e-ISSN: 3026-1473

CROWN
Journal of Dentistry and Health Research

Journal website: https://phlox.or.id/index.php/crown

Influence of Preparation Design on the Fracture Resistance of Endodontically Treated Teeth Restored with Full-Coverage Crowns in Jakarta, Indonesia

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ARTICLE INFO

Keywords:
Endodontically treated teeth
Fracture resistance
Full-coverage crowns
Indonesia
Preparation design

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All authors have reviewed and approved the final version of the manuscript.

https://doi.org/10.59345/crown.v1i2.89

A B S T R A C T

Introduction: Endodontically treated teeth are more susceptible to fracture due to the loss of tooth structure and moisture. Full-coverage crowns are often used to restore these teeth and enhance their fracture resistance. However, the influence of different preparation designs on the fracture resistance of endodontically treated teeth remains a topic of investigation. This study aimed to evaluate the fracture resistance of endodontically treated teeth restored with full-coverage crowns with different preparation designs in Jakarta, Indonesia. **Methods:** Forty extracted human premolars were endodontically treated and divided into four groups (n=10): Group 1: Butt-joint margin with a 1 mm chamfer finish line; Group 2: Shoulder margin with a 1.5 mm chamfer finish line; Group 3: Deep chamfer margin with a 2 mm chamfer finish line; and Group 4: Shoulder margin with a rounded shoulder finish line. All teeth were prepared for full-coverage crowns and restored with standardized metal-ceramic crowns. A universal testing machine was used to apply compressive load to the teeth until fracture. The fracture resistance values were recorded in Newtons (N) and analyzed using one-way ANOVA and Tukey's post-hoc test ($\alpha=0.05$). **Results:** The mean fracture resistance values (N) were as follows: Group 1 (1250 ± 150), Group 2 (1480 ± 180), Group 3 (1180 ± 130), and Group 4 (1550 ± 200). One-way ANOVA revealed significant differences in fracture resistance among the groups ($p<0.05$). Tukey's post-hoc test indicated that Group 4 exhibited significantly higher fracture resistance than Group 1 and Group 3 ($p<0.05$). Group 2 also demonstrated significantly higher fracture resistance than Group 3 ($p<0.05$). **Conclusion:** Within the limitations of this study, the shoulder margin with a rounded shoulder finish line provided the highest fracture resistance for endodontically treated teeth restored with full-coverage crowns. The butt-joint margin and deep chamfer margin preparations exhibited lower fracture resistance.

1. Introduction

Endodontic treatment, encompassing procedures like root canals, plays a vital role in preserving teeth compromised by irreversible pulpitis (inflammation) or necrosis (tissue death). While endodontic treatment is often the preferred alternative to extraction, it inevitably alters the tooth's structure and, subsequently, its biomechanics. The very process involves the removal of a significant portion of the inner tooth, including dentin, the hard tissue that lies beneath the enamel. This removal weakens the tooth, making it more susceptible to fracture, especially under the stresses and strains of normal chewing and biting. Furthermore, endodontic treatment disrupts the tooth's natural hydration. Vital teeth receive moisture from the pulp, the living tissue within the tooth. This moisture contributes to the tooth's overall strength and flexibility. When the pulp is removed during endodontic treatment, the tooth can become dehydrated and brittle, further increasing its vulnerability to fracture. The consequences of tooth fracture can range from minor discomfort to severe complications, potentially leading to tooth loss. Therefore, restoring and reinforcing endodontically treated teeth is crucial to ensure their long-term survival and functionality. Full-coverage crowns have emerged as a common restorative option for these teeth, providing a protective "helmet" that encapsulates the weakened tooth structure.[1-3]

Crowns serve several critical functions in protecting endodontically treated teeth. Firstly, they redistribute the forces generated during chewing and biting more evenly across the tooth structure. This prevents stress from concentrating at weakened points, reducing the risk of catastrophic fracture. Secondly, crowns provide a physical barrier against further damage, guarding the remaining tooth structure from the forces and wear of everyday use. However, the effectiveness of a crown in preventing fracture is not solely dependent on its mere presence. Several factors interplay to influence the overall outcome, including the material of the crown, the type of cement used to adhere the crown to the tooth, and the design of the tooth preparation. The preparation design, in particular, is a crucial consideration. It dictates the shape and form of the tooth structure that remains after the tooth is modified to receive the crown. This, in turn, affects the retention of the crown (how well it stays in place), the resistance form (how well it withstands forces), and the overall structural integrity of the tooth-crown complex.[4-6]

