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# Comparative Evaluation of Fracture Patterns of CAD/CAM, 3D Printed Resin Matrix Ceramic, and Zirconia Implant Supported Crowns

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**ABSTRACT**

**Background:** implant-supported crowns are widely used for the replacement of missing teeth. Recent advances in digital dentistry have introduced CAD/CAM and 3D-printing technologies, providing a variety of restorative materials with different mechanical properties. However, evidence regarding their fracture behavior and failure patterns remains limited.

**Objective:** To compare the fracture patterns of CAD/CAM nano-hybrid ceramic, 3D printed resin matrix ceramic, and zirconia implant supported crowns
**Material and method:** vericom Mazic® Duro (CAD/CAM Nano Hybrid Ceramic) and saremco Print Crowntec (3D printable resins-based) were used as resin matrix ceramic and IPS e.max. ZirCAD ivoclar (zirconia) was utilized to fabricate lower first molar screw-retained, implant-supported crowns. following fabrication, the crowns were glued onto stock abutments-previously secured to analogs embedded in acrylic resin -using Rely X U200 self-adhesive resin cement (3M ESPE, Germany) . At last , all specimens were subjected to a fracture resistance test. Chi-square was applied to assess the fracture patterns.
**Results**: Statistical evaluation using the chi-square test revealed no significant relationship between fracture mode and methods (p-value =0.109) .The failure mode in Group A and Group B showed that all specimens failed due to crown fracture, with 83.3% exhibiting mode 1 (Crown fracture) and the remaining 16.7% experiencing mode 2 (Crown fracture + total debonding). In Group C, the failure modes were evenly distributed, with 50% classified as mode 1 and the remaining 50% as mode 2.
**Conclusion:** The different materials do not impact the mechanism of fracture of an implant-supported crown. The higher incidence of debonding in zirconia crowns may be related to the absence of silica on the zirconia surface

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## 1. INTRODUCTION

Implant-supported restorations are a practical and effective therapeutic choice for restoring the function, appearance, and speech capabilities that are lost due to losing teeth. Multiple materials are accessible for computer-aided design/computer-aided manufacture (CAD/CAM) in implant-supported restorations, including ceramics, metals, composites, and resin-based materials (1).

When selecting materials for implant supported crown, it is important to consider that implants are subjected to the higher occlusal stresses than natural teeth. Unlike teeth, implants lack periodontal ligament which normally absorb forces and provide proprioceptive feedback. Consequently, masticatory forces transmitted directly to the implant and surrounding bone, making the choice of a durable restorative material essential for long term clinical success (2).

Because of its excellent mechanical qualities (it can endure masticatory stresses), good biocompatibility, and attractive white color, zirconia is regarded as an appropriate material for prosthetic rehabilitation of the teeth. For the creation of indirect computer-aided design (CAD)/computer-aided manufacturing (CAM) restorations, ceramic and composite resin materials are used. CAD/CAM composite materials are becoming more and more common for single-unit restorations, despite having less appealing qualities (3).

Because of their shock-absorbing qualities, resin-based materials might be used in place of implant-supported restorations (4,1). The benefits of CAD-CAM composites superior high marginal stability, predictable and uncomplicated of intraoral repairability, and simplified post-processing procedures (5). Furthermore, definitive composite repairs made using 3D printing have been documented in researches (6,7).

The occlusal loading condition is considered a critical determinant of the long-term viability of the implant-abutment-crown complex. While there is no clinical data available about the effect of overloading on peri-implant bone loss, it is crucial to regulate the pressures that are communicated to the bone implant interface in terms of biomechanical factors.

Maximum bite forces in natural dentition typically rang from200 to 900N, with higher value reported in posterior teeth. Although CAD/CAM and 3D-printed restorative materials are increasingly for implant supported crown, evidence regarding their fracture resistance and failure patterns remains limited (9-10).

The null hypothesis for this study was that there will beno significance difference in failure patterns among implants supported crowns fabricated from different CAD/CAM and 3D-printed restorative materials

## 2. MATERIAL AND METHOD

This in vitro comparative experimental study was conducted to evaluate and compare the fracture patterns of implant-supported crowns fabricated from (CAD/CAM, 3D printed) resin-matrix ceramic and zirconia materials. A total of n=36 implant-abutment analogs made of titanium grade IV( Dentium) that used in this study , along with stock titanium abutments ( 5.5mm length , 6.5mm diameter) . The abutments were attached to the analogs using a torque driver, following the manufacturer's instructions with a force of 30 N (11,12). Then put into a mold (specially made for this study) with self cure acrylic at dough stage. The acrylic was poured at about 3 mm of acrylic between implant analogue and abutment margin (13,14).

