RESEARCH PAPER

Evaluation of Marginal Microleakage in CAD-CAM Fabricated Interim Crowns Cemented with Different Provisional Luting Agents: An In Vitro Comparative Study

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ABSTRACT

Background: Marginal microleakage of provisional restorations may result in bacterial infiltration, postoperative discomfort, pulpal irritation, and failure of definitive prosthodontic treatment. However, CAD-CAM produced temporary crowns exhibit better marginal adaptability although the sealing performance is mostly dependent on the provisional luting cement utilized. To analyze and compare the marginal microleakage of CAD/CAM manufactured interim crowns cemented with zinc oxide eugenol, zinc oxide non-eugenol and zinc polycarboxylate provisional luting cements following thermocycling using dye penetration technique.

Materials and Methods: Twenty-four removed human maxillary first premolars were prepped for full coverage crowns and repaired with CAD-CAM milled PMMA interim crowns. The specimens were randomly divided into three groups (n = 8) according to the type of provisional luting cement used: zinc oxide eugenol, zinc polycarboxylate and zinc oxide non-eugenol. After cementation, all specimens were thermocycled and immersed in 2% methylene blue dye. The teeth were cut longitudinally and the marginal microleakage was measured using a stereomicroscope and a standardized scoring system. Statistical analysis was performed using the Kruskal–Wallis test. A p-value <0.05 was considered statistically significant.

Results: The three groups showed a statistically significant difference in marginal microleakage ($\chi 2 = 16.832$, $p < 0.001$). Zinc oxide non-eugenol cement had the least marginal microleakage (mean rank 5.00) while zinc polycarboxylate cement (13.63) had the next least. Zinc oxide eugenol cement demonstrated highest mean rank (18.88) suggesting best dye penetration and lowest marginal seal.

Conclusion: The type of provisional luting cement is an important factor affecting the marginal sealing capacity of CAD-CAM manufactured interim crowns. Zinc oxide non-eugenol cement had the best sealing ability and can be considered the luting agent of choice to minimize marginal microleakage in CAD-CAM interim restorations.

Keywords: CAD-CAM, Interim crowns, Marginal microleakage, Provisional luting cement, Thermocycling, Dye penetration, Fixed prosthodontics.

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INTRODUCTION

Provisional restorations are a vital part of fixed prosthodontic therapy and offer protection to prepared teeth as well as function, esthetics, occlusal stability, and periodontal health until the permanent prosthesis is supplied. The optimal interim restoration should maintain pulpal vitality, avoid tooth migration, maintain proximal and occlusal contacts, and create an appropriate marginal seal to prevent bacterial contamination. The biological and mechanical success of definitive restorations is highly dependent on the quality and performance of the provisional restoration during the interim therapy phase. Provisional restorations are no longer considered as temporary replacements but are substantial therapeutic restorations that greatly contribute to the outcome of prosthodontic treatment.[1-4]

One of the most important elements affecting the clinical performance of temporary restorations is their marginal adaption. Marginal differences at the tooth-restoration interface enhance the penetration of saliva, germs, oral fluids and their metabolic products leading to marginal microleakage. Persistent microleakage can result in postoperative discomfort, pulpal irritation, secondary cavities, plaque accumulation, gingival inflammation and failure of both provisional and permanent restorations. Hence, it is important to reduce the marginal microleakage to protect the pulpal and periodontal health and make the fixed prosthodontic therapy successful in the long run.[5-9]

The recent breakthroughs in digital dentistry have changed the manufacture of provisional restorations with the introduction of computer-aided design and computer-aided manufacturing (CAD-CAM) technologies. CAD-CAM provisional crowns fabricated from pre-polymerized polymethyl methacrylate (PMMA) blocks are better than conventionally fabricated provisional restorations in terms of dimensional accuracy, mechanical properties, surface smoothness, polymerization shrinkage, fracture resistance, and marginal adaptation. Such advantages have led to the extensive use of CAD-CAM technology in modern prosthodontic practice especially in the production of long-span provisional restorations and implant supported prostheses.[10-15]