Different preparation designs, such as the chamfer, shoulder, and butt-joint margins, each with varying finish line configurations, can significantly impact the stress distribution within the tooth and its ability to withstand fracture. A well-engineered preparation design should provide a delicate balance between ensuring adequate retention and resistance form while preserving as much healthy tooth structure as possible. While the influence of preparation design on the fracture resistance of endodontically treated teeth has been the subject of numerous investigations, the findings have not always been consistent. There is no universally accepted consensus on the optimal preparation design. This lack of clarity underscores the need for further research to shed more light on this critical aspect of restorative dentistry. Moreover, most of the existing studies have been conducted in specific geographical locations and populations. The results of these studies may not be directly applicable to other populations due to potential variations in tooth morphology, dietary habits, and oral hygiene practices. These factors can all influence the behavior of teeth under stress and, consequently, the effectiveness of different preparation designs.[7-10] Therefore, this study aimed to evaluate the fracture resistance of endodontically treated teeth restored with full-coverage crowns using different preparation designs in a specific population in Jakarta, Indonesia.

2. Methods

This in vitro study was conducted at Private Dental Clinics in Jakarta, Indonesia. In vitro studies, performed outside the living body using extracted teeth or models, allow for standardized conditions and precise control over variables, minimizing the confounding factors that often arise in clinical settings. This rigorous control enhances the reliability and internal validity of the study, ensuring that the observed effects can be confidently attributed to the factors under investigation. Ethical approval for this study was obtained from the Institutional Review Board of CMHC Research Center, Indonesia before the commencement of the study. This step ensured the research adhered to the highest ethical standards, respecting the rights and welfare of the individuals whose extracted teeth were used in the study.

Forty extracted human premolars, free from caries (cavities), cracks, or previous restorations (fillings), were collected from patients undergoing tooth extraction for orthodontic or periodontal reasons. The use of extracted human teeth enhances the clinical relevance of the study, as these teeth retain their natural morphology, structure, and material properties. This contrasts with artificial teeth or models, which may not fully replicate the behavior of natural teeth under stress. The teeth were stored in 0.1% thymol solution at room temperature until they were used in the study. Thymol solution is a commonly used storage medium for extracted teeth, helping to prevent microbial growth and maintain the integrity of the tooth structure. Proper storage is essential to ensure the collected teeth remain viable and representative of their natural state, minimizing any potential influence on the study's outcomes. All teeth underwent standardized endodontic treatment using a step-back technique and were obturated with gutta-percha and sealer. The step-back technique is a widely employed method for root canal preparation, involving the sequential enlargement of the root canal to ensure thorough cleaning and shaping. Gutta-percha, a natural polymer, is the standard material used for filling the root canal space, while sealer enhances the seal and prevents leakage. The access cavities, created to gain entry to the root canal system during endodontic treatment, were restored with composite resin. Composite resin is a tooth-colored restorative material that mimics the appearance of natural tooth structure. Its use in this study ensured that the access cavities did not influence the fracture resistance of the teeth, maintaining the focus on the preparation designs. The teeth were randomly divided into four groups, each containing ten teeth, based on the preparation design. Randomization is a crucial step in research, ensuring that each tooth has an equal chance of being assigned to any of the groups. This minimizes the risk of selection bias, where certain characteristics of the teeth might inadvertently influence the results.

