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ORIGINAL ARTICLE

Influence of aging process and restoration thickness on the fracture resistance of provisional crowns: A comparative study

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Abstract *Background:* The advancement of digital dentistry enhanced the fabrication of indirect provisional restorations utilizing durable materials, yet the performance of provisional crowns fabricated with various techniques, and different thickness remains unknown. Thus, this in-vitro study aimed to evaluate the influence of restoration thickness and aging on the fracture behavior of provisional crowns fabricated using different techniques.

Methods: A dentiform maxillary first molar was prepared using a highly filled epoxy resin material to construct identical die replicas. Four groups of provisional crowns were fabricated: Group 1 was milled at 1.5 mm occlusal thickness; Group 2 was milled at 0.9 mm thickness; Group 3 was 3D-printed at 1.5 mm occlusal thickness; and Group 4 was 3D-printed at 0.9 mm occlusal thickness. Eight crowns from each group were subjected to a thermocycling process for 5000 cycles between baths held at 5 °C and 55 °C with a dwell time of 30 s and transfer time of 5 s. All crowns (aged and non-aged (control)) were loaded for fracturing using a universal testing machine at a 0.5 mm/min crosshead speed. Data were analyzed using a two-way analysis of variance and multiple comparisons at ($\alpha = 0.05$).

Results: The maximum mean force load was found in the non-aged milled group (M1.5) at 1706.36 ± 124.07 N; the minimum mean force load was recorded for the aged 3D-printed group (3D0.9)

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at 552.49 ± 173.46 N. A significant difference was observed before and after thermocycling ($p < 0.01$).

Conclusion: Computer-aided design and manufacture of milled provisional crowns is superior to 3D-printed crowns for fracture resistance.

1. Introduction

Indirect provisional restorations are important during either short or prolonged periods of dental treatment before the insertion of the final restorations (Miura et al., 2019). These prostheses are attributed to protect the vital pulp, maintain the prepared teeth position, and restore both function and aesthetics (Peng et al., 2020). Provisional restorations should be fabricated using materials that can withstand diverse oral loading conditions, particularly in the posterior region of the mouth (Alt et al., 2011). Posterior occlusal forces have been reported to range between 400 and 650 N in females and between 490 and 800 N in males (Varga et al., 2011, Sathyanarayana et al., 2012).

Provisional restorations are usually fabricated by direct or indirect methods using polymethyl methacrylate (PMMA), poly(ethyl methacrylate) (PEMA), dimethacrylate, or bis-acrylic resins (Burns et al., 2003). However, this technique has some limitations including irritation caused by exothermic reactions, poor marginal integrity, and color instability (Gratton and Aquilino 2004). Alternatively, the introduction of computer aided design/ computer aided manufacturing (CAD/CAM) in dentistry has enhanced the production quality and minimized the number of laboratorial steps (Rekow, 2020). The advancement in digital dentistry have also allowed the fabrication of provisional restorations by means of subtractive or additive manufacturing (Van Noort, 2012). Subtractive fabrication technique which also known as milling technique involve milling resin blocks or discs. Restorations manufactured using the subtractive technique exhibited better physical outcome because the blocks are manufactured under ideal conditions, and also the pre-polymerized blocks undergo a high degree of conversion (Li et al., 2014, Alsarani et al., 2018).

In addition to the subtractive fabrication method, the additive technique or a three-dimensional (3D) printing techniques have gained popularity for producing several dental appliances and prostheses including provisional restorations (Javaid and Haleem 2019). This technique was utilized to create an 3D model from CAD data by laying consecutive layers of resin material. The 3D method or additive technique is a cost-effective choice for both dental offices and laboratories and reduces material waste (Groth et al., 2014). Several additive technologies have been used to create 3D object including stereolithography, selective laser sintering, fused deposition modeling and polyjet 3D printing (Javaid and Haleem 2019). Different studies have assessed and evaluated the mechanical and physical outcome of utilizing both subtractive and additive techniques (Reeponmaha et al., 2020, Abad-Coronel et al., 2023). For example, the conventional and milled restorations showed inferior mechanical properties compared with 3D printed provisional restorations in a recent study (Martín-Ortega et al., 2022). In contrast, Henderson et al. reported that 3D printed restorations exhibited less fracture resistance in comparison to conventional provisional restorations (Henderson et al., 2022).

