocan, 2021). Its incidence has been gradually increasing, especially due to population growth and aging (Globocan, 2021). Among the different types of head and neck cancer, smoking and alcohol consumption are the main risk factors for oral cancer development (Globocan, 2021). The treatment of head and neck cancer involves surgery, chemotherapy, and radiotherapy, which may be employed individually or combined (Jawad et al., 2015).

Radiation therapy for head and neck cancer treatment leads to severe side effects (Molesmi et al., 2016; Fonseca et al., 2019). The most common are oral mucositis, hyposalivation/xerostomia, trismus, osteoradionecrosis, and radiation-related caries (Molesmi et al., 2016; Fonseca et al., 2019).

The etiology of radiation-related caries is multifactorial, and several studies suggest direct damage from radiation to dental structures (de Siqueira Mellara et al., 2014; Gupta et al., 2015; Campos et al., 2017; Fonseca et al., 2019). Other studies associate this phenomenon with many factors, such as hyposalivation, changes in the oral microbiota, compromised oral hygiene, poor oral health status before and after treatment, increased consumption of carbohydrates, and insufficient fluoride exposure, regardless of the direct radiation to teeth (Kielbassa et al., 2006; Brennan et al., 2010).

However, it is consolidated in the literature that restorative materials bonding to irradiated dentin are compromised (Aggarwal et al., 2009; Rodrigues et al., 2018; Lopes et al., 2020). Radiation promotes the degeneration of the odontoblastic processes (Gonçalves et al., 2014), obliteration of the dentinal tubules (Kielbassa et al., 1999), and breakdown of the collagen fibrils network of the dentin organic matrix (Cancelier et al., 2023), hindering the monomeric diffusion of adhesive systems (Reed et al., 2015; Rodrigues et al., 2018).

Conversely, in patients with head and neck cancer undergoing radiotherapy, surgical procedures, such as tooth extraction, should be avoided due to the high risk of osteoradionecrosis (Raggio et al., 2018). For this reason, the rehabilitation of teeth with severe coronal destruction using fiberglass posts has become a common clinical practice for oncological patients (Reed et al., 2015; Rodrigues et al., 2018). Therefore, the quality of irradiated dentin has been widely studied (Reed et al., 2015; Rodrigues et al., 2018).

The adhesion of fiberglass post to intraradicular dentin is performed with resin cement (Sarkis-Onofre et al., 2014). Resin cement may used with 3-step (etch-and-rise) or self-adhesive adhesive systems. The etch-and-rinse adhesive system requires etching with 37% phosphoric acid before primer and adhesive placement to promote dentin demineralization and exposure of the collagen fibrils network (Pereira et al., 2018). Conversely, self-etch adhesive systems do not require acid etching and rinsing, as they contain acid resin monomers in their primers' composition (Pereira et al., 2018).

Adhesive strategies for fiberglass posts' bonding using resin cement that require etch-and-rinse adhesive systems are more complex due to the numerous operative steps for proper dentin hybridization (Chersoni et al. 2005; D'arcangelo et al. 2008). On the other hand, self-etching adesive system has lower sensitivity of the technique because it has less steps (Chersoni et al. 2005; D'arcangelo et al. 2008; Sarkis-Onofre et al. 2014).

Ultrasonic inserts are widely used in endodontics for activation of irrigating solutions to optimize the sanitization of the root canal system (Hachem et al., 2022; Kaplan & Erdemir, 2023), and more recently, to increase the sealing capacity of root canal sealers (Wiesse et al., 2018; De Bem et al., 2020). Verdum et al. (2022) demonstrated that ultrasonic activation of a self-etch adhesive system increased its penetration into the dentinal tubules, improving the retention of fiberglass posts. However, whether ultrasonic activation will also be able to enhances the retention of fiberglass posts luted with etch-and-rinse or self-etch adhesive systems on irradiated dentin must be investigate.

Therefore, this study aimed to evaluate the effect of ultrasonic activation of two adhesive systems (etch-and-rinse and self-etch) on the bond strength of the resin cement to the irradiated intraradicular dentin. The following hypothesis was tested: would the ultrasonic activation of both types of adhesive systems increase the bond strength of the resin cement to the irradiated intraradicular dentin?

2. Materials and methods

2.1. Ethical approval and sample size calculation

After approval from the Research Ethics Committee (CAAE: 51465221.5.0000.0121), and under the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments, eighty human teeth were selected. Sample size calculation was based on the study by Verdum et al. (2022), with the G*Power software (version 3.1.9.6) (http://www.psycho.uni-duesseldorf.de/abteilungen/aap/gpower3/). The following parameters were considered for calculation: α error = 0.05 (5% significance level), test power (1-β) = 0.80, and effect size = 0.5. Wilcoxon signed-rank statistical test (matched pairs) was performed. The type of power analysis was set *a priori* (compute required sample size - given α, power, and effect size). The calculation was carried out based on two factors and a normal parental distribution. The sample size calculation determined the number of ten specimens per experimental group for a proper statistical analysis.

2.2. Specimens selection

Eighty (n=10) maxillary incisor and canine teeth freshly extracted from human subjects for reasons unrelated to this study were used. The teeth investigated in this survey had similar dimensions, fully formed root and closed apical portion, a single and straight canal, no signs of resorption or internal/external calcifications. These characteristics were verified using periapical radiography. Teeth with cracks, signs of fracture, or carious lesions were excluded from the final sample. The selected teeth were immersed in 0.5% chloramine T solution at 4°C for up to 1 month following extraction. After this period, the teeth were washed in running water for 24 hours and then, individually stored in flasks containing distilled water, and kept in an oven at 37ºC to avoid dehydration until use.

The teeth were decoronated at the cementoenamel junction with a double-sided diamond disk (Fava, São Paulo, SP, Brazil) under copious water cooling. Root length was standardized at 15 mm. The diameter of the cervical portion of the root canal was also standardized (buccolingual and mesiodistal ratio). The cervical portion of the root canal was measured with a digital caliper (Starret 727, Starret, Itu, SP, Brazil). Specimens with a cervical diameter greater than 1.5 mm (post diameter) were discarded from the final sampling and replaced (Pereira et al. 2017).

2.3. Experimental groups distribution

Initially, the specimens were randomly distributed into 8 experimental groups (n=10) (www.random.org), according to the type of adhesive system used (etch-and-rinse or self-etch), ultrasonic activation or not of the adhesive system and the experimental condition of the intraradicular dentin (irradiated or non-irradiated) as represented in figure 1.

2.4. Specimens irradiation

The specimens were irradiated at the Department of Radiotherapy of the Oncology Research Center (CEPON; Florianópolis, SC, Brazil) under the responsibility and supervision of a physicist and a radio-oncologist. The irradiation was performed in a linear accelerator (Clinac 2100C; Varian Medical Systems, Inc., Palo Alto, CA, USA) by the Intensity Modulated Radiotherapy Technique (IMRT) with dynamic collimators (Dynamic Multileaf Collimator - DMLC) (Cancelier et al., 2023; Coelho et al., 2023). A tomographic analysis of the specimens was performed before radiotherapy. Then, a dose distribution map was prepared to ensure that the total predicted irradiation dose was uniformly delivered to all specimens. The specimens were placed in plastic support and completely immersed in distilled and deionized water, aligned and equidistant from the source of radiation, ensuring a standardized distribution of doses (400 UM/min) (Da Cunha et al. 2016; Lopes et al., 2020). The specimens irradiation followed the CEPON protocol for the treatment of head and neck cancer, with 6MV of energy (photons) and total administration of 70 Gy, divided into 2 Gy daily, 5 days a week, for 7 weeks (Yamin et al., 2018; Cancelier et al., 2023; Coelho et al., 2023). At the end of each irradiation cycle, the distilled and deionized water was replaced by artificial saliva and the teeth were kept in an oven at 37ºC to simulate the oral conditions. For a new cycle of irradiation, the artificial saliva was replaced by distilled and deionized water. After 7 weeks of irradiation, the teeth were stored again in artificial saliva at 37°C until use (**Figure 1**).

