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COMPARATIVE ANALYSIS OF MICROLEAKAGE IN FRACTURED ANTERIOR TEETH RESTORED WITH INNOVATIVE BEVEL CONFIGURATIONS AND DIRECT COMPOSITE: AN IN VITRO INVESTIGATION

Dentistry

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ABSTRACT

With the advent of aesthetic restoration, dentists all over the world have been focusing on replacing the cavity surface with tooth-colored restorations. Although composite materials have a main disadvantage, which is polymerisation shrinkage, which causes porosity, cracking, deformation and microleakage, which eventually reduces the material's binding strength. To improve retention and aesthetic appeal, bevels are advised to reduce strains at bonding interference and microleakage. This study compared microleakage of different bevel designs in fractured anterior teeth restored with direct composite restoration. Sixty extracted non-carious maxillary central incisors were allocated into three groups according to bevel configurations: Group A with a primary bevel, Group B with a zigzag bevel, and Group C with a starburst bevel. The samples were repaired with composite material and exposed to thermal cycling. Nail varnish coated all surfaces except the restoration area and a 1 mm surrounding it. The samples were soaked in methylene blue dye for a period of 24 hours. The teeth were subsequently divided and observed using a stereomicroscope. Results showed that the starburst bevel group demonstrated the least microleakage, followed by the zigzag bevel group, while the primary bevel group showed the highest degree of dye penetration. The differences between the groups were statistically significant ($p < 0.05$). Innovative bevel configurations, especially the distinctive starburst bevel design, have demonstrated a substantial reduction in marginal microleakage when compared to standard or conventional bevel preparations.

KEYWORDS

Microleakage, Bevel Design, Composite Resin, Fractured Anterior Teeth, Starburst Bevel, Zigzag Bevel

INTRODUCTION

Traumatic injuries to anterior teeth represent one of the most common clinical scenarios in conservative dentistry, particularly affecting children, teenagers, and young adults as a result of sports injuries, traffic accidents, and falls. The teeth most generally affected are the upper front teeth, known as the maxillary central incisors, due to of their prominent position in the dental arch.[1]. Such injuries compromise not just mastication and phonetics but also significantly impact facial aesthetics and psychosocial well-being, making prompt and esthetically acceptable restorative management essential.

Due to the increasing focus on minimally invasive dentistry, direct composite resin restorations have emerged as the favoured treatment option for uncomplicated fractures of anterior teeth. It is well documented that they can preserve sound tooth structure, provide excellent esthetic outcomes, allow for intraoral repair, and are cost-effective [2]. Advances in filler technology, resin chemistry, and optical properties have further enhanced the clinical performance of contemporary resin composites.

Modern resin composites demonstrate superior mechanical properties, enhanced wear resistance, and improved optical characteristics that closely resemble those of natural tooth structure. Even with these enhancements, polymerisation shrinkage continues to be an intrinsic limitation of restorative materials based on resin. As polymerisation occurs, the resin matrix undergoes volumetric contraction, creating shrinkage stresses at the tooth-restoration margin that can surpass the adhesive system's bond strength. This phenomenon often leads to the formation of marginal gaps, a compromised sealing ability, and subsequent microleakage [3,4].

Microleakage describes the microscopic movement of bacteria, ions, fluids, or other molecular substances between the tooth and the restorative material, which cannot be observed during a clinical examination. This is a key factor influencing the lifespan of composite restorations and their overall success. Microleakage has been linked to issues such as marginal discolouration, recurrent caries, pulpal inflammation, post-operative sensitivity, and ultimately failure of restoration [5]. Due to the high aesthetic demands on anterior teeth, marginal discoloration is a particular concern, making it essential to prevent microleakage during restorative procedures [6].

The extent of microleakage in composite restorations is affected by several factors, including the cavity configuration factor (C-factor), the quality of the bonding surface, the adhesive system used, the curing technique, incremental placement strategy, and design of the cavity margin [7,8]. Among these factors, the design of the cavosurface margin is crucial for establishing marginal adaptation and stress distribution. Composite restorations offer the possibility of modifying enamel margins to improve bonding and esthetic integration, in contrast to traditional amalgam restorations that necessitate a butt-joint cavosurface margin [9].