A butt-joint margin is a preparation design where the crown's edge meets the tooth structure at a sharp, 90-degree angle. This design is often favored for its esthetics, particularly in anterior teeth, as it minimizes the visibility of the crown margin. The 1 mm chamfer finish line refers to a small bevel or slope created at the tooth's edge, providing a smooth transition between the tooth and the crown. A shoulder margin involves creating a distinct shoulder or ledge around the tooth's perimeter, providing a more defined seat for the crown. This design enhances the resistance form of the preparation, improving the crown's ability to withstand forces. The 1.5 mm chamfer finish line adds a bevel to the shoulder, creating a smooth transition and reducing stress concentration. A deep chamfer margin is similar to a standard chamfer but extends further down the tooth structure. This design can provide good retention but may also compromise the structural integrity of the tooth, particularly in areas with thin tooth structure. The 2 mm chamfer finish line creates a wider bevel, potentially influencing the stress distribution in the tooth. This design combines the shoulder margin's enhanced resistance form with a rounded shoulder configuration. The rounded shoulder minimizes sharp internal line angles, which can act as stress concentration points and initiate fracture. This design aims to maximize both retention and resistance while preserving tooth structure. All tooth preparations were performed by a single experienced prosthodontist using a high-speed handpiece with water cooling and standardized diamond burs. Having a single, experienced operator perform all preparations ensures consistency and minimizes variability. The use of water cooling during the preparation process prevents excessive heat buildup, which could damage the tooth structure. Standardized diamond burs guarantee that the preparations are performed with precision and uniformity. The following preparation parameters were maintained for all groups; Occlusal reduction: 2 mm; Axial reduction: 1.5 mm; Total convergence angle: 6 degrees. These standardized parameters ensure that all groups receive similar modifications, isolating the effect of the preparation design as the primary variable under investigation.

Standardized metal-ceramic crowns were fabricated for all prepared teeth using the lost-wax technique. Metal-ceramic crowns combine the strength and durability of metal with the esthetics of porcelain. The lost-wax technique is a traditional method for creating dental restorations, known for its precision and ability to reproduce intricate details. The crowns were cast in nickel-chromium alloy, a biocompatible material known for its strength, corrosion resistance, and affordability. The use of a standardized alloy minimizes variability in the crown's material properties, ensuring that the focus remains on the preparation design. The crowns were then veneered with porcelain, a tooth-colored ceramic material that provides a natural and esthetically pleasing appearance. The internal surface of the crowns was air-abraded with 50-μm aluminum oxide particles. Air abrasion roughens the crown's interior, increasing its surface area and enhancing the bond between the crown and the cement. The prepared teeth were etched with 37% phosphoric acid for 15 seconds, rinsed, and dried. Etching removes the outer layer of the tooth structure, creating microscopic irregularities that improve the mechanical retention of the cement. The crowns were cemented using a resin-modified glass ionomer cement (RelyX Luting 2, 3M ESPE) according to the manufacturer's instructions. Resin-modified glass ionomer cement combines the favorable properties of both glass ionomer and resin-based cements. It offers good adhesion, fluoride release, and ease of use, making it suitable for cementing metal-ceramic crowns. Using a standardized cementation procedure and material ensures consistency and minimizes variability across all groups. Excess cement was removed, and the margins were finished and polished. This meticulous cleanup ensures that the excess cement does not interfere with the fit or function of the crown and that the margins are smooth and well-sealed, reducing the risk of microleakage and secondary decay.

The specimens were embedded in acrylic resin blocks, leaving the crown and 3 mm of the root exposed. Embedding the teeth in acrylic resin provides stability during testing, preventing movement or dislodgement that could influence the results. The blocks were mounted on a universal testing machine (Instron, Norwood, MA, USA) with the long axis of the tooth parallel to the direction of the applied force. A universal testing machine is a standardized instrument used to apply controlled forces to materials or structures, measuring their response. Aligning the tooth's long axis with the direction of force ensures that the applied force simulates the natural forces experienced by teeth during chewing. A compressive load was applied to the occlusal surface of the crown using a steel indenter with a 4 mm diameter at a crosshead speed of 1 mm/min until fracture occurred. The occlusal surface is the biting surface of the tooth, and applying the load here replicates the forces encountered during chewing. The steel indenter ensures a standardized contact area, while the crosshead speed controls the rate at which the load is applied, maintaining consistency across all specimens. The fracture resistance values were recorded in Newtons (N), the unit of force in the International System of Units. Recording the force required to fracture the teeth provides a quantitative measure of their resistance to fracture, allowing for objective comparisons between the different preparation designs.

The data were analyzed using SPSS software (version 25, IBM Corp., Armonk, NY, USA), a widely used statistical software package. SPSS provides a comprehensive suite of tools for managing, analyzing, and interpreting data. One-way analysis of variance (ANOVA) was used to compare the fracture resistance values among the four groups. ANOVA is a statistical test used to compare the means of two or more groups. In this study, it helps determine if there are any statistically significant differences in fracture resistance between the different preparation designs. Tukey's post-hoc test was performed for pairwise comparisons. Tukey's test is a multiple comparison procedure used to determine which specific groups differ from each other when ANOVA indicates a significant difference. This test helps identify the specific preparation designs that result in significantly different fracture resistance values. The level of significance was set at $\alpha=0.05$. The significance level represents the probability of rejecting the null hypothesis when it is true. Setting $\alpha=0.05$ is a common practice in research, indicating that there is a 5% chance of concluding that a difference exists between groups when there is no real difference.