2.5. Specimens preparation

The root canals (irradiated and non-irradiated) were initially negotiated with a size 10 K-file (Dentsply-Maillefer, Ballaigues, Switzerland). The working length (WL) was established by the visual method, subtracting 1 mm from the total root canal length after the tip of the instrument was visualized in the apical foramen. The chemical-mechanical preparation was performed with an R40 instrument (40/.06 - 21 mm) (Reciproc system; VDW GmbH, Munich, Germany), coupled to a 6:1 reducing contra-angle (Schuster Equipamentos Odontologistas, Santa Maria, RS, Brazil) driven by an electric motor (Sensory; Schuster Equipamentos Odontológicos), in reciprocating motion mode, according to the manufacturer's instructions.

The instrument was inserted into the root canal in pecking motions to prepare the cervical, middle, and apical thirds, with an amplitude of movement not greater than 3 mm at each insertion. At the end of each root third preparation, the instrument was removed for cleaning in sterile gauze soaked in alcohol. Then, the root canals were irrigated with 2 mL of 2.5% sodium hypochlorite solution (Asfer, Santa Maria, RS, Brazil) using a 30-gauge needle (Ultradent Products Inc., South Jordan, UT, USA) coupled to a 5-mL plastic syringe (Ultradent Products Inc.) 2 mm below the WL.

Apical patency during preparation was maintained with a size 15 K-file on the apical foramen. After preparation completion, final irrigation was performed with 3 mL of 17% EDTA (Farmácia Formula e Ação, São Paulo, SP, Brazil) for 3 minutes, followed by 2 mL of 2.5% sodium hypochlorite solution for smear layer removal. The root canals were dried with R40 absorbent paper cones (VDW GmbH). Root canal obturation was performed using the Tagger hybrid technique with an epoxy resin-based sealer (AH Plus Jet; Dentsply, Petrópolis, RJ, Brazil) and gutta-percha cones (VDW GmbH), as shown in Fig. 1.

2.6. Fiberglass posts preparation

The materials used in the adhesive procedures are described in Table 1. After the endodontic sealer had set, the roots were inserted into silicon molds (Express XT, 3M, Sumaré, SP, Brazil) to simulate the alveolar bone. Then, 2/3 of the filling material was removed, followed by post space preparation with the specific drills from the fiberglass post system selected (Exacto; Angelus, Londrina, PR, Brazil), according to the cervical diameter of the root canals used in this study ($\geq$1.5 mm).

The root canals were cleaned by copious irrigation with distilled water. The fiber post was selected according to the diameter of the drill used in the post space preparation. The fiberglass posts were cleaned with 70% alcohol for 30 seconds, washed in running water for 30 seconds and jet-air dried. The silane bonding agent (Angelus) was applied on the fiberglass posts' surface for 60 seconds with the aid of a microbrush (KG Brush Extra Fine Microapplicator; KG Sorensen, Cotia, SP, Brazil), jet-air dried for 5 seconds and reserved until use.

Table 1 - Materials used for the adhesive procedures.

Material	Composition	Batch	Manufacturer
Adper Scotchbond Multipurpose (etch-and-rinse)	Primer: 2-hydroxyethyl methacrylate and polyalkenoic acid. Adhesive: Bis-GMA, 2-hydroxyethyl methacrylate, and amines.	2230100849	3M ESPE, Sumaré, SP, Brazil
Clearfil SE Bond (self-etch)	Primer: MDP, HEMA, hydrophilic dimethacrylate, CQ, N,N-Diethanol p-toluidine. Adhesive: MDP, Bis-GMA, HEMA, hydrophobic dimethacrylate, CQ, N,N-Diethanol p-toluidine, Silanized Colloidal Silica.	000181	Kuraray Medical Inc., Kurashiki, Japan
RelyX ARC (resin cement)	Bis-GMA, TEGDMA, pigments, tertiary amine, benzoyl peroxide, 67.5 wt% inorganic zirconia/silica particles (mean particle size: 1.5 µm).	2305800125	3M ESPE, Sumaré, SP, Brazil
Fusion-Duralink	37% phosphoric acid, surfactant, and coloring agent.	010323	Angelus, Londrina, PR, Brazil

Bis-GMA - Bisphenol A-Glycidyl dimethacrylate; UDMA - Urethane Dimethacrylate, Bis-EMA - Bisphenol A Ethoxylate Dimethacrylate, TEGDMA - Triethylene Glycol Dimethacrylate, HEMA - Hydroxyethyl Methacrylate; MDP - 10-Methacryloyloxydecyl dihydrogen phosphate; CQ - Camphorquinone.

2.7. Etch-and-rinse groups

The same adhesive procedure was performed for irradiated and non-irradiated teeth (n=40). The root canal walls were pre-etched with 37% phosphoric acid (Fusion-Duralink, Angelus) for 15 seconds, copiously washed with distilled water for 20 seconds, and then dried with absorbent paper. Two layers of primer (Scotchbond Multipurpose; 3M ESPE) were applied on the root canal walls with a microbrush (KG Brush Extra Fine; KG Sorensen) for 10 seconds, and jet-air dried for 5 seconds both. Then, two layers of adhesive (Adper Scotchbond Multipurpose, 3M ESPE) were applied on the root canal walls with a microbrush for 10 seconds and light-cured for 20 seconds (VALO; Ultradent, Indaiatuba, SP, Brazil - light intensity (power): 1600 mW/ cm^2 (peak); wavelength range: 395 - 480nm). In half of the samples (irradiated and non-irradiated), the primer and adhesive layers were ultrasonically activated with a 0.2 mm diameter insert (E1 Irrisonic; Helse Ultrasonics, Santa Rosa do Viterbo, SP, Brazil) coupled to an ultrasonic device (Schuster Sonic Evo Led Odontológico; Schuster Equipamentos Odontológicos), set at the “ENDO” mode, with a potency of 1, as recommended by the manufacturer.

The ultrasonic activation was performed as described in the study by Verdum et al. (2022). The first layer of primer was applied, then the ultrasonic insert was positioned within the root canal, 1 mm below the post space preparation length. The insert was moved towards the root canal walls for 10 seconds, and jet-air dried for 5 seconds. The procedure was repeated one more time. Sequentially, the first layer of adhesive was applied, than the insert was positioned within the root canal, 1 mm below the post space preparation length. The insert was moved towards the root canal walls for 10 seconds, and jet-air dried for 5 seconds. This procedure was repeated one more time, followed by light-curing for 20 seconds (VALO; Ultradent).