Although CAD-CAM fabrication provides great accuracy, the ultimate clinical success of an interim restoration is also influenced by the characteristics of the provisional luting cement. The luting agent is the key contact between the prepared tooth and the restoration, regulating retention, marginal adaption, ease of retrieval and resistance to microleakage. A good provisional luting cement should have acceptable retentive strength, low film thickness, low solubility in oral fluids, dimensional stability, biocompatibility and easy removal without injury to the prepared tooth or replacement. Marginal sealing can be considerably affected by the physical and chemical properties of the interim cements, even with good internal and marginal fit of the restorations.[16-20]

Of the temporary luting agents available for clinical usage, zinc oxide eugenol, zinc oxide non-eugenol and zinc polycarboxylate cements are widely used due to their good handling properties and clinical performance. Zinc oxide eugenol cement has been traditionally considered as the material of choice owing to its calming effect on the dental pulp and ease of handling. However, its relative high solubility and the inhibitory effect of eugenol on polymerization of resin have prompted concerns about its long-term sealing ability and compatibility with adhesive restoration techniques. To overcome these constraints zinc oxide non-eugenol cements were created with good handling features and better physical properties. Zinc polycarboxylate cement has also been proposed as an alternate provisional luting agent owing to its chemical adherence to tooth structure and excellent biocompatibility. But the resistance of these two materials to marginal microleakage may be influenced by their differences in composition, solubility, mechanical characteristics and adhesion.[21-23]

Dye penetration techniques have been traditionally used for assessment of marginal microleakage as they are simple, inexpensive, reproducible and can reveal small routes along tooth–cement contact. Thermocycling is a standard laboratory technique used to imitate the temperature changes occurring in the mouth cavity. Repeated exposure to opposing temperatures is known to cause expansion and contraction of restorative materials and tooth structure and so, is a challenge to the integrity of the marginal seal. Thus, thermocycling in combination with dye penetration analysis is a clinically relevant method for evaluating the sealing efficacy of provisional luting cements under simulated oral circumstances.

Although there are several studies that have evaluated the marginal adaptation of CAD-CAM provisional restorations and the properties of different temporary luting agents, there are few studies available that compare the marginal microleakage of zinc oxide eugenol, zinc oxide non-eugenol and zinc polycarboxylate cements in particular with CAD-CAM fabricated interim crowns under standardized experimental conditions. Furthermore, the published findings continue to be contradictory because to variances in study design, restorative materials, fabrication procedures, thermocycling protocols, and methods employed to evaluate the microleakage. These differences underline the necessity for more comparison studies to determine whether provisional luting cement offers the best marginal seal for CAD-CAM provisional restorations.

Hence, the aim of the present in-vitro study was to evaluate and compare the marginal microleakage of CAD-CAM fabricated interim crowns cemented with zinc oxide eugenol, zinc oxide non-eugenol and zinc polycarboxylate provisional luting cements after thermocycling by dye penetration technique. The null hypothesis was no

statistically significant difference in marginal microleakage among the three provisional luting agents.

METHODOLOGY

This in vitro experimental comparative study was conducted in the Department of Prosthodontics and Crown & Bridge, including Implantology, SIBAR Institute of Dental Sciences, Guntur, Andhra Pradesh, India. A total of twenty-four freshly extracted human maxillary first premolars were selected for the study. Teeth exhibiting caries, restorations, fractures, cracks, developmental anomalies, abrasion, erosion, or any structural defects were excluded. Following extraction, the teeth were cleaned thoroughly to remove soft tissue remnants and calculus deposits using ultrasonic scalers and were disinfected before being stored in normal saline solution until use to maintain hydration.

Each specimen was mounted vertically in a putty index to facilitate standardized tooth preparation. Full-coverage crown preparations were performed using high-speed diamond rotary instruments under continuous water coolant. A dental surveyor was used throughout the preparation procedure to maintain a uniform path of insertion and standardized taper among all specimens. The preparations were completed according to conventional prosthodontic principles to achieve uniform occlusal reduction, axial reduction, and finish-line configuration in all samples.

After completion of tooth preparation, each specimen was scanned using a three-dimensional optical scanner to obtain digital impressions. The digital images were converted into Standard Tessellation Language (STL) files and imported into Exocad software for computer-aided designing of provisional crowns. The finalized designs were transferred to the computer-aided manufacturing unit, where interim crowns were milled from pre-polymerized polymethyl methacrylate (PMMA) blocks. Following milling, all restorations were finished, polished, and verified for complete seating on their corresponding prepared teeth before cementation.