Beveling of enamel margins has been widely advocated in anterior composite restorations as it increases the surface area available for bonding, exposes the ends of enamel rods for more effective etching, and provides a gradual transition in tooth structure and restorative material [10,8]. Additionally, beveling helps to camouflage the restoration margins, improving esthetic integration. From a biomechanical perspective, bevels are believed to reduce polymerisation shrinkage stresses by altering the direction of shrinkage vectors and improving resin adaptation at the margins [11].

The traditional primary bevel, typically formed at an angle of approx 45 degrees along an enamel edge, is the most commonly used bevel design. This design, while straightforward and conventional, may not sufficiently deal with stress concentration along a linear cavosurface margin [12]. It has been suggested that modified bevel designs, like the zigzag bevel, could break up linear shrinkage patterns and improve micromechanical retention by creating greater surface irregularity. Prior research has shown that zigzag bevels can lower marginal leakage compared to traditional primary bevels [13].

Recently, new bevel designs like the starburst bevel have been developed to enhance marginal integrity even more. Multiple micro-bevels radiating from the fracture margin form a star-like pattern, which is the defining feature of the starburst bevel. The design is proposed to greatly enlarge the enamel surface area, enhance resin penetration, and allow for more even stress dissipation during polymerisation. The starburst bevel can reduce stress concentration and minimize marginal gap formation by transforming a single linear margin into multiple intersecting margins.

Many in vitro studies have examine the impact of conventional and modified bevel designs on microleakage, most of the existing literature centers on comparisons between primary and zigzag bevels. Though starburst bevel designs are becoming more commonly used in esthetic restorative dentistry, scientific evidence of their effectiveness is still limited. Moreover, it is crucial to conduct a comparative assessment of these bevel designs under standardized conditions in order to develop evidence-based clinical guidelines.

Therefore, this in vitro study aimed to assess and compare the degree of microleakage linked to three distinct bevel designs: primary bevel, zigzag bevel, and starburst bevel, in anterior teeth with fractures that were restored using direct composite resin. The results of this study aim to provide important insights into how innovative bevel designs can enhance marginal sealing and contribute to the long-term success of anterior composite restorations.

MATERIAL AND METHODOLOGY

The present study was conducted in the department of Conservative Dentistry and Endodontics and ethical clearance was obtained from the institutional ethical committee prior to commencement of the study, in accordance with standard research guidelines.

Sample Size Determination

A total of sixty extracted human maxillary central incisors were included in the study to detect statistically significant differences among the groups with a confidence level of 95% and a power of 80%.

Selection and Storage of Teeth

Freshly extracted, non-carious permanent maxillary central incisors extracted for periodontal reasons were collected. All teeth were thoroughly cleaned using ultrasonic scalers to remove calculus, soft tissue remnants, and surface debris. Magnified observations were carried out to exclude the teeth that have any kind of fractures, caries, cavities, restoration, or abrasions. These were kept in distilled water at normal temperatures. The water was replaced from time to time to avoid drying.

Inclusion Criteria

- Permanent maxillary central incisors
- Intact crowns with sound enamel and dentin
- Teeth free from caries, restorations, cracks, or developmental anomalies

Exclusion Criteria

- Teeth with carious lesions or restorations
- Teeth exhibiting visible cracks, craze lines, or fractures
- Teeth with abrasion, erosion, or structural defects

Specimen Mounting and Standardization

In order to create uniformity in the positioning of specimens, each individual tooth was cast in cube-shaped blocks using modelling wax. Each tooth was positioned vertically in such a way that the cemento-enamel junction was set on a leveled plane above the wax block. It was made sure that the long axis of each tooth was kept vertical to the block's base.

Standardisation of Fracture Preparation

Each tooth received a standardized fracture of the dentin-enamel complex at the mesio-incisal corner using a diamond disc that was continuously cooled with water. Standardization of the fracture lines involved creating fractures that extended 3 mm coronally from the incisal margin in order to mimic the common type of anterior tooth fracture known as Ellis Class II.