2.8. Self-etch groups

The same adhesive procedure was performed for irradiated and non-irradiated teeth (n=40). Two thin layers of primer (Clearfil SE Bond; Kuraray Medical Inc.) were actively applied on the root canal walls with the aid of a microbrush for 10 seconds, and jet-air dried for 5 seconds. Next, two layers of adhesive (Clearfil SE Bond; Kuraray Medical Inc.) were applied with a microbrush and light-cured for 20 seconds (VALO; Ultradent). In half of the samples (irradiated and non-irradiated), the primer and adhesive were ultrasonically activated, as described above.

2.9. Fiberglass posts luting

Once the application of the adhesive systems was completed, the resin cement (RelyX ARC; 3M ESPE) was dispensed onto a glass plate and manipulated for 10 seconds until a homogeneous paste was obtained. The resin cement was placed within the root canal with a No. 16 endodontic probe (Hu-Friedy Mfg. Co., Chicago, IL, USA). A thin layer of cement was applied on the fiberglass posts' surface, which was inserted apically inside the root canal in a rotational movement. The excess of resin cement was removed using a composite resin spatula, followed by light-curing for 60 seconds (VALO; Ultradent). All adhesive procedures were performed according to the manufacturer's instructions (Fig.1).

2.10. Push-out bond strength test

After the fiberglass posts' luting, the roots were removed from their silicone molds and individually embedded in colorless self-curing acrylic resin (JET, Clássico, São Paulo, SP, Brazil) to form resin blocks (25.0 mm x 10.0 mm). The resin blocks were transversally cross-sectioned in relation to their long axis with a diamond cutting disc (152.4 mm x 0.5 mm x 12.7 mm) (Buehler, Lake Forest, IL, USA) mounted on a high-speed metallographic precision cutter (Isomet 1000; Buehler) with a weight of 150 g and a constant speed of 250 RPM, under copious water cooling. Two dentin discs 1.0-mm thick (+ 0.1 mm) were obtained per root third. One dentin disc per root third was selected for the push-out bond strength test.

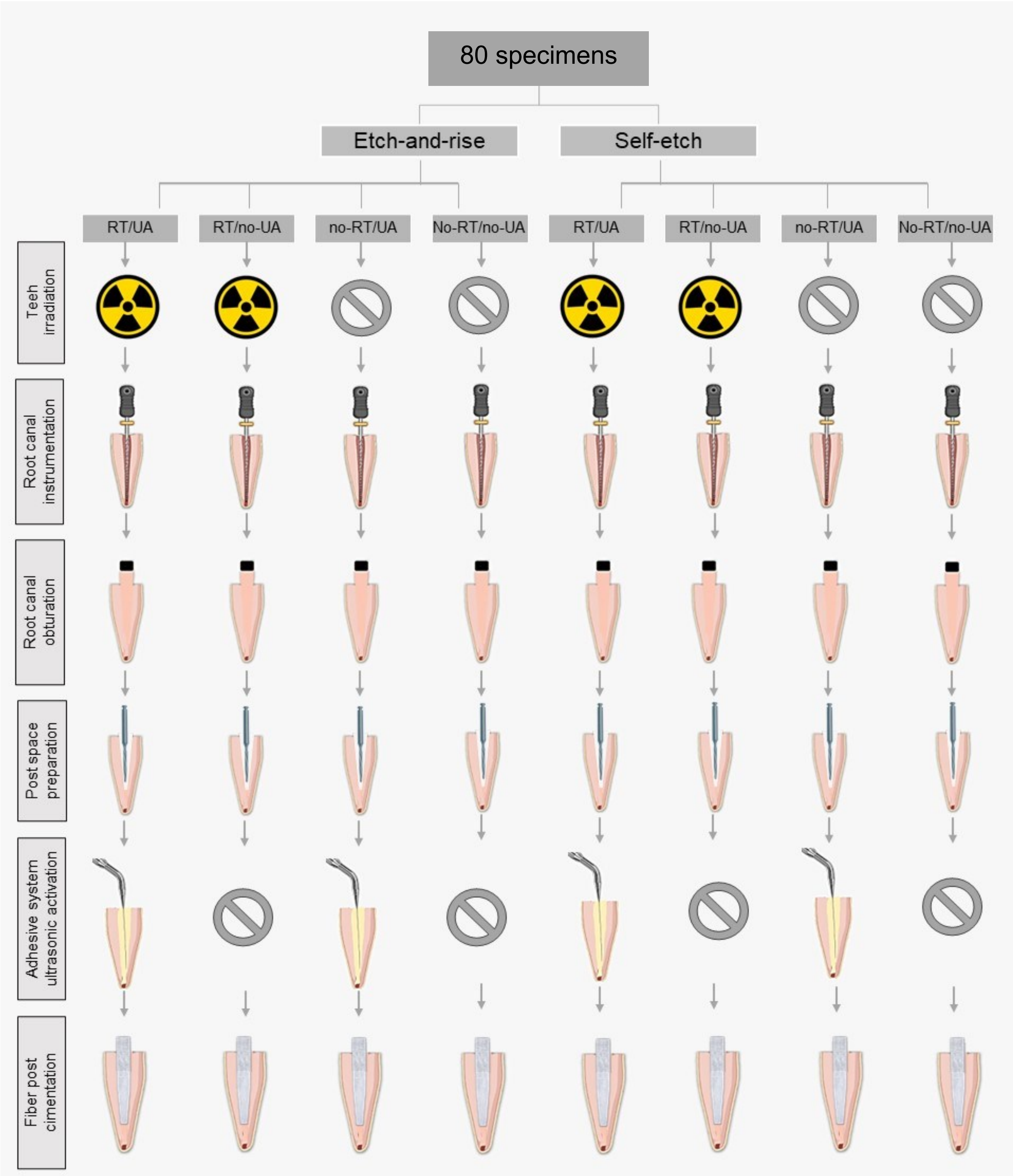

Fig. 1 - Experimental design and groups distribution.

The dentin discs were individually fixed on a stainless steel metal base, containing a 2.5 mm diameter hole in the central region, coupled to the lower portion of the universal testing machine (Model 4444; Instron, Canton, MA, USA). Metallic cylindrical plungers, with an active tip selected according to the diameter of the fiberglass posts (0.47 mm to 1.3 mm) in each dentin disc (cervical, middle, and apical third) were fixed in the upper portion of the machine and driven in the apical-cervical direction (crosshead speed of 0.5 mm/min) until the displacement of the post/adhesive/resin cement set (de Souza et al., 2022). The force required for displacement was measured in kiloNewtons (kN), transformed into Newtons (N) and divided by the bonding surface area (BSA) (mm^2), and then converted into MPa (MegaPascal).

The BSA was calculated using the following formula:

$$BSA = \pi (R + r) \sqrt{h2 + (R - r)2}$$

where, R = root canal radius in its cervical portion; r = root canal radius in its apical portion; and h = height/thickness of the dentin disc.

2.11. Failure mode analysis

Once the push-out bond strength test was completed, the dentin discs were subjected to visual inspection under a stereomicroscope (SteREO Discovery.V12, Carl Zeiss, Jena, Germany) (×40). The failure modes were classified, as follows: 1) adhesive - dentin surface free of resin cement; 2) cohesive of the cement - fracture of the bonding area, with part of the intraradicular dentin covered by cement; 3) cohesive of the fiberglass post - post fracture; and 4) mixed - two different types of failure in the same specimen. Failure mode was expressed as a percentage of the total number of specimens in a group.