The thirty-six specimens were included and randomly allocated into three groups each group with 12 sample: Group A, vericom Mazic® Duro (CAD/CAM Nano Hybrid Ceramic, Korea); Group B, saremco Print Crowntec (3D printable resins-based materials, Switzerland); Group C, included zirconia (IPS e.max. ZirCAD ivoclar vivadent Germany).

Prior to scanning, every abutment was coated with Scanning spray (NHT) to provide accurate scanning procedure after that a three-dimensional digital image of abutment was obtained using extraoral scanner (Medit T710, korea) and the data were then transferred into the CAD software (ExoCAD) (14). A standardized crown design featuring a screw access channel was created using CAD software and exported in standard tessellation language(STL) format.

The crowns were then treated according to manufacturers' recommendations prior to cementation (Table 1).

**Table 1**. Surface treatment protocols for the tested materials.

| Material | Surface treatment |
|---|---|
| Mazic Duro CAD/CAM nano-hybrid ceramic | Airborne-particle abrasion with 25-30 µm $Al_2O_3$ at 0.2 MPa, followed by cleaning with oil-free air and ethanol. |
| Crowntec 3D-printed resin matrix ceramic | Airborne-particle abrasion with 110 µm $Al_2O_3$ particles. |
| IPS e.max ZirCAD zirconia | Airborne-particle abrasion with 25-70 µm $Al_2O_3$ at 1 bar pressure, followed by water rinsing and air drying. |

In accordance with procedure described by Zacher et al., Teflon tape was utilized to seal the screw apertures , and light-curing composite (DIAFIL, Korea) was used to seal the screw access holes (15). all specimens were then subjected to airborne particle abrasion (50 µm $Al_2O_3$, at distance about 10 mm , 1 bar pressure, for about 60 seconds per abutment) (11).

Rely X U200 self-adhesive resin- cement (3M ESPE, Germany) was utilized to bond all samples to the matching implant abutment in turn.

Each crown was seated onto its corresponding implant under finger pressure, and excess cement was carefully removed. A standardized vertical load of 5 kg was then applied to the occlusal surface of each crown for 6 min by using a custom-designed loading device (16). after that, all crown surfaces were light-cured for 20 seconds in accordance to instruction of manufacturer. After that, the samples were immersed in deionized distilled water at room temperature (25 °C)for seven days (17,18).

All specimens underwent to thermal aging for 500 thermocycles (5 and 55 °C) with a dwell time of 30 s as a short-term artificial aging procedure. This protocol was selected in accordance with ISO/TS 11405 recommendations and has been widely used as a minimum aging regimen in laboratory studies evaluating dental restorative materials prior to mechanical testing. Although higher numbers of cycles have been proposed to simulate longer clinical service periods, 500 cycles remain an accepted protocol for standardized short-term aging and facilitate comparison with previous investigations (19,11). Fracture resistance testing was then conducted using A LARYEE Universal testing machine.

The load was transferred via 5-mm diameter metal sphere that was placed on the occlusal surface, to provide tension relief during applying the force ,1mm thick of rubber layer was placed between the rod and crown. The crosshead speed was set at 1mm/min until spontaneous fracture occurred (11). All crowns were examined under a stereomicroscope (Meiji Techno& Tokyo, Japan) under ×25magnification figure (1), figure (2)