The thickness of permanent restoration is influenced by the type of restoration, the material selection, and the preparation design (Conrad et al., 2007, Lebedenko et al., 2020). Conservative preparation can be performed when durable restorative materials are used. Zirconia, for example, could be fabricated with a minimum thickness of 0.7 mm, but all-ceramic restoration fabricated with lithium disilicate glass–ceramic should maintain 1.5 mm occlusal thickness (Sun et al., 2014, Leitão et al., 2022). Thus, during the fabricating of permanent restorations, the prepared dentitions must be restored with provisional restorations that simulate the thickness and shape of their permanent counterpart.

Data regarding the performance of provisional crowns of different thicknesses and fabrication techniques are limited. Therefore, this in-vitro investigation aimed to evaluate the influence of restoration thickness and aging on the fracture behaviour of provisional crowns fabricated using different techniques. The null hypothesis was that the thermocycling aging process and restoration thickness would not significantly affect the milled or 3D printed provisional crowns.

2. Materials and methods

2.1. Tooth replica preparation

Tooth preparation was performed on dentiform maxillary first molar with a 1.5 mm occlusal reduction, 1 mm wall reduction, and gingival margin at 1 mm with a circumferential shoulder. This tooth was used to prepare identical replicas ($n = 16$) made of a highly filled epoxy resin material (Viade Products Inc, Amarillo, Calif). Based on a pilot study, the sample size was calculated using G*Power software to maintain 80% power and 95% precision ($\alpha = 0.05$).

2.2. Crown fabrication

The prepared tooth was placed on typodont standard cast in order to perform scanning the prepared tooth along with the adjacent and opposing dentitions by using dental lab scanner (D2000, 3shape, Copenhagen, Denmark). Milled and 3D-printed crowns were designed according to their thicknesses (1.5 mm or 0.9 mm). The first crown was designed with a 1.5 mm occlusal thickness, and the file was saved in a standard tessellation language (STL) format. This file was used to fabricate identical crowns but with a reduced occlusal thickness of 0.9 mm. These two files were used to fabricate all restorations in the current study.

The CAD/CAM provisional crowns were milled by using a 5-axis dental milling machine (Zenotec t1, WIELAND Dental, Pforzheim, Germany) using (Telio CAD, Ivoclar Vivadent, Liechtenstein) according to the manufacturers' recommendations; (16 crowns at 1.5 mm occlusal thickness (M1.5) and 16 crowns at 0.9 mm occlusal thickness (M0.9)). For the 3D printed crowns, the same STL files were utilized to construct 3D printed crowns with two different thicknesses (16 crowns at 1.5 mm occlusal thickness (3D1.5) and 16 crowns at 0.9 mm occlusal thickness (3D0.9)) by using a 3D printer (NextDent 5100, NextDent, Soesterberg, Netherlands) with micro filled hybrid 3D print resin (NextDent C&B MFH, NextDent, Soesterberg, Netherlands) according to the manufacturer's instructions.

2.3. Cementation

All provisional crowns fabricated using different techniques were tried in to their corresponding die replica to ensure they fit accurately. Eugenol-free temporary cement (RelyX Temp NE, 3 M ESPE, St Paul, MN) was utilized to lute the crowns according to the manufacturer's recommendations. A constant pressure (50 N) was applied to the occlusal surface of the crowns for 6 min to ensure a complete temporary bonding followed by the removal of excess cement.

2.4. Thermocycling and fracture resistance testing

Half the crowns from each group were subjected to a thermocycling process for 5000 cycles between bathes held at 5 $^{\circ}C$ and 55 $^{\circ}C$ with a dwell time of 30 s and transfer time of 5 s. After completing the thermocycling process, all crowns (aged and non-aged (control)) were subjected to a fracture test using a universal testing machine (Instron 5965, Canton, USA) under an axial load at a crosshead speed of 0.5 mm/min to fracture. The load was applied to the central fossa using tungsten ball with a diameter of 5 mm (Fig. 1). A thin Teflon layer was placed between the loading ball and the crown to prevent direct and sharp contact between the restoration and load application and also to distribute the forces.

