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Evaluation of Marginal Adaptation and Fracture Resistance of Implant-Supported Crowns Fabricated from Advanced Lithium Disilicate and High-Performance Polymer

(An In-Vitro Comparative Study)

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Abstract

Background: The success of fixed prosthesis is dependent on marginal adaptation and fracture resistance. Although several studies were performed on lithium disilicates and PEEK, studies on advanced lithium disilicates and BioHPP are insufficient. **Aim of Work:** This study aimed to compare implant-supported crowns fabricated from advanced lithium disilicate (ALD) and high-performance polymer (BioHPP) regarding MA and FR. **Material and methods:** Twenty prefabricated Ti-bases were screwed to implant fixtures, then embedded in epoxy resin molds. They were divided into 2 groups (n=10): Group 1: crowns fabricated from ALD, and Group 2: crowns fabricated from BioHPP. Scanning and designing of maxillary first premolar crowns were done. Crowns were subjected to thermocycling prior to marginal gap detection using a stereomicroscope at x40 magnification during three phases. Fracture resistance was evaluated using a universal testing machine. Statistical analysis was done using Mann Mann-Whitney U test and the Friedman test. Failure mode was analyzed using Chi chi-square test. **Results:** Advanced lithium disilicate showed significantly higher MA than BioHPP during different phases. The lowest values were recorded after cementation, with a median of (26.04 µm) in ALD and (40.06 µm) in BioHPP. Both groups showed significantly better marginal fit after cementation. Significantly higher FR was found in the ALD group with a median value of (837.68 N), than in the BioHPP group with a median value of (641.41 N). **Conclusions:** Advanced lithium disilicate crowns showed superior MA and FR than BioHPP. Both materials showed better MA after cementation.

Keywords: Marginal adaptation, fracture resistance, Computer-aided design and computer-aided manufacturing (CAD-CAM), advanced lithium disilicate, BioHPP.