3. Results

Table 1 provides a breakdown of the characteristics of the 40 extracted premolars used in this study, offering insights into the sample's demographics and clinical features. The teeth were extracted from patients across a wide age range (20-60+ years), with the majority falling within the 30-49 year age bracket

(55%). This distribution suggests a fairly representative sample of the adult population, although it skews slightly younger with limited representation of older adults (60+). The sample is relatively balanced in terms of sex, with a slightly higher proportion of teeth originating from male patients (55%) compared to female patients (45%). Both maxillary (upper jaw) and mandibular (lower jaw) premolars were included in the study, with a slightly higher proportion of maxillary premolars (52.5%). This inclusion ensures that the findings are applicable to both upper and lower premolars. The most common reason for extraction was orthodontic treatment (62.5%), followed by periodontal disease (25%). This information is relevant as it indicates that the majority of teeth were extracted for reasons unrelated to their structural integrity or any pre-existing conditions that might have affected their fracture resistance. The oral hygiene of the patients from whom the teeth were extracted varied, with the largest proportion classified as having "fair" oral hygiene (45%). This distribution reflects real-world conditions, where oral hygiene practices can differ significantly among individuals. Most teeth (75%) had no previous restorations, indicating that they were generally sound before extraction. This minimizes the potential influence of previous restorations on the fracture resistance of the teeth.

Table 1. Participant characteristics.

Characteristic	Category	Number of teeth	Percentage (%)
Age (years)	20-29	8	20
	30-39	12	30
	40-49	10	25
	50-59	8	20
	60+	2	5
Gender	Male	22	55
	Female	18	45
Tooth type	Maxillary Premolars	21	52.5
	Mandibular Premolars	19	47.5
Reason for extraction	Orthodontic	25	62.5
	Periodontal	10	25
	Other (Impacted, etc.)	5	12.5
Oral hygiene	Good	15	37.5
	Fair	18	45
	Poor	7	17.5
Previous restorations	None	30	75
	Composite	7	17.5
	Amalgam	3	7.5

Table 2 presents the mean fracture resistance values (in Newtons) for each preparation design group, along with their standard deviations and the results of pairwise comparisons; Group 4 (Shoulder margin with rounded shoulder): This group exhibited the highest mean fracture resistance (1550 N), suggesting that this design may offer the greatest protection against fracture; Group 2 (Shoulder margin with 1.5 mm chamfer): This group had the second-highest mean fracture resistance (1480 N), indicating that the shoulder margin, in general, may be a favorable design choice; Group 1 (Butt-joint margin with 1 mm chamfer): This group showed the lowest mean fracture resistance (1250 N), suggesting that this design might be the least resistant to fracture; Group 3 (Deep chamfer margin with 2 mm chamfer): This group had a mean fracture resistance (1180 N) slightly higher than the butt-joint group but lower than both shoulder margin groups. The table also includes p-values from Tukey's post-hoc test, which indicate the statistical significance of the differences between each pair of groups; Group 1 vs. Group 4: The p-value of 0.023 indicates a statistically significant difference between these groups, suggesting that the shoulder margin with a rounded shoulder provides significantly higher fracture resistance than the butt-joint margin; Group 2 vs. Group 3: The p-value of 0.038 also indicates a statistically significant difference, suggesting that the shoulder margin with 1.5 mm chamfer offers significantly higher fracture resistance than the deep chamfer margin; Group 3 vs. Group 4: A p-value of 0.011 shows a statistically significant difference, again highlighting the superior fracture resistance of the shoulder margin with a rounded shoulder compared to the deep chamfer margin.

Table 2. Fracture resistance values (N) and pairwise comparisons.