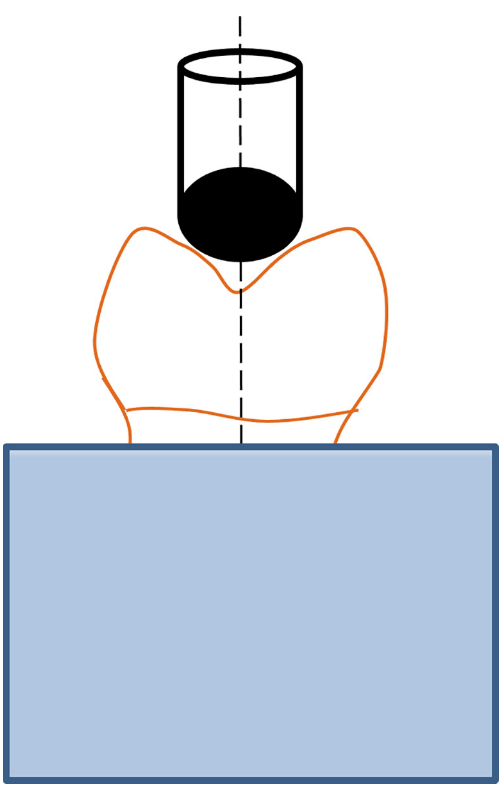

Fig. 1 Schematic illustration of sample position and load application.

The mode of fracture was also recorded according to the Burke's classification (Burke and Watts 1994) as follows;

Class I – minimal fracture or crack in crown
Class II – less than half of crown lost
Class III – crown fracture through midline; half of crown displaced or lost
Class IV – more than half of crown lost
Class V – severe fracture of tooth and/or crown

2.5. Statistical analysis

The data were analyzed using IBM SPSS software (SPSS 29 V, IBM). The comparison of the mean fracture values was performed using analysis of variance (ANOVA). Post-hoc multiple comparisons were performed using Tukey's test. The significance level was set at $\alpha = 0.05$.

3. Results

The mean fracture values and standard deviations are listed in Table 1. Analysis showed the maximum mean force value at fracture was found in the non-aged (control) (M1.5) group (1706.36 ± 124.07 N); the minimum mean force value at fracture was recorded for the aged group (3D0.9) at (552.49 ± 17 3.46 N) (Fig. 2).

A significant difference was observed before and after thermal cycling ($p < 0.01$). The common fracture modes in all test groups were Class I, II, and III (Figs. 4,5).

4. Discussion

This study investigated the fracture resistance of provisional crowns fabricated using different thicknesses and techniques after being subjected to cyclic thermal aging. A statistically significant difference was observed among the tested groups, and the null hypothesis was rejected because the fracture strength varied among the groups.

Ideally, provisional restorations should withstand occlusal force variations and different oral conditions to restore function and aesthetics (Peng et al., 2020). The results of the present study indicated that CAD/CAM milled restorations, irrespective of crown thickness, showed better fracture resistance compared to their 3D printed counterpart. This finding might be attributed to the industrial manufacturing of Polymethyl methacrylate CAD/CAM blocks that are manufactured and polymerized under ideal conditions (Li et al., 2014). In agreement with our findings, (Benli et al., 2021) reported that PMMA milled crowns resisted the fracture better

Table 1 The mean and standard deviation force value at the fracture (N) in each group.

Technique	Crown Thickness	Aging Condition	Mean (N)	SD (N)
CAD/CAM	1.5 mm	Aged	1399.60	215.71
		Non-aged	1706.36	124.07
3D Printed	1.5 mm	Aged	1141.57	196.47
		Non-aged	1506.12	172.28
CAD/CAM	0.9 mm	Aged	1186.17	177.05
		Non-aged	1431.32	142.52
3D Printed	0.9 mm	Aged	552.49	173.46
		Non-aged	781.55	159.89