Specimens from the most representative areas of the failure modes were selected and examined under a Scanning Electron Microscope (SEM) (Jeol JSM 5410; Sony, Tokyo, Japan) in ×100, ×300, ×500, ×1000 and ×1500 magnifications.

2.12. Adhesive interface analysis

The adhesive interface from the dentin discs which were not submitted to the push-out bond strength test was analyzed under SEM (Jeol JSM 5410; Sony). Initially, the dentin discs were attached with a double-sided tape into Teflon rings

(5.0-mm-thick x 2.0-cm in diameter) with the cervical surface facing downwards, and then, embedded in epoxy resin. Next, the specimens were polished with abrasive sandpaper (Norton, São Paulo, SP, Brazil) in decreasing order of abrasiveness (#400, 600, and 1200), followed by polishing with abrasive disks and pastes (0.3 and 0.1 µm) (Arotec, São Paulo, SP, Brazil). After fixation and dehydration, the specimens were demineralized with 6 mol/L hydrochloric acid (Dermus, Florianópolis, SC, Brazil) for 30 seconds, followed by deproteinization with 2% NaOCl solution (Asfer) for 10 minutes. The specimens were washed in distilled water, dried, and placed in a vacuum chamber to be sputter-coated with a layer of gold of 300 Å (BalTec SCD 005, BalTec Co., Canonsburg, PA, USA) (Tedesco et al., 2014). Images of different portions of each dentin disc were obtained at ×100, ×300, ×1000 and ×1500 magnifications. The following structures were considered during the qualitative analysis (Tedesco et al., 2014): integrity of the adhesive interface between intraradicular dentin and resin cement (presence of gaps or voids, or a continuous and homogeneous interface); and density and depth of penetration of the resinous tags within the dentinal tubules.

2.13. Statistical analysis

The statistical analysis was performed using the IBM SPSS Statistics software (IBM Corp., Armonk, NY, USA). The normality of the data distribution was confirmed by the Shapiro-Wilk test, and the equality of variances by the Levene test ($P > 0.05$). Therefore, parametric tests were applied. The effect of radiotherapy, adhesive systems, ultrasonic activation, and their interaction, were assessed using the ANOVA test, followed by the Tukey's post hoc test ($P < 0.05$). The influence of the root thirds was assessed using the ANOVA test for repeated data and the Tukey's post hoc test ($P < 0.05$). The distribution of the failure mode within the experimental groups was compared using the Fisher's exact test ($P < 0.05$). The significance level was set at 5% for all analyses ($\alpha = 0$ .05).

3. Results

3.1. Push-out bond strength

No specimens were lost during the push-out bond strength testing. The bond strength results may be seen in Tables 2 and Figs. 2 and 3.

Radiotherapy significantly affected the bond strength of the self-etch adhesive system ($P < 0.0001$). Irradiated specimens had significantly lower bond strength than the non-irradiated ones, except in the cervical third, when ultrasonic activation was performed ($P = 0.701$). Radiotherapy also led to a decrease in the bonding strength of the etch-and-rinse adhesive system within all root thirds of the root, particularly when the specimens were not subjected to ultrasonic activation ($P < 0.0001$). Only the apical third showed significant difference in the ultrasonically-activated specimens, exhibiting decreased bond strength in the irradiated ones ($P = 0.013$).

When the adhesive systems were not ultrasonically activated and the specimens were not irradiated, the etch-and-rinse adhesive system showed greater bond strength than the self-etch adhesive system in the cervical third ($P < 0.05$). There was no significant difference in the other root thirds ($P > 0.05$). In the irradiated specimens, no difference was observed between the adhesive systems ($P > 0.05$).

In instances where the adhesive systems underwent ultrasonic activation and the specimens were not subjected to irradiation, the etch-and-rinse adhesive system showed greater bond strength in the cervical third compared to the self-etch adhesive system ($P < 0.05$). Conversely, the self-etch adhesive system had greater bond strength than the etch-and-rinse adhesive system in the middle and apical thirds ($P < 0.05$). In the irradiated specimens, the etch-and-rinse adhesive system had greater bond strength than the self-etch adhesive system in the cervical third. There was no significant difference in the other root thirds.

Table 2 - Mean values and standard deviation of bond strength (MPa) for both adhesive system at the different root thirds.

Non-irradiated	Etch-and-rinse (no-ultrasonic activation)	Etch-and-rinse (ultrasonic activation)	Self-etch (no-ultrasonic activation)	Self-etch (ultrasonic activation)
Cervical	6.72 ± 1.04A,a	7.95 ± 1.39A,a	5.17 ± 1.32A,b	6.31 ± 0.73A,b
Middle	5.86 ± 1.39A,a	8.54 ± 1.08A,a	5.53 ± 1.60A,a	10.95 ± 1.02A,b
Apical	4.57 ± 1.07A,a	7.41 ± 1.28A,b	3.85 ± 1.25A,a	10.94 ± 1.72A,c
Irradiated	**Etch-and-rinse (no-ultrasonic activation)**	**Etch-and-rinse (ultrasonic activation)**	**Self-etch (no-ultrasonic activation)**	**Self-etch (ultrasonic activation)**
Cervical	4.06 ± 1.29B,a	7.64 ± 1.28A,a	3.72 ± 0.72B,a	6.11 ± 0.95A,b
Middle	4.21 ± 0.72B,a	7.90 ± 1.26A,a	3.81 ± 1.29B,a	8.08 ± 1.19B,a
Apical	3.21 ± 1.14B,a	6.06 ± 1.11B,a	2.46 ± 0.75B,a	6.16 ± 0.96B,a

*Same capital letters in columns indicate no difference among experimental the experimental conditions (radiotherapy); Same lowercase letters on lines indicate no difference among experimental groups. ANOVA and ANOVA-repeated data tests, Tukey's post hoc test ($P < 0.05$).

When the root thirds were compared, the self-etch adhesive system, with no-ultrasonic activation, had significantly greater bond strength values in the cervical and middle thirds than the apical third, in both irradiated and non-irradiated specimens (*P* < 0.0001). After ultrasonic activation of the self-etch adhesive system, a greater bond strength in the middle and apical thirds than the cervical third in the non-irradiated specimens was observed (*P* < 0.0001). In the irradiated specimens, the bond strength in the middle third was greater when compared to the cervical and apical thirds (*P* < 0.0001) (Fig. 2).

The etch-and-rinse adhesive system, with no-ultrasonic activation, had greater bond strength in the cervical and middle thirds, compared to the apical third, in non-irradiated specimens (*P* = 0.001). In the irradiated specimens, no significant difference was observed among the root thirds (*P* = 0.101). After ultrasonic activation of the etch-and-rinse adhesive system, no significant difference was observed among the root thirds in the non-irradiated specimens (*P* > 0.05). When irradiated, the cervical and middle thirds had greater bond strength than the apical third (*P* = 0.005) (Fig. 3).