Group	Preparation design	Mean (N)	Standard Deviation (N)	Group 1	Group 2	Group 3	Group 4
1	Butt-joint margin with 1 mm chamfer	1250	150	-	0.105	0.879	**0.023**
2	Shoulder margin with 1.5 mm chamfer	1480	180	0.105	-	**0.038**	0.980
3	Deep chamfer margin with 2 mm chamfer	1180	130	0.879	**0.038**	-	**0.011**
4	Shoulder margin with rounded shoulder	1550	200	**0.023**	0.980	**0.011**	-

4. Discussion

The results of this study clearly demonstrate that the choice of preparation design significantly influences the fracture resistance of endodontically treated teeth restored with full-coverage crowns. Understanding why certain designs perform better than others requires a closer look at the interplay of mechanical forces and structural characteristics. A fundamental principle in restorative dentistry is achieving an intimate and precise fit between the restoration and the prepared tooth. This is particularly crucial for full-coverage crowns, where any discrepancies or gaps can lead to uneven stress distribution and increase the risk of fracture. The shoulder margin provides a distinct and well-defined finish line, which offers several advantages in achieving this precise fit. The shoulder margin creates a clear and defined boundary for capturing the preparation details in the impression. This allows for a more accurate reproduction of the tooth preparation in the die, which in turn leads to a more accurately fabricated crown. With conventional impression materials, a butt-joint preparation can be challenging to capture accurately, as the margin may be obscured or distorted. The distinct shoulder acts as a guide, ensuring that the impression material flows accurately around the margin and captures its precise location and configuration. The shoulder margin provides a definitive seat for the crown, facilitating its proper seating during cementation. This helps to ensure that the crown is fully seated and that the cement is evenly distributed, minimizing the risk of voids or gaps that can compromise the restoration's integrity. A well-seated crown with uniform cement thickness contributes to a more homogenous and predictable stress distribution, reducing the likelihood of localized stress concentrations that can lead to fracture. Even minor discrepancies at the margin of a crown can act as stress concentration points. The shoulder margin, with its well-defined finish line, minimizes these discrepancies, promoting a more even transfer of forces and reducing the risk of fracture initiation at the margins. Marginal discrepancies can arise from inaccuracies in the impression, die fabrication, or crown fabrication process. The shoulder margin helps to mitigate these inaccuracies by providing a clear and consistent reference point for each step of the restorative process. Stress concentration refers to the localized increase in stress that occurs at sharp corners or angles in a structure. In dentistry, sharp internal line angles within a tooth preparation can act as stress concentration points, making these areas more susceptible to crack initiation and propagation under occlusal forces. The rounded shoulder configuration minimizes these stress concentration points, contributing to enhanced fracture resistance. The rounded shoulder creates a gradual and smooth transition between the axial and occlusal surfaces of the preparation. This smooth contour allows for a more even distribution of stress, preventing the build-up of excessive forces at sharp angles. In contrast, sharp internal angles disrupt the smooth flow of stress, leading to stress concentration and an increased risk of fracture. Cracks are more likely to initiate at points of stress concentration. By minimizing these stress concentration points, the rounded shoulder configuration reduces the likelihood of crack initiation and subsequent propagation. This is particularly important in endodontically treated teeth, which are already more susceptible to fracture due to the loss of tooth structure and moisture. Teeth are subjected to repeated cyclic loading during chewing and biting. This cyclic loading can lead to fatigue failure over time, even at stress levels below the ultimate tensile strength of the tooth structure. The rounded shoulder configuration, by minimizing stress concentration, enhances the fatigue resistance of the tooth-crown complex, increasing its longevity and reducing the risk of fracture over time. Endodontic treatment inevitably involves the removal of tooth structure, which weakens the tooth and makes it more prone to fracture. Therefore, preserving as much sound tooth structure as possible during the preparation for a crown is crucial for maximizing the tooth's resistance to fracture. The shoulder margin preparation, compared to other designs like the deep chamfer or butt-joint, is advantageous in this regard. The shoulder margin allows for less tooth reduction in the cervical region, which is a critical area for resisting occlusal forces. The cervical region is naturally thinner and more vulnerable to fracture due to the complex interplay of stresses in this area. By preserving more tooth structure in this region, the shoulder margin provides a stronger foundation for the crown and helps to distribute stresses more effectively, reducing the risk of cervical fracture. The ferrule effect refers to the encirclement of the remaining tooth structure by the crown, providing a reinforcing "band" that enhances its resistance to fracture. The shoulder margin, by preserving more tooth structure in the cervical region, maximizes the ferrule effect, further strengthening the tooth-crown complex. A strong ferrule effect is particularly important for endodontically treated teeth, as it helps to compensate for the loss of structural integrity caused by the removal of the pulp and dentin. The shoulder margin provides a more defined and resistant form for the crown, enhancing its ability to withstand occlusal forces. This improved resistance form contributes to the overall stability and longevity of the restoration, reducing the risk of dislodgement or fracture under function. The shoulder acts as a buttress, providing additional support and resistance to lateral forces, which can be particularly detrimental to endodontically treated teeth.[11-13]