**Figure (1):** Fracture mode assessment with stereomicroscope under ×25 magnification

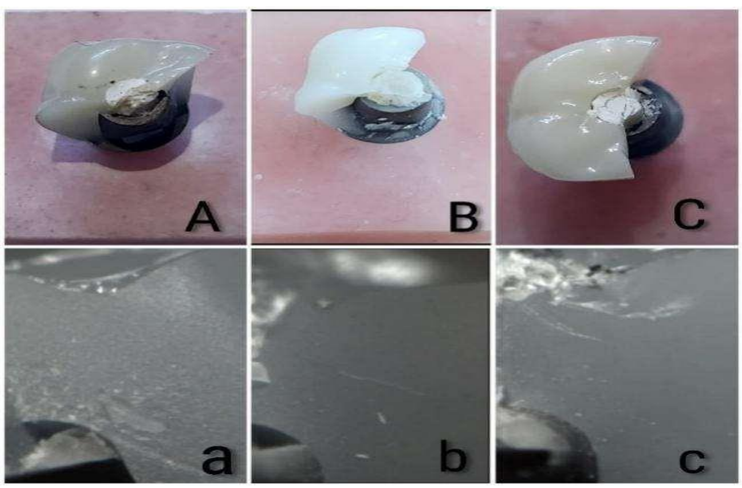


**Figure (2):** Stereomicroscopic assessment of fracture modes and representative specimens from each group after fracture testing. A/a: CAD/CAM nano-hybrid ceramic; B/b: 3D-printed resin matrix ceramic; C/c: zirconia.

to determine the fracture pattern, which was classified according to a standardized classification system as shown in table (2) for implant supported restorations (20)

**Table 2**. Fracture mode classification.

| Mode | Description |
|---|---|
| Mode 1 | Crown fracture |
| Mode 2 | Crown fracture with total debonding |
| Mode 3 | Crown indentation |
| Mode 4 | Crown and abutment fracture |
| Mode 5 | Screw fracture |
| Mode 6 | Implant/analog deformation |

## 3. Statistical analysis

The statistical analysis was performed by SSPS 26.0 (SPSS Inc., Chicago, IL , USA).

Descriptive statistics were calculated for all variable. The Chi-square test was used to compare fracture patterns among the study groups. Statistical significance was set at $p < 0.05$

## 4. RESULTS

Analysis of fracture patterns illustrated rang of failure modes across all experimental groups. However statistical evaluation using the chi-square test revealed no significant relationship between fracture mode and methods (p-value =0.109) table (3), figure (3).

The failure mode in Group A and Group B revealed all specimens failed as show in figure (1-3) due to crown fracture, with 10 specimens (83.3%) exhibiting mode 1 (Crown fracture) and 2 specimens (16.7%) experiencing mode 2 (Crown fracture + total debonding). In Group C, the failure modes were evenly distributed, with 6 specimens (50%) classified as mode 1 and 6 specimens (50%) as mode 2.

**Table 3**. Distribution of fracture modes among the study groups.

| **Groups** | **Descriptive** | **Mode of fracture** | | $X^2$ | **P. Value** | **d.f** |
|---|---|---|---|---|---|---|
| | | **Mode 1** | **Mode 2** | | | |
| **Vericom (cad/cam)** | **Number of sample** | 10 | 2 | 4.431 | 0.109 | 2 |
| | **Percentage** | 83.3% | 16.7% | | | |
| **Seramco (3D printing )** | **Number of sample** | 10 | 2 | | | |
| | **Percentage** | 83.3% | 16.7% | | | |
| **Zirconia** | **Number of sample** | 6 | 6 | | | |
| | **Percentage** | 50% | 50% | | | |