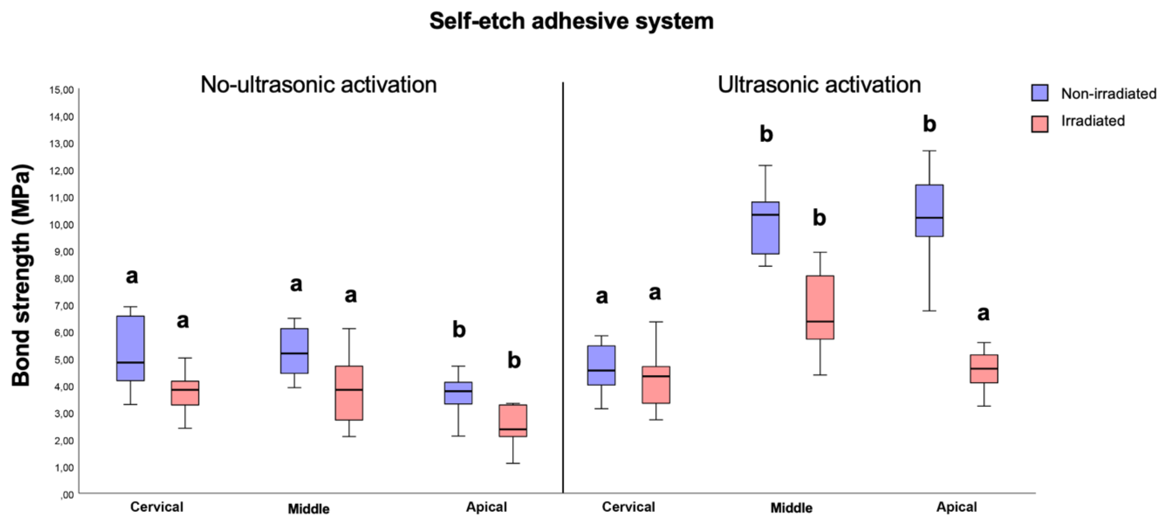

Fig. 2. Box plot graphical representation of bond strength (MPa) for the self-etch adhesive system in the different root thirds. Same lowercase letters indicate no difference among groups. ANOVA and ANOVA-repeated data tests, Tukey's post hoc test, *P* < 0.05.

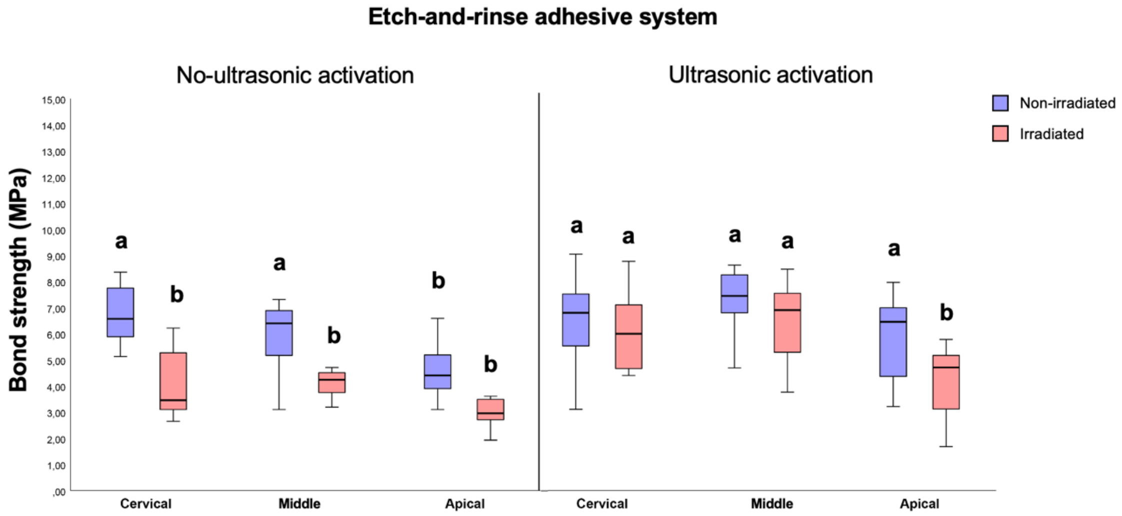

Fig. 3. Box plot graphical representation of bond strength (MPa) for the etch-and-rinse adhesive system in the different root thirds. Same lowercase letters indicate no difference among groups. ANOVA and ANOVA-repeated data tests, Tukey's post hoc test, $P < 0.05$.

3.2. Failure mode analysis

Fig. 4 presents the frequency of failure modes in each experimental group, in the different root thirds. Representative SEM images of the failure modes may be seen in Fig. 5. Radiotherapy significantly affected the failure mode in the middle (P = 0.024) and apical (P = 0.032) thirds, in which a higher incidence of adhesive-type failures was observed. In the non-irradiated specimens, there was a higher incidence of cohesive of the resin cement and mixed failures. This difference was observed, especially, when the etch-and-rinse adhesive system was used (P = 0.001). No significant differences were observed between irradiated and non-irradiated specimens in the cervical third ($P > 0.05$).

Ultrasonic activation of the adhesive systems did not affect the failure mode of irradiated and non-irradiated specimens ($P > 0.05$). Regarding the adhesive systems, a significant difference was observed only in the apical third of the irradiated and ultrasonically-activated specimens. The self-etch adhesive system had a higher incidence of cohesive of the resin cement failure, while the etch-and-rinse adhesive system had more adhesive-type failures (P = 0.035). In the other experimental conditions, the adhesive systems had no difference regarding the failure mode ($P > 0.05$).

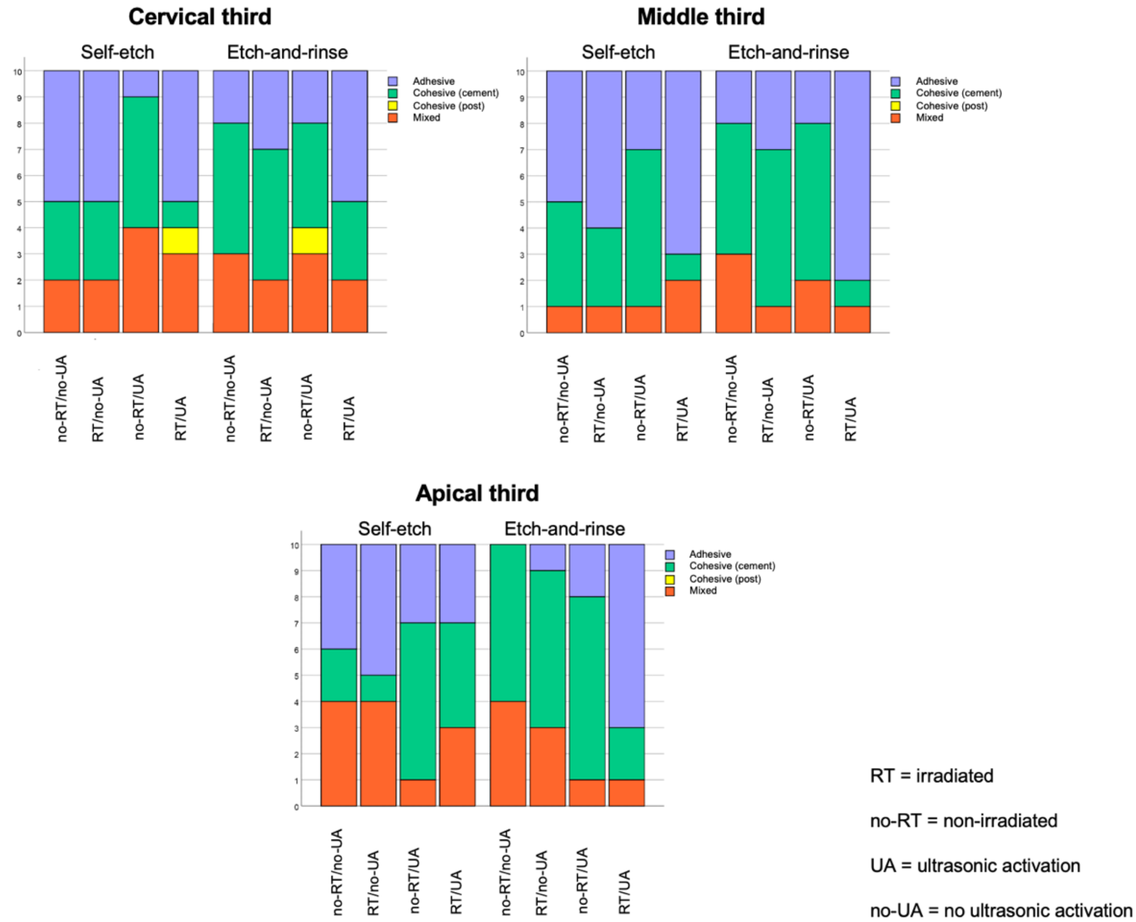

Fig. 4. Graphical representation of the failure mode (%) at the different root thirds.