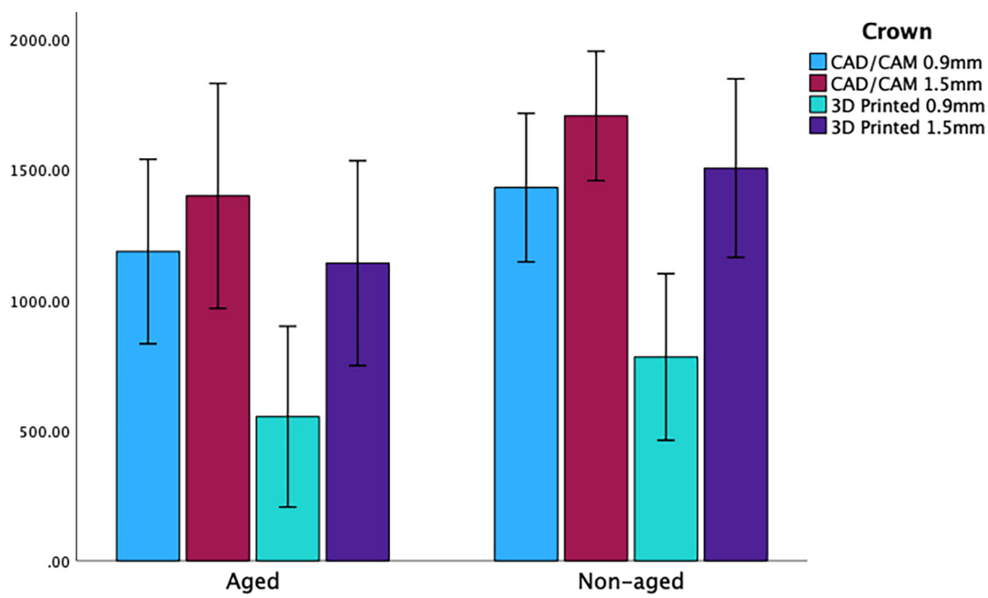

Fig. 2 Bar graph representing the mean and SD of the fracture strength (N).

than 3D printed crowns. In contrast, an in-vitro study indicated that fixed dental prostheses constructed using the 3D printing technique showed superior fracture resistance compared to the milled restorations (Reymus et al., 2020). The 3D printed restorations are fabricated using a layering technique, oriented either vertically or horizontally. Restorations constructed using vertical build orientations have been shown to display superior mechanical properties compared to those fabricated with horizontal build orientation (Alharbi et al., 2016). The fracture resistance of 3D-printed crowns in the current study was inferior to that of milled crowns, possibly because of the horizontal orientation technique and low polymerization rate; CAD/CAM–milled crowns fabricated from blocks exhibit high polymerization rates because of industrial manufacturing (Jain et al., 2022).

Thermocycle aging involves subjecting dental restorations to alternating hot and cold temperatures to mimic the effects of temperature variations in the oral environment. In the current study, eight crowns from each group were subjected to a thermocycling aging process for 5000 cycles (5 $^{\circ}C$ and 55 $^{\circ}C$), representing six months in the oral setting (Angwarawong et al., 2020). The results of this study indicated that the mean force value at fracture decreased dramatically in all tested groups after subjecting the restorations to the thermocycling aging process. Water could escape between the layers of the 3D printed restorations, possibly changing the material's dimensional stability and causing distortions, potentially affecting the material's performance, and increasing the likelihood of fracture (Berli et al., 2020).

The thickness of the provisional crown can vary depending on the material used, the location in the mouth, and the clinical situation. Different studies have evaluated the influence of fabrication techniques, the aging processes, and preparation designs (Abdullah et al., 2016, Henderson et al., 2022, Martín-Ortega et al., 2022). However, little evidence is available regarding the minimal thickness of provisional restorations capable of withstanding the diverse loading conditions in the oral environment. The results of the present study revealed that the mean force value of provisional crowns with a 0.9 mm thickness fabricated using 3D printing technique was less than those fabricated using the CAD/CAM milling technique at the same thickness. Therefore, thinner provisional crowns constructed using the 3D printing technique were more susceptible to fracture, possibly caused by the printing layer thickness and post-polymerization time (Reymus et al., 2020). In the present study, the printing layer thickness was