Group Allocation

The sixty specimens were randomly allocated into three experimental groups (n = 20 per group) based on the type of bevel design prepared:

Table 1: Groups Based on the Bevel Design Prepared

GROUPS	BEVEL
Group A	Primary Bevel
Group B	Zigzag Bevel
Group C	Starburst Bevel

Randomisation was performed to minimise allocation bias.

Bevel Preparation

Bevel preparations were carried out by a single operator with a standardized fine grit diamond bur and with continuous water spray to avoid any variation between operators.

- **Primary Bevel Group (Group A):** A primary bevel was made along the cavosurface margin of the tooth at 45-degree angle to the surface of enamel extending 2 mm from the fracture line covering complete thickness of enamel.
- **Zigzag Bevel Group (Group B):** Zigzag bevel group comprised a series of sharp bevels arranged in a zigzag manner along the fracture margin, which extended for 2mm from the fracture margins.
- **Starburst Bevel Group (Group C):** A starburst bevel included making many micro bevels radiating from the fracture margin giving a star-shaped appearance to cover maximum enamel surface.

Figure 1: Primary Bevel,

Figure 2: Zigzag Bevel,

Figure 3: Starburst Bevel

Restorative Procedure

For all samples, the margins of the enamel were etched for 15 seconds using 35% phosphoric acid gel followed by rinsing in water for 15 seconds. Air drying was done gently to obtain a moist surface of enamel. The bonding agent (Palfique Bond, Tokuyama) was uniformly applied to all samples as per the guidelines of the manufacturer and then cured using LED light-curing unit for 20 seconds.

Nanohybrid composite resin (Palfique Omnichroma, Tokuyama) was used to restore all samples. The resin was applied in incremental layers, with the maximum layer thickness being 2 mm. Light curing was done for 20 seconds for each increment after application. After restoration was done, finishing and polishing were done on all samples using Super Snap Rainbow Technique Kit (Shofu Dental India Pvt. Ltd.), which provided smooth margins and surface continuity. All the restored samples were subjected to thermal cycling between 5°C and 55°C for 1,500 cycles with a dwell period of 30 seconds in each bath.

Microleakage Assessment

All the surfaces of teeth were painted with two coats of nail polish, except for a zone of 1mm around the margins of the restorations. These specimens were placed in a solution of methylene blue dye for 24 hours. After dyeing the specimens were sectioned mesiodistally through the centre of the restoration with the help of a diamond disc while keeping the specimens cool with water. Examination was performed under a Stereomicroscope with a magnification of 10×.

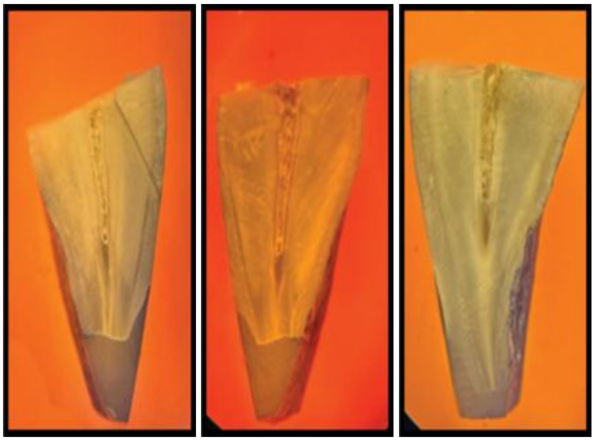


Figure 2: Microleakage Images; A- Primary Bevel, B- Zigzag Bevel, C- Starburst Bevel.

Scoring Criteria

Microleakage was scored using an ordinal scoring system based on the depth of dye penetration:

Table 2: Dye Penetration Scoring Criteria

Score	Dye penetration
Score 0	No dye penetration
Score 1	Dye penetration up to half the depth of the restoration
Score 2	Dye penetration beyond half the depth, but not reaching the axial wall
Score 3	Dye penetration reaching the axial wall

Statistical Analysis

The study utilized a sample of 60 extracted human maxillary central incisors, divided equally into three groups (n=20 per group). To assess the differences in dye penetration (microleakage) between these groups, the researchers employed a One-way Analysis of Variance (ANOVA). A p-value of less than 0.05 was considered statistically significant.