The prepared specimens were randomly divided into three equal groups comprising eight samples each according to the provisional luting cement used. Group I specimens were cemented using zinc oxide eugenol cement, Group II specimens were cemented using zinc polycarboxylate cement, and Group III specimens were cemented using zinc oxide non-eugenol cement. Each luting agent was manipulated strictly according to the manufacturer's instructions to ensure uniform consistency and working characteristics. Cement was applied uniformly to the internal surface of each CAD-CAM fabricated interim crown, which was then seated on the prepared tooth under standardized axial finger pressure. Excess cement was carefully removed after initial setting, and all cemented specimens were stored in distilled water at 37°C for 24 hours before further testing.

To simulate thermal variations encountered in the oral environment, all specimens were subjected to thermocycling according to the experimental protocol. Following thermocycling, two layers of nail varnish were applied to all tooth surfaces except for approximately 1 mm surrounding the crown margin to restrict dye penetration exclusively to the restoration interface. The specimens were subsequently immersed in a 2% methylene blue solution for 24 hours at room temperature. After dye immersion, the samples were rinsed thoroughly with water and sectioned longitudinally in the buccolingual direction using a diamond disc under continuous water irrigation to prevent heat generation during sectioning.

The sectioned specimens were examined under a stereomicroscope at 20× magnification by a single calibrated examiner who was blinded to the group allocation. Marginal microleakage was assessed according to the extent of methylene blue dye penetration at the tooth–cement interface using a standardized ordinal scoring system. A score of 0 represented the absence of dye penetration, score 1 indicated dye penetration extending to one-third of the axial wall, score 2 indicated penetration extending to two-thirds of the axial wall, score 3 represented dye penetration along the complete axial wall, and score 4 indicated dye penetration reaching the occlusal surface.

The primary outcome measure of the study was the extent of marginal microleakage observed in each specimen. The collected data were entered into Microsoft Excel and analyzed using the Statistical Package for the Social Sciences (SPSS). Descriptive statistics were calculated and expressed as frequencies, percentages, means, and standard deviations. Differences among the three experimental groups were evaluated using one-way analysis of variance (ANOVA), followed by Tukey's post hoc test for pairwise comparisons. A *p*-value of less than 0.05 was considered statistically significant.

RESULTS

The marginal microleakage of 24 CAD-CAM manufactured interim crowns cemented with three different provisional luting agents was investigated after thermocycling with 2% methylene blue dye. All specimens were subjected to the experimental technique and were included in the final statistical analysis. The marginal microleakage was examined with a stereomicroscope and a standardized scoring system. The data were analyzed with the Kruskal–Wallis test. There was a statistically significant difference in marginal microleakage between the three experimental groups ($\chi^2 = 16.832$, $p < 0.001$), which showed that the kind of provisional luting cement had a substantial effect on the marginal sealing performance of CAD-CAM manufactured interim crowns.

In the three groups, the mean rank of zinc oxide eugenol cement was the highest (18.88), which means the largest degree of dye penetration and the poorest marginal sealing ability. The zinc polycarboxylate cement had an intermediate mean rank (13.63) demonstrating moderate resistance to microleakage. However, zinc oxide non eugenol cement showed the lowest mean rank (5.00) with the least marginal microleakage and best marginal seal. The results reveal that the zinc oxide non-eugenol cement had a

better sealing ability than the other temporary luting agents tested. These observations were confirmed by the stereomicroscopic examination. The zinc oxide non-eugenol group showed minimum dye penetration, zinc polycarboxylate group showed moderate dye penetration and zinc oxide eugenol group showed extensive dye penetration which was in agreement with the quantitative analysis.