The butt-joint margin, while offering certain aesthetic advantages, particularly in anterior teeth where minimizing the visibility of the crown margin is desirable, exhibited the lowest fracture resistance among the preparation designs evaluated in this study. This outcome can be attributed to several inherent limitations of the butt-joint margin that compromise its ability to effectively protect and reinforce endodontically treated teeth. The defining characteristic of the butt-joint margin is the absence of a distinct finish line. The crown's edge meets the tooth structure at an abrupt 90-degree angle, creating a sharp junction with no defined shoulder or chamfer. This lack of a distinct finish line poses significant challenges in achieving an accurate impression and a precise fit of the crown, ultimately compromising the restoration's long-term success. Capturing the precise location and configuration of the margin is crucial for fabricating an accurately fitting crown. The lack of a distinct margin in the butt-joint preparation makes this task challenging. Impression materials may struggle to accurately flow and capture the fine details of the margin, particularly in areas with limited access or subgingival margins. This can lead to inaccuracies in the die, which in turn compromises the fit of the crown. The butt-joint margin, with its abrupt transition, can be easily obscured or distorted during impression-making, resulting in an inaccurate representation of the preparation's true dimensions. The inaccuracies in the impression and die, coupled with the lack of a defined finishing line, can lead to an ill-fitting crown. This can result in uneven stress distribution, with stress concentrating at points of discrepancy between the crown and the tooth. Such stress concentration can initiate cracks and lead to catastrophic fracture of the tooth-crown complex. When a crown fits poorly, stresses are not evenly distributed across the tooth structure. Instead, they tend to concentrate at areas of discrepancy, such as gaps or overhangs. These localized stress concentrations can exceed the tooth's ability to withstand those forces, leading to crack initiation and propagation. An ill-fitting crown can also lead to microleakage, the microscopic penetration of bacteria and fluids between the crown and the tooth. This can compromise the integrity of the cement seal, leading to secondary decay, pulpal irritation, and further weakening of the tooth structure. Microleakage can also accelerate the degradation of the luting agent, further compromising the retention of the crown and increasing the risk of dislodgement or fracture. The presence of bacteria and fluids at the tooth-crown interface can initiate or exacerbate caries, leading to further loss of tooth structure and weakening of the tooth. Pulpal irritation can also occur, potentially leading to discomfort or the need for further endodontic treatment. To achieve adequate retention and resistance form with a butt-joint margin, more tooth reduction in the cervical region is often required compared to other preparation designs. This increased tooth reduction can compromise the structural integrity of the tooth, particularly in the cervical region, which is critical for resisting occlusal forces. The cervical region is naturally thinner and more vulnerable to fracture due to the complex stress patterns in this area. Excessive tooth reduction in this region further weakens the tooth structure, making it more susceptible to fracture under occlusal loading. The butt-joint margin's requirement for increased cervical reduction can compromise the ferrule effect, reducing the crown's ability to reinforce the remaining tooth structure. The ferrule effect, the encirclement of the remaining tooth structure by the crown, is crucial for reinforcing endodontically treated teeth. Increased tooth reduction in the cervical region compromises the ferrule effect, reducing the crown's ability to provide adequate support and protection to the weakened tooth structure. This can increase the risk of vertical root fracture, a catastrophic complication that often leads to tooth loss. The ferrule effect, the 360-degree encirclement of the remaining tooth structure by the crown, is a crucial factor in reinforcing endodontically treated teeth. It acts like a "箍," providing a rigid support that helps to prevent vertical root fracture. Increased tooth reduction in the cervical region compromises the ferrule effect, reducing the crown's ability to provide adequate support and protection to the weakened tooth structure. This can increase the risk of vertical root fracture, a catastrophic complication that often leads to tooth loss. The increased tooth reduction associated with the butt-joint margin can also lead to sharper internal line angles, which can act as stress concentration points. These stress concentration points can initiate cracks and lead to fracture, particularly in the presence of uneven stress distribution caused by an ill-fitting crown. Stress concentration refers to the localized increase in stress that occurs at sharp corners or angles in a structure. In dentistry, sharp internal line angles within a tooth preparation can act as stress concentration points, making these areas more susceptible to crack initiation and propagation under occlusal forces.[14-16]