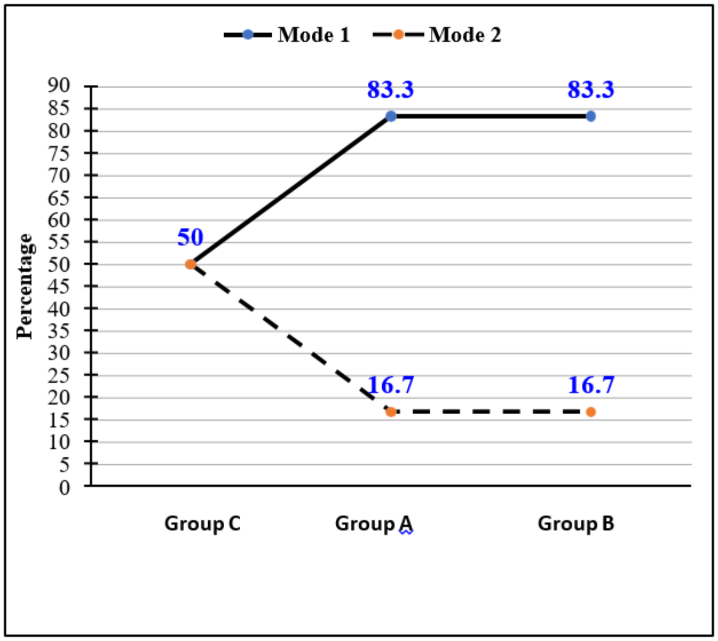


**Figure (3):** distribution of fracture modes among study groups

## 5. DISCUSSION

Two resin matrix ceramics made using various manufacturing processes and zirconia were utilized to investigate the impact of various materials on the fracture mode. Since no statistically significant difference was observing among the tested materials, the null hypothesis was accepted. The fracture mode in Group A, B of resin matrix ceramic material showed same result that ten of samples exhibiting Crown fracture and the remaining 2 samples experiencing Crown fracture + total deboning while in group C the failure modes were evenly distributed, with six samples exhibiting Crown fracture and six samples experiencing Crown fracture + total deboning.

Failure modes 1 and 2 were observed in the present study, whereas modes 3-6 were not detected. This finding suggests that failure was predominantly confined to the restorative component, which act s weakest link within the implant-supported assembly. Under compressive loading, fracture initiation occurred within the crown material or at the crown-abutment interface before stresses reached levels sufficient to reduce damage to the abutment, screw, or implant analog (21).

The predominance of crown fracture in all groups indicates that the restorative material itself represented the primary site of failure under compressive loading conditions. This finding suggests that the implant-abutment complex remained mechanically stable during testing. This observation is consistent with previous studies on implant-supported crowns, which demonstrated that crown fracture remains the most common failure mode under static loading conditions regardless of the restorative material used (22).

The fracture mechanism and stress concentration were ascertained using the specific single load to failure test. Every sample under investigation exhibited a fracture in its crown at the point where the occlusal surface of the crown and indenter met, per results of fractographic study. Tensile stress at the crown margins may be caused by mastication pressures on the occlusal surfaces of dental crowns, according to a different research that used fractographic examination of clinically cracked zirconia crowns (23).

This further shown that the pores, contaminants, or insufficient sintering in crowns served as fracture initiators. This suggests that more care and attention should be given to the zirconia crowns during CAD/CAM machining and any post-production adjustments. Furthermore, inside veneer or glazing will hinder cement flow during cementation, thereby increasing hoop stress or leading to inadequate seating (23,24).

The intricate contact among the abutment, adhesive layer, and restorative materials requires careful attention, the adhesive interface may represent a potential weak area within the restorative-abutment complex. The higher incidence of debonding observed in the zirconia group may be related to the absence of silica on the surface. Previous evidence has shown that durable zirconia bonding depends largely on appropriate surface treatment and the use of MDP-containing primers. Therefore, the effectiveness of the bonding protocol may play an important role in the long-term clinical performance of zirconia restorations (21,25).

It's should be noted that CAD/CAM composite materials exhibit greater resilience, water absorption, and coefficients of thermal expansion compared with ceramic CAD/CAM materials. These inherent properties may compromise the long-term stability adhesive interface. Hygroscopic expansion of resin-based restorations following water absorption generates hydrolytic stresses that are concentrated at the luting interface, thereby increasing interfacial tension and promoting adhesive degradation (26).

Consequently, these factors may play a critical role in the occurrence of debonding failures. Within the framework of CAD/CAM composite materials, fracture propagation happens via the resin matrix and the matrix-particle contact. Bridging effects and fracture deflection are two mechanisms that strengthen the material and have an impact on this process (27).

The fracture resistance of all-ceramic crowns is affected by the stiffness of the supporting structure, resulting in different stress distribution patterns between tooth-supported and implant-supported restorations during function (23,28).

The characteristics of the support material (abutment material) may play a crucial role in evaluating CAD/CAM composite materials. If the support complex lacks resilience, the majority of damage is expected to occur internally in the CAD/CAM composite due to its lower Modulus of Elasticity. Consequently, the layer of adhesive may undergo deformation (6,29,30).

## 6. Study limitations:

The primary limitation of this study is its in vitro design, which cannot completely reproduce the complex oral environments. additional research is required to clarify the precise function of various surface treatments on the intricate abutment-adhesive layer-restoration material.

## 7. Conclusion:

Restorative material did not significantly influence the fracture pattern of implant-supported crowns. Crown fracture was the most common mode of failure in all groups. Zirconia crowns exhibited a higher tendency toward debonding compared with resin matrix ceramic crownsFurther studies are required to investigate the influence of surface treatment and bonding protocols on failure behavior.

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