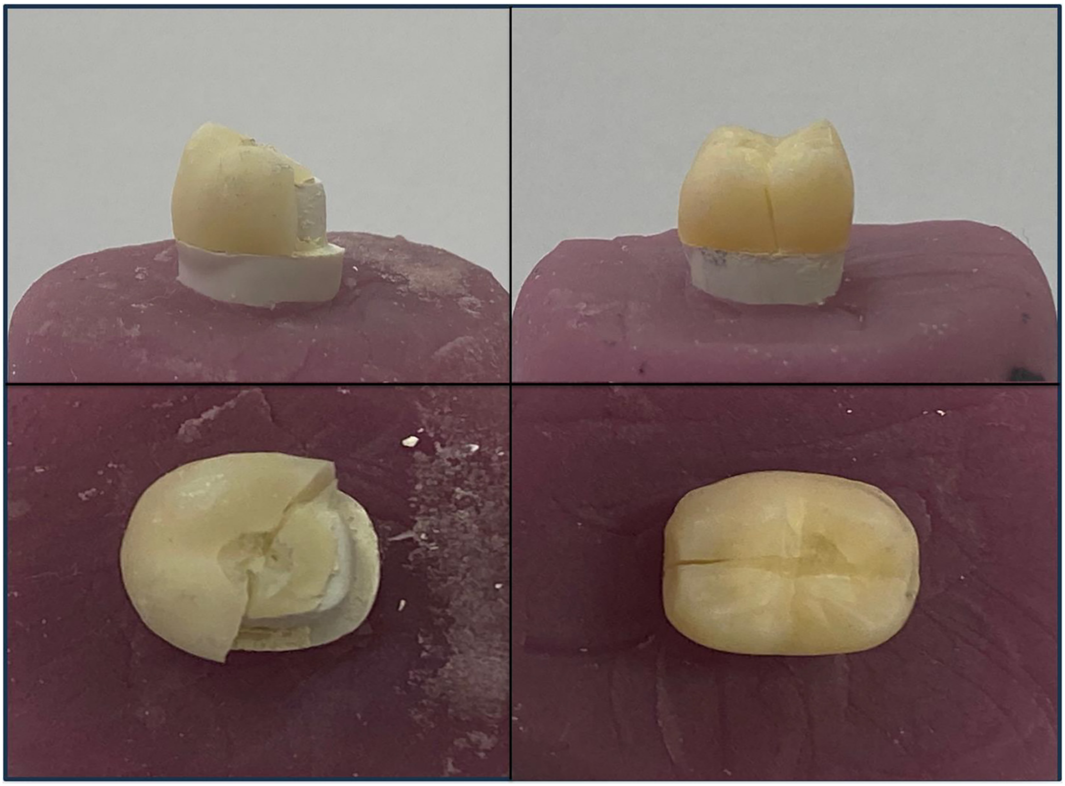

Fig. 3 Different fracture modes.