The deep chamfer margin, a frequently employed preparation design in restorative dentistry, demonstrated lower fracture resistance compared to the shoulder margin preparations in this study. This outcome highlights the importance of critically evaluating the potential drawbacks of even commonly used techniques, especially when dealing with compromised teeth. The reduced fracture resistance associated with the deep chamfer margin can be attributed to specific characteristics that negatively influence the biomechanics of the tooth-crown complex. The deep chamfer margin is characterized by a wider and deeper chamfer that extends further down the axial wall of the tooth compared to a standard chamfer. While this deeper chamfer can provide increased retention for the crown by creating a more pronounced ledge for the crown to grip, it also has the unintended consequence of creating sharper internal line angles at the junction between the chamfer and the axial wall. These sharp internal line angles disrupt the smooth flow of stress through the tooth structure, acting as stress concentration points and increasing the risk of fracture. Stress concentration is a phenomenon where stress levels are significantly higher at sharp corners or angles in a structure compared to the surrounding areas. In the context of a deep chamfer margin, the sharp internal line angles created by the abrupt transition between the chamfer and the axial wall act as stress concentrators. When forces are applied to the tooth, such as during chewing, these sharp angles experience a disproportionately high level of stress, making them more susceptible to crack initiation. Cracks in a material are more likely to initiate at points of stress concentration. The sharper the angle, the greater the stress concentration and the higher the risk of crack initiation. Once a crack initiates, it can propagate or spread through the tooth structure, potentially leading to a complete fracture of the tooth or the restoration. The deep chamfer margin, with its sharper internal line angles, increases the risk of crack initiation and propagation compared to the rounded shoulder configuration, which promotes a more even stress distribution and minimizes stress concentration. The increased stress concentration at the sharp internal line angles of a deep chamfer margin becomes particularly significant under occlusal loading. When the teeth come into contact during chewing or biting, substantial forces are transmitted through the crown and into the tooth structure. These forces can exacerbate the stress concentration at the sharp angles of a deep chamfer margin, increasing the risk of fracture. The magnitude and direction of these occlusal forces can vary depending on factors such as the patient's bite, chewing habits, and the type of food being consumed. Another factor contributing to the lower fracture resistance of the deep chamfer margin is its potential to compromise the bulk of the crown, particularly in the cervical region. The cervical region is the area where the crown meets the tooth at the gum line, and it is a critical area for resisting occlusal forces. Reducing the crown's bulk in this area can weaken its ability to provide adequate support and protection to the tooth. The deep chamfer, extending further down the axial wall, can result in a thinner crown in the cervical region. This reduced crown thickness can compromise the crown's ability to resist deformation or fracture under occlusal loading. A thinner crown is more likely to flex or deform under stress, which can lead to debonding from the tooth, microleakage, or even fracture of the crown itself. The crown acts as a splint, reinforcing the remaining tooth structure and distributing stresses more evenly. Reducing the crown's bulk in the cervical region weakens its ability to provide adequate support and protection to the tooth, particularly in endodontically treated teeth that are already structurally compromised. This can increase the risk of fracture, particularly in the cervical region, which is naturally thinner and more vulnerable to stress due to its anatomical configuration. The ferrule effect is a crucial factor in the long-term success of crowns, especially on endodontically treated teeth. It refers to the 360-degree encirclement of the remaining tooth structure by the crown, providing a reinforcing "band" that enhances its resistance to fracture. The deep chamfer margin, by reducing the crown's bulk in the cervical region, can compromise the ferrule effect, reducing the crown's ability to provide adequate support and protection to the weakened tooth structure. This can increase the risk of vertical root fracture, a catastrophic complication that often leads to tooth loss.[17,18]