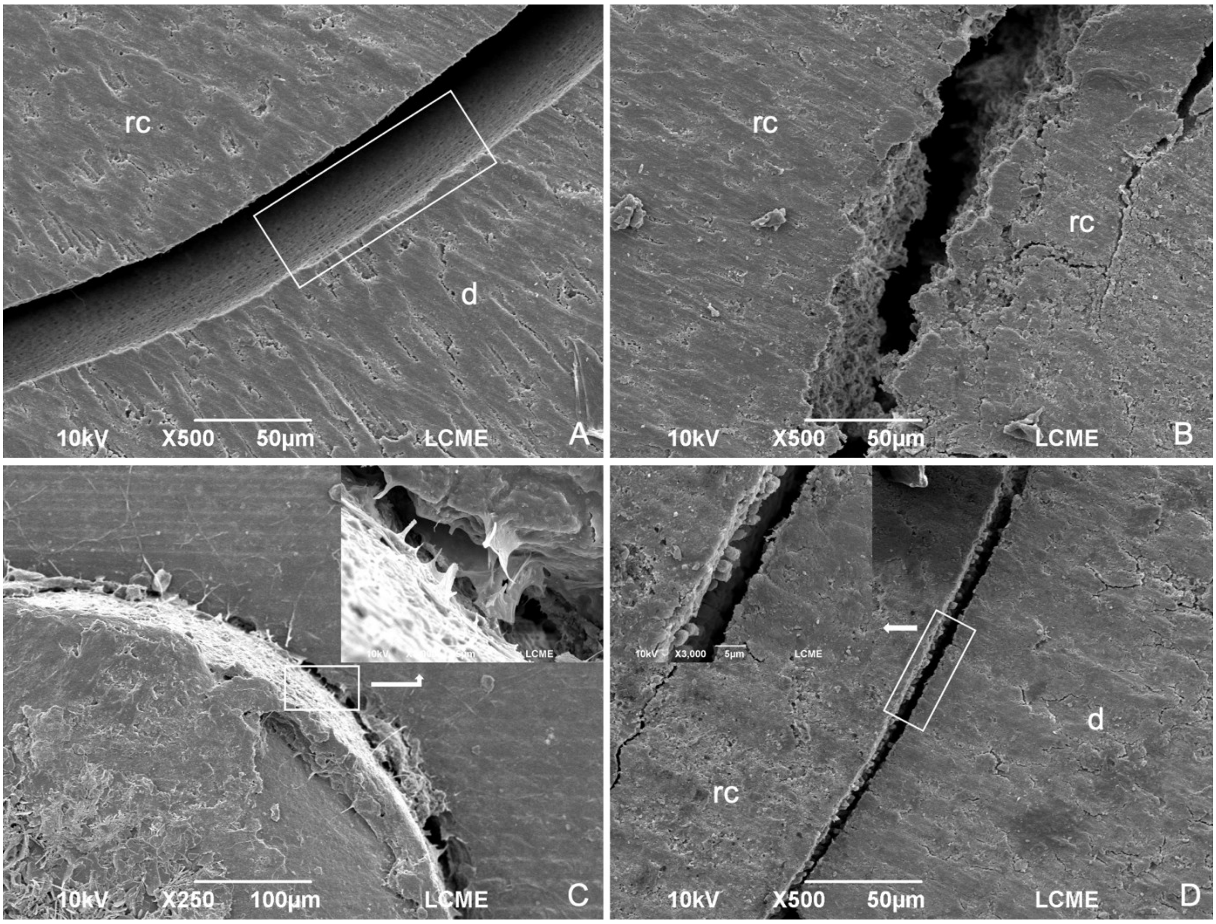

Fig. 5. Representative SEM images of the failure mode after the push-out bond strength test. A: Self-etch adhesive system (irradiated/no-ultrasonic activation) - adhesive failure. Note the dentinal tubules free of resin cement/adhesive system (detail); dentin (d), resin cement (rc). B: Self-etch adhesive system (non-irradiated/ultrasonic activation) - cohesive failure of the resin cement (rc). C: Etch-and-rinse adhesive system (irradiated/ultrasonic activation) - mixed failure. Areas corresponding to adhesive and cohesive failures of the resin cement. Note in higher magnification the cohesive failure of the adhesive system at the top of the hybrid layer (detail). D: Etch-and-rinse adhesive system (irradiated/ultrasonic activation) - cohesive failure of the resin cement (rc). Note the fractured resinous tags (detail) in higher magnification.

3.3. Adhesive interface analysis

SEM images of the qualitative analysis of the adhesive interface may be seen in Fig. 6. Gaps in the adhesive interface were observed in both irradiated and non-irradiated specimens, regardless of the type of adhesive system used. However, in the irradiated specimens, the incidence and frequency of gaps were greater than in the non-irradiated ones. Non-irradiated specimens had a more homogeneous adhesive interface. When ultrasonically activated, both adhesive systems had a higher prevalence of areas of juxtaposition between resin cement and intraradicular dentin. Furthermore, resinous tags, in greater number and density, and penetrating more deeply into the dentinal tubules were also noted. These features were observed regardless of the experimental condition of the dentin substrate (irradiated or non-irradiated).