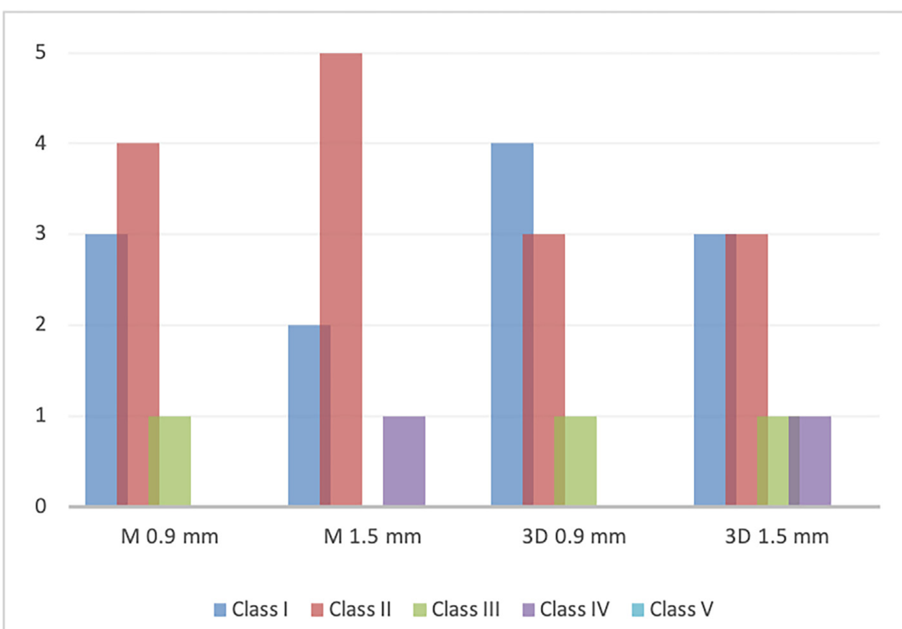

Fig. 4 Classification of fracture mode (non-aged crowns).

printed with 0.075 mm layer thickness. Specimens printed with a layer thickness of < 0.050 mm and increased post-polymerization temperature enhanced the strength of 3D-printed restorations (Steyrer et al., 2017, Bayarsaikhan et al., 2021).

Fracture modes were assessed in the current study. The analysis found that the typical fracture pattern among the fractured specimens was Class II (less than half of the crown lost), followed by Class I (minimal fracture or cracking in the crown), irrespective of the aging condition. This finding is con-

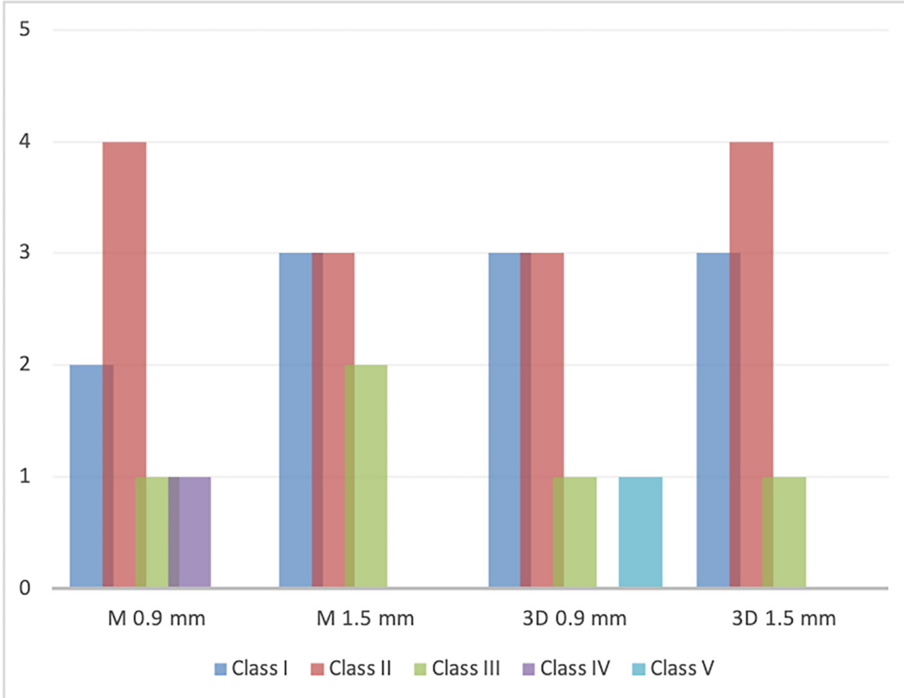

Fig. 5 Classification of fracture mode (aged crowns).

sistent with previous results; the Class II fracture pattern was recorded as a common fracture mode (Abdullah et al., 2016).

Other factors may influence the fracture resistance of provisional crowns, including the restoration design, occlusion condition, and cementation type. Therefore, these factors should be considered in conjunction with provisional crown thickness when assessing fracture resistance. In addition, the provisional crowns in this study were evaluated under static loads, which may differ if tested in diverse loading conditions and aging solutions. Further studies are required to evaluate the influence of the marginal finish line on different provisional crown thicknesses fabricated with additive and subtractive manufacturing techniques.

5. Conclusions

With the limitation of this in-vitro investigation, it can be concluded that provisional CAD/CAM milled crowns resist fractures in a superior fashion compared to 3D-printed crowns. Therefore, 3D printing is not a viable technique for fabricating provisional crowns with occlusal thicknesses of < 1 mm.

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.

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