Table 1. Intergroup comparison of marginal microleakage among the three provisional luting cements using the Kruskal–Wallis test

Group	n	Mean Rank	Kruskal–Wallis χ^2 value	P-value
Zinc oxide eugenol	8	18.88	**16.832**	**<0.001**
Zinc oxide non-eugenol	8	5.00		
Zinc polycarboxylate	8	13.63		

DISCUSSION

The present in vitro study evaluated the marginal microleakage of CAD-CAM fabricated interim crowns cemented with three commonly used provisional luting agents after thermocycling and dye penetration analysis. The findings demonstrated a statistically significant difference in marginal microleakage among the three groups, indicating that the type of provisional cement significantly influences the sealing ability of CAD-CAM interim restorations. Zinc oxide non-eugenol cement exhibited the least marginal microleakage, followed by zinc polycarboxylate cement, whereas zinc oxide eugenol cement showed the greatest dye penetration. These findings reject the null hypothesis and highlight the importance of selecting an appropriate provisional luting cement to preserve marginal integrity and minimize bacterial leakage.[24-26]

The superior performance of zinc oxide non-eugenol cement is consistent with previous studies by Bandgar et al.[24] and Arora et al.[25], who reported significantly lower marginal microleakage with non-eugenol temporary cements compared with zinc oxide eugenol cements. Similarly, Farah and Elezky[26] concluded that the physical properties and composition of temporary cements play a decisive role in determining their sealing ability. The present findings therefore support existing evidence that non-eugenol cements provide a more durable marginal seal under simulated oral conditions.

The use of CAD-CAM fabricated interim crowns minimized fabrication-related discrepancies and allowed a more accurate evaluation of the luting agents. Previous studies by Rayyan et al.[27] and Herrera et al.[28] have shown that CAD-CAM provisional restorations possess superior marginal adaptation due to reduced polymerization shrinkage and improved dimensional stability. However, the present study demonstrates that restoration accuracy alone cannot eliminate microleakage, as the sealing ability is also dependent on the properties of the provisional cement. This observation supports the findings of Edelhoff and Özcan[29], who emphasized that the long-term success of fixed prostheses depends on both restoration precision and the functional performance of the luting material.

The superior sealing ability of zinc oxide non-eugenol cement may be attributed to its lower solubility, improved dimensional stability, and greater resistance to degradation during thermocycling. These properties help maintain a continuous cement layer and reduce marginal gap formation. In contrast, zinc oxide eugenol cement is more susceptible to dissolution, resulting in greater dye penetration and marginal leakage. Zinc polycarboxylate cement demonstrated intermediate performance, likely because its chemical adhesion to tooth structure improves retention, although its relatively higher film thickness and moisture sensitivity may limit its sealing effectiveness. Oilo[30] also reported that cement composition, viscosity, film thickness, and solubility significantly influence marginal sealing performance.

From a clinical perspective, the findings suggest that zinc oxide non-eugenol cement may be the preferred provisional luting agent for CAD-CAM interim crowns, particularly in cases requiring prolonged provisionalization or complex prosthodontic rehabilitation. Appropriate cement selection can reduce bacterial penetration, preserve pulpal and periodontal health, and improve the longevity of provisional restorations.[31-33]

A major strength of this study is the standardized use of CAD-CAM fabricated crowns, uniform tooth preparation, thermocycling, and stereomicroscopic evaluation, which enhanced methodological reliability and reduced operator-related variability.[34] However, the study was conducted under in vitro conditions and could not replicate the complex oral environment, including masticatory forces, salivary enzymes, pH fluctuations, and long-term functional loading. Moreover, only three provisional cements and one CAD-CAM PMMA material were evaluated, limiting the generalizability of the findings.[35]

Future studies should incorporate larger sample sizes, longer aging protocols, cyclic mechanical loading, and advanced techniques such as micro-CT or scanning electron microscopy to better simulate clinical conditions. Randomized clinical trials are also needed to validate these laboratory findings and establish evidence-based recommendations for provisional cement selection in CAD-CAM restorations.

CONCLUSION

The present study demonstrated that the type of provisional luting cement significantly influences the marginal sealing ability of CAD-CAM fabricated interim crowns. Zinc oxide non-eugenol cement exhibited the least marginal microleakage, followed by zinc polycarboxylate cement, while zinc oxide eugenol cement showed the highest dye penetration. These findings suggest that, in addition to the precision of CAD-CAM fabrication, the appropriate selection of provisional luting cement is essential for

achieving an effective marginal seal and improving the biological success of fixed prosthodontic restorations.

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