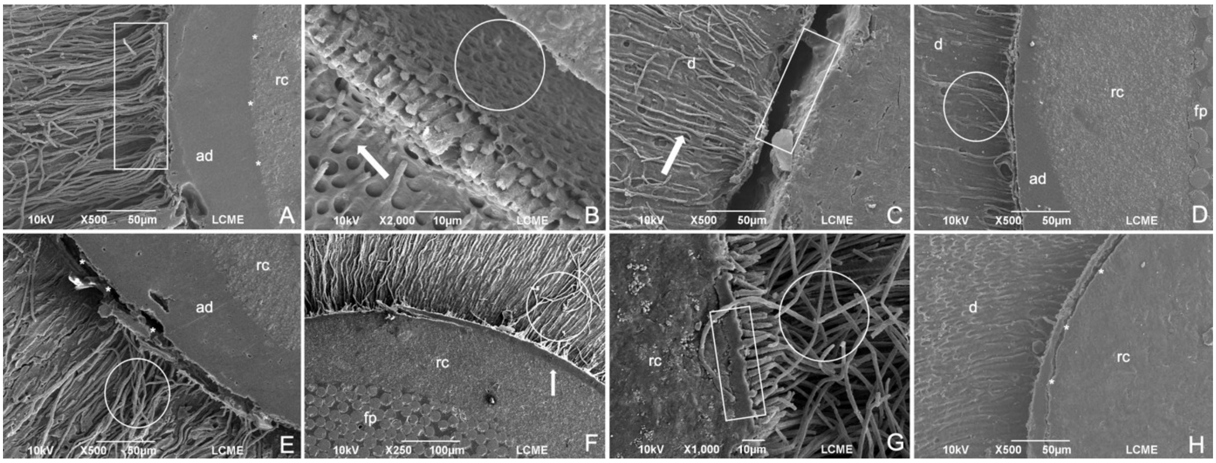

Fig. 5. Representative SEM images of the adhesive interface. A: Etch-and-rinse adhesive system (non-irradiated/ultrasonic activation) - intratubular penetration of the resin cement after ultrasonic activation. Note the number, density, and depth of the resinous tags (detail); adhesive layer (ad), resin cement (rc); hybrid layer (*). B: Etch-and-rinse adhesive system (irradiated/no ultrasonic activation) - lower density of the resinous tags (arrow). Observe the obliteration of the dentinal tubules entrance after irradiation (circle). C: Etch-and-rinse adhesive system (irradiated/ultrasonic activation) - desruption of the hybrid layer (detail). However, is still possible to note a considerable number of resinous tags after ultrasonic activation (arrow), dentin (d). D: Etch-and-rinse adhesive system (irradiated/no ultrasonic activation) - a small number of resinous tags (circle), dentin (d), adhesive layer (ad), resin cement (rc), fiberglass post (fp). E: Self-etch adhesive system (irradiated/ultrasonic activation) - a discontinuous interface between the adhesive layer and dentin (*). However, note the density and depth of resinous tags after ultrasonic activation (circle). F: Self-etch adhesive system (irradiated/no ultrasonic activation) - a thin layer of the adhesive system(arrow). The small number of resinous tags (circle), resin cement (rc), fiberglass post (fp). G: Self-etch adhesive system (non-irradiated/ultrasonic activation) - the continuous adhesive interface between resin cement layer and dentin (*). Note the greater number of resinous tags after ultrasonic activation (circle), resin cement (rc). H: Self-etch adhesive system (irradiated/no ultrasonic activation) - discontinuous adhesive interface (*). Note the absence of resinous tags in this area, resin cement (rc), dentin (d).

4. Discussion

Oncological patients who have received radiotherapy for head and neck cancer have a higher risk of experiencing osteoradionecrosis (Rodrigues et al., 2018). As a result, it is recommended to avoid extracting teeth with substantial coronal damage and instead focus on their restoration (Jawad et al., 2015; Rodrigues et al., 2018).

Nonetheless, the impact of radiotherapy on dentin microstructure presents difficulties in performing restorative treatments in these patients, as it detrimentally influences the bond strength between resin-based materials and the dentin substrate (Başer Can et al., 2022).

In a recent study, Verdum et al. (2022) reported that ultrasonic activation improved the penetration of a self-etch adhesive system into the dentinal tubules of sound teeth, increasing the retention of fiberglass posts luted with resin cement. Conversely, there is no information in the literature regarding the effect of ultrasonic activation of the adhesive system on the bond strength of the resin cement to irradiated intraradicular dentin. The assessment of this clinical topic for oncological patients undergoing radiotherapy is crucial.

Bearing this in mind, the purpose of the present study was to evaluate the effect of ultrasonic activation of adhesive systems on the bond strength of resin cement to irradiated intraradicular dentin. Based on the results obtained, the tested hypothesis was confirmed, since the ultrasonic activation of the adhesive systems (etch-and-rinse and self-etch) increased the bond strength of the resin cement in irradiated and non-irradiated teeth.

In the present *in vitro* study, the specimens were irradiated by a treatment modality named IMRT (Parahyba et al., 2016). Clinically, this radiation therapy modality allows the delivery of high doses of radiation to neoplastic cells, avoiding the overexposure of healthy tissues to unnecessary irradiation (Parahyba et al., 2016).

The total dose of irradiation delivered to the adjacent tissues is always dependent on the primary location of the tumor (Parahyba et al., 2016). Hence, the construction of a dose distribution map before radiotherapy is important in accurately determining the amount of radiation delivered to the tumor center and the adjacent tissues (Parahyba et al., 2016). In this study, a dose distribution map was elaborated before specimen irradiation. The total dose of irradiation applied to the specimens was 70 Gy, which is in line with standard clinical protocols for head and neck cancer treatment, which are emulated in laboratory conditions (Verdonck et al., 2009; Thariat et al., 2012; Velo et al., 2018). Other studies reported using doses that ranged from 55 to 70 Gy (Santos-Filho et al., 2014; Guldener et al., 2016; Yamin et al., 2018; Velo et al., 2018). However, it is prudent to mention that the total irradiation dose delivered to teeth in laboratory studies may not correspond to the clinical reality (Parahyba et al., 2016).

The total dose of irradiation delivered to teeth during radiotherapy is most often under or overestimated because it is based on data referring to doses delivered to the maxilla or the mandible (Verdonck et al., 2009; Thariat et al., 2012). Parahyba et al. (2016) assessed the maximum (Dmax) and mean (Dmed) doses of irradiation delivered to the teeth, maxilla, and mandible of patients with oropharyngeal and nasopharyngeal cancer treated by the IMRT. The authors reported that the amount of radiation delivered to the teeth was lower than what was delivered to the maxilla or the mandible. It was also found that the maxillary teeth of patients with nasopharyngeal tumors received more irradiation than patients with oropharyngeal tumors (Parahyba et al., 2016). Despite this limitation of laboratory studies, the assessment of the effects of radiation therapy on dental structures is imperative for the adoption of clinical protocols that meet the restorative/prosthetic needs of oncological patients.

Human maxillary incisor and canine teeth, with root canals with similar dimensions (buccolingual and mesiodistal ratio ≤1.5), were used in the present study (Pereira et al., 2017). The push-out bond strength test was carried out using cylindrical metallic plungers with similar diameters (0.47 mm-1.3 mm) of the central area of the fiberglass post at each root third. Therefore, it was possible to apply a shear force as close as possible to the resin cement/adhesive system/dentin interface (Alencar et al., 2021). The analyzes of the failure mode and the adhesive interface were also performed to interpret the push-out bond strength findings.

Radiation therapy negatively affected the bond strength of the resin cement/adhesive system to the intraradicular dentin. However, ultrasonic activation was a positive strategy for both adhesive systems, regardless of the experimental condition of the dentin (irradiated and non-irradiated). The acoustic energy produced by the ultrasonic insert within the post space preparation pushes the primer and adhesive against the root canal walls, increasing their penetration into hard-to-reach areas, such as the dentinal tubules (Verdun et al., 2022).

One of the most negative effects of radiation therapy on dentin substrate is the collapse of the collagen fibrils network (Reed et al., 2015; Rodrigues et al., 2018; Cancelier et al., 2023). However, the heat created during ultrasonic activation decreased the primer and adhesive viscosity, enhancing monomer diffusion into dentin, and consequently, their bonding capacity (Loguercio et al., 2011; Zarpellon et al., 2016). Although the primer and adhesive viscosity were not measured in this study, etch-and-rinse adhesive systems are more viscous than self-etch ones (Verdun et al., 2022). In the present study, the analysis of the adhesive interface corroborated these findings. A homogeneous interface, with few gaps, and resinous tags in greater number, density, and depth, were observed in the ultrasonically-activated specimens, for both adhesive systems, especially in the non-irradiated specimens.