The findings of this study are consistent with several previous studies that have reported higher fracture resistance for shoulder margin preparations compared to chamfer and butt-joint margins. These studies have similarly shown that shoulder margin preparations provide a more even distribution of stress, reduce stress concentration, and preserve more tooth structure, all of which contribute to increased fracture resistance. However, some studies have reported no significant difference between shoulder and chamfer margins. These discrepancies may be attributed to differences in the study design, tooth type, crown material, and testing methods. Factors such as the type of teeth used (premolars vs. molars), the material of the crown (metal-ceramic vs. all-ceramic), and the method of applying force during testing can all influence the results and contribute to variations in findings across different studies. The results of this study align with a significant body of literature that supports the superior fracture resistance of shoulder margin preparations compared to chamfer and butt-joint margins. Several studies have demonstrated that shoulder margin preparations provide a more even distribution of stress, reduce stress concentration, and preserve more tooth structure, all of which contribute to increased fracture resistance. The shoulder margin provides a more defined and stable seat for the crown, promoting a more even distribution of stresses across the tooth structure. This helps to prevent localized stress concentration, which can initiate cracks and lead to fracture. The shoulder margin minimizes the presence of sharp internal line angles, which can act as stress concentration points. By reducing stress concentration, the likelihood of crack initiation and propagation is minimized, thereby increasing the overall fracture resistance of the tooth-crown complex. The shoulder margin preparation generally requires less tooth reduction compared to chamfer and butt-joint margins, particularly in the critical cervical region. Preserving more tooth structure in this region provides a stronger foundation for the crown and helps to distribute stresses more effectively, reducing the risk of fracture. While many studies support the superior fracture resistance of shoulder margin preparations, some studies have reported no significant difference between shoulder and chamfer margins. These discrepancies highlight the complexity of the issue and the influence of various factors on the fracture resistance of teeth restored with full-coverage crowns. Differences in study design, such as the sample size, the type of teeth used, the method of preparation, and the testing protocol, can all influence the results. For example, studies with smaller sample sizes may have less statistical power to detect significant differences between groups. The type of teeth used in the study can also influence the results. Molars, with their larger occlusal surface area and multiple cusps, experience different stress patterns compared to premolars. This can affect the relative performance of different preparation designs. The material of the crown can also influence the results. Metal-ceramic crowns, used in this study, have different mechanical properties compared to all-ceramic crowns. These differences can affect the stress distribution and fracture resistance of the tooth-crown complex. The method of applying force during testing can also influence the results. Different testing protocols, such as the type of loading, the rate of loading, and the point of load application, can all affect the measured fracture resistance. The discrepancies between different studies highlight the need for careful interpretation of the results and the importance of considering the specific factors that may influence the fracture resistance of teeth restored with full-coverage crowns. It is essential to critically evaluate the study design, tooth type, crown material, and testing methods when comparing the results of different studies. Meta-analyses, which combine the results of multiple studies, can provide a more comprehensive understanding of the relative effectiveness of different preparation designs. By pooling data from multiple studies, meta-analyses can increase statistical power and provide more robust conclusions. The development of standardized testing protocols can help to reduce variability between studies and facilitate more accurate comparisons of different preparation designs. Standardized protocols should specify the type of loading, the rate of loading, and the point of load application, among other factors. While in vitro studies provide valuable insights into the mechanical properties of different preparation designs, it is important to remember that these studies may not fully reflect the clinical situation. In vivo studies, conducted on living patients, are needed to confirm the findings of in vitro studies and assess the long-term clinical performance of different preparation designs.[19,20]

5. Conclusion

Within the limitations of this in vitro study, the shoulder margin with a rounded shoulder finish line provided the highest fracture resistance for endodontically treated teeth restored with full-coverage crowns. The butt-joint margin and deep chamfer margin preparations exhibited lower fracture resistance. These findings suggest that the choice of preparation design significantly influences the fracture resistance of endodontically treated teeth restored with full-coverage crowns. The shoulder margin with a rounded shoulder finish line appears to offer the best protection against fracture, while the butt-joint margin and deep chamfer margin preparations may compromise the tooth's resistance to fracture. It is important to note that this was an in vitro study, and the results may not fully reflect the clinical situation. Further research, including in vivo studies, is needed to confirm these findings and assess the long-term clinical performance of different preparation designs. Additionally, the study was conducted on extracted human premolars, and the results may not be directly applicable to other tooth types, such as molars. Despite these limitations, the findings of this study provide valuable insights into the influence of preparation design on the fracture resistance of endodontically treated teeth restored with full-coverage crowns. The results suggest that dentists should consider using a shoulder margin with a rounded shoulder finish line when restoring endodontically treated teeth with full-coverage crowns. This preparation design appears to offer the best protection against fracture, helping to ensure the long-term survival and functionality of these teeth.

6. References

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