Table 3: Distribution of Sample Based on Degree of Microleakage

Degree of microleakage	Group-A (Primary bevel)		Group-B (Zigzag Bevel)		Group-C (Starburst Bevel)		Total	
	n	%	n	%	n	%	n	%
0	2	10.00	8	40.00	12	60.00	22	36.67
1	3	15.00	5	25.00	4	20.00	12	20.00
2	5	25.00	4	20.00	2	10.00	11	18.33
3	10	50.00	3	15.00	2	10.00	15	25.00
Total	20	100.00	20	100.00	20	100.00	60	100.00

The proportion of 'Score 0 'is the highest in Group-C (60%), followed by Group-B (40%) and the lowest in case of Group-A (10%). On contrary, the proportion of 'Score 3 'is the highest in Group-A (50%), followed by Group-B (15%) and the lowest in case of Group-C (10%), respectively. Hence, it is observed that the degree of microleakage is relatively low in case of Group-C. Graphically it is present in the figure given below:

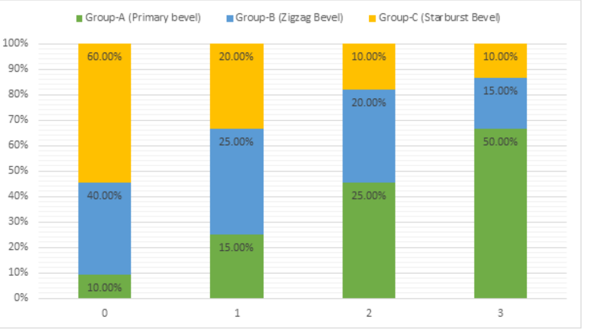


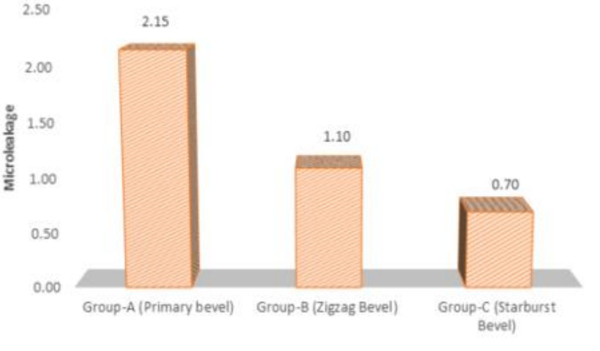
Figure 3: Distribution of Sample on the Basis of Degree of Microleakage

Table 4: Comparative Assessment of Microleakage Among Different Groups with Each Other.

Group	N	Mean	±SD	Mean difference	p-value
Group-A (Primary bevel)	20	2.15	1.04		0.000
Group-B (Zigzag Bevel)	20	1.10	1.12		
Group-C (Starburst Bevel)	20	0.70	1.03		
Group-A Vs Group-B				1.05	0.008
Group-A Vs Group-C				1.45	0.000
Group-B Vs Group-C				0.40	0.465

Test applied: One-way analysis of variance

The mean score of microleakage turned out to be the lowest in case of Group-C (0.70), followed by Group-B (1.10) and the highest in case of Group-A (2.15). The mean difference is statistically significant (p=0.000). Therefore, the Group-C is emerged as better group in terms of microleakage. When we compared these three study groups with each other, the mean difference of differ significantly in case of Group-A and Group-B (p=0.008), Group-A and Group-C (p=0.000), while it is non-significant between Group-B and Group-C, respectively. Graphically is presented below:



DISCUSSION

In the case of successful outcomes for direct composite restorations, particularly in the anterior regions where aesthetic considerations and functional forces coincide, marginal integrity plays a major role. Even with advancements in adhesive techniques and composite resin materials, microleakage caused by polymerization shrinkage and inadequate fit between the restoration and tooth structure remains an ongoing problem [4,14].

From the results obtained from the current experiment, it can be concluded that there were significant differences between the three bevels when it came to microleakage. The major bevel demonstrated higher microleakage compared to the starburst and zigzag bevels, which had lower levels of microleakage. These results emphasize the role played by cavosurface margin configuration in improving marginal integrity.