The etch-and-rinse adhesive system had greater push-out bond strength than the self-etch adhesive system when no ultrasonic activation was performed in the non-irradiated specimens. Such a fact demonstrates that ultrasonic activation was more important to increase the bond strength in specimens that used the self-etch adhesive system, especially in the middle and apical thirds, as reported by Verdum et al. (2022). The self-etch adhesive system used in this study has acid resin monomers in its primer composition (Gordan et al., 1997; Borges et al., 2009). The etching capacity of these acid resin monomers is lower than the phosphoric acid used in the etch-and-rinse adhesive systems (Gordan et al., 1997; Borges et al., 2009). Therefore, the smear layer is not removed during dentin hybridization and becomes part of the hybrid layer (Gordan et al., 1997; Borges et al., 2009). This phenomenon may lead to adhesive failures due to lower monomer infiltration and dentinal tubule penetration, decreasing the bond strength values (Gordan et al., 1997; Borges et al., 2009). These findings might explain the lowest bond strength for the self-etch adhesive system with no ultrasonic activation (Verdun et al., 2022).

Conversely, in the irradiated specimens, no bond strength difference between the adhesive systems was noted. Previous studies have already shown that etch-and-rinse adhesive systems have higher bond strength than self-etching ones in irradiated teeth (Muñoz et al., 2020; Başer Can et al., 2022). Therefore, it might be suggested that ultrasonic activation proved to be an important strategy for obtaining adequate bonding of resin cement to irradiated dentin, especially when using self-etch adhesive systems (Verdun et al., 2022).

The Adper Scotchbond Multipurpose (etch-and-rinse) and Clearfil SE Bond (self-etch) were used in the study because they presented better adhesion results to dentin when compared to other adhesives systems (Hardan et al., 2023; Tsujimoto et al., 2022). However, further studies are needed with universal adhesives, since they are more frequently used in clinical practice (Hardan et al., 2023; Tsujimoto et al., 2022).

Radiation therapy significantly affected the failure mode in the middle and apical thirds, in which a higher incidence of adhesive-type failures was observed. In addition to the deleterious changes caused by ionizing radiation (Muñoz et al., 2020; Başer Can et al., 2022), the distribution and the diameter of dentinal tubules in the middle and apical thirds are lower than the cervical third (Ferrari et al., 2000). The morphological peculiarities of these portions of the root canal are harmful to adhesive strategies, such as acid etching, adhesive system/resin cement placement and penetration into the dentinal tubules, moisture control, and limited light-curing, contributing to inappropriate polymerization (Ferrari et al., 2000).

On the other hand, ultrasonic activation of the adhesive systems did not affect the failure mode of irradiated and non-irradiated specimens. Overall, the self-etch adhesive system had a predominance of cohesive failures of resin cement, while the etch-and-rinse adhesive system had more adhesive-type failures. Although radiotherapy significantly affects the organic portion of dentin, which highly compromises the adhesion of resinous materials, such a phenomenon does not seem to be relevant in determining the failure mode observed in the ultrasonically-activated experimental groups (Muñoz et al., 2020; Başer Can et al., 2022).

Based on the findings of our study, it is licit to state that clinical protocols based on scientific evidence are essential for oncological patients' dental management. The restorative technique assessed in the present *in vitro* study bridged a gap in the current literature, showing promising results concerning the retention of fiberglass posts luted with resinous materials. Conversely, further studies must be performed to complement and scientifically validate this clinical protocol for oncological patients.

5. Conclusions

This is the first investigation to assess the effect of ultrasonic activation of etch-and-rinse and self-etch adhesive systems on the bond strength of resin cement to irradiated dentin. Within the limits of this laboratory study, the following conclusions may be drawn:

1. The ultrasonic activation significantly increased the bond strength of the resin cement to irradiated and non-irradiated intraradicular dentin, regardless of the type of adhesive system.

2. The ultrasonic activation of both adhesive systems positively affected their intratubular penetration.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgments

The authors would like to thank the Department of Radiotherapy of the Oncology Research Center (CEPON - Florianópolis, SC, Brazil) for the irradiation of the specimens.

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4 CONCLUSÃO

Apesar das limitações de um estudo laboratorial, pode-se concluir que:

1. A ativação ultrassônica aumentou significativamente a resistência de união do cimento resinoso à dentina intrarradicular irradiada e não irradiada, independentemente do tipo de sistema adesivo.

2. A ativação ultrassônica de ambos os sistemas adesivos afetou positivamente a penetração intratubular.

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ANEXOS

Anexo A - Parecer consubstanciado do Comitê de Ética em Pesquisa com Seres Humanos da UFSC.

UNIVERSIDADE FEDERAL DE SANTA CATARINA - UFSC

PARECER CONSUBSTANCIADO DO CEP

DADOS DO PROJETO DE PESQUISA

Título da Pesquisa: Efeito da ativação ultrassônica do sistema adesivo na resistência de união de pinos de fibra de vidro à dentina radicular irradiada

Pesquisador: LUCAS DA FONSECA ROBERTI GARCIA

Área Temática:

Versão: 2

CAAE: 51465221.5.0000.0121

Instituição Proponente: CENTRO DE CIÊNCIAS DA SAÚDE

Patrocinador Principal: Financiamento Próprio

DADOS DO PARECER

Número do Parecer: 5.102.330

Apresentação do Projeto:

As informacoes que seguem e as elencadas nos campos "Objetivo da pesquisa" e "Avaliacao dos riscos e beneficios" foram retiradas do arquivo PB_INFORMACOES_BASICAS_DO_PROJETO_1814629.pdf, de 06/10/2021, preenchido pelos pesquisadores.

Segundo os pesquisadores:

RESUMO

"Apos a radioterapia, a dentina apresenta uma serie de alteracoes que dificultam a adesao de diversos materiais, como os sistemas adesivos. Varias tecnicas vem sendo desenvolvidas para contornar essa situacao. Sendo assim, o objetivo desta pesquisa e avaliar o efeito da ativacao ultrassonica de sistemas adesivos de multiplos passos (etch-and-rinse) e auto condicionante (self-etch) na resistencia de uniao do cimento resinoso/pino de fibra de vidro a dentina intraradicular de dentes submetidos a radiacao ionizante. Oitenta dentes humanos anteriores serao distribuidos em 8 grupos (n=10), de acordo com o tipo de sistema adesivo utilizado (multiplos passos ou auto condicionante), a ativacao ultrassonica ou nao dos sistemas adesivos e a condicao da dentina intrarradicular (irradiada e nao-irradiada): G1 - sistema adesivo de multiplos passos/sem ativacao ultrassonica/dentina nao-irradiada; G2 - sistema adesivo de multiplos passos/sem ativacao ultrassonica/dentina irradiada; G3 - sistema adesivo de multiplos passos/ativacao

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UF: SC **Município:** FLORIANOPOLIS
Telefone: (48)3721-6094 **E-mail:** cep.propesq@contato.ufsc.br

Situação do Parecer:
Aprovado

Necessita Apreciação da CONEP:
Não

FLORIANOPOLIS, 12 de Novembro de 2021

Assinado por:
Nelson Canzian da Silva
(Coordenador(a))