The 45-degree linear bevel that is commonly known as the primary bevel was traditionally used in order to optimize the aesthetic integration between the composite restoration and the tooth enamel. Nevertheless, the stresses generated during the process of polymerization shrinkage might be confined to a single plane within the margins because of the nature of the primary bevel, which is linear [3]. Such an accumulation of stresses can surpass the bonding force of the adhesive interface, causing the formation of a marginal gap that results in microleakage. The higher microleakage rates exhibited by the primary bevel group in this investigation align with other studies demonstrating that simple linear bevels are inadequate for overcoming polymerization stresses in complicated restorations [12,11].

The results indicate a significant reduction in microleakage with regard to the zigzag bevel design when compared to the primary bevel. The zigzag bevel geometry, characterized by its serrations, alters the integrity of the cavosurface margin and modifies the resultant stress vectors generated from the composite curing process. It is believed that the zigzag bevel could help in optimizing stress distribution and minimizing marginal debonding as it will reduce the linear cavosurface margin [15]. In addition, the zigzag geometry may facilitate improved micromechanical interlocking with the resin bonding system due to its non-linear surface of the tooth.

Another reason for the improved performance of the starburst bevel might also be because of its ability to increase the restoration's configuration factor (C-factor). Starburst bevel may prevent stress transfer from the composite material to the adhesive interface by decreasing internal stresses created within the composite volume due to the greater free surface created during the process of polymerization [7,15]. This phenomenon has been well documented in the scientific literature on restorative dentistry, where cavity design alterations that decrease the C-factor have been found to improve marginal adaptation and reduce microleakage.

An efficient method of detecting marginal gaps between tooth and restoration interfaces is evaluating microleakage through dye penetration testing with methylene blue at a concentration of 2%, which was carried out in the current research [5,16]. Thermocycling enhances the relevance of the experiment by imitating temperature changes in the oral cavity. However, it is important to remember that some biophysical challenges found in vivo cannot be reproduced in vitro.

The findings from this study corroborate previous in vitro research that stresses the importance of bevel design in improving marginal adaptation and reducing microleakage in composite restorations.

Coelho-De-Souza et al. [12] and Rajagopal et al. [13] noted that the use of modified bevels greatly improved marginal seal formation than the traditional bevel design. This study further validates the efficacy of the starburst bevel, a novel concept that has received little attention in the literature.

However, despite the advantages of the existing study, it also has some shortcomings. Since it is an in vitro study, one cannot assume that the findings are applicable in clinical settings. Factors such as bite forces, saliva, pH variations, and long-term aging are some of the elements not accounted for in this study. Operator error, which has been minimized through the standardization of processes, can never be entirely eliminated. More research needs to be done to demonstrate the clinical significance of the starburst bevel.

Nevertheless, the results presented from this study give some important insights regarding the way innovation in the geometry of the bevel can positively affect the marginal integrity of anterior composite restorations. The incorporation of modern geometrical techniques such as that of the starburst bevel in the restoration procedures may constitute an easy yet valuable approach.

CONCLUSION

In conclusion, the results from this research indicate that manipulation of the bevel morphology is a straightforward and clinically viable method for improving the margins' quality of anterior composite restorations. Introduction of novel bevel shapes, including the starburst bevel, could be of clinical benefit through minimizing marginal leakage, tooth sensitivity, and susceptibility to recurrent decay.

From the three tested bevels, the starburst bevel revealed the best marginal sealing property, with the lowest level of microleakage. This could be explained by the multidirectional shape of the starburst bevel, resulting in an increase in the contact surface and more effective dissipation of polymerization shrinkage stress. Furthermore, the zigzag bevel performed better than the conventional primary bevel regarding the margin quality, probably owing to changes in linear stress vectors.

But since this research was performed using in vitro conditions, the outcome should be treated with caution. Further clinical investigations are necessary to verify the efficacy of advanced bevel design concepts when subjected to functional loads and oral environment stimuli. In absence of this evidence, the starburst and zigzag bevels could serve as an alternative to traditional bevel designs for treating fractured anterior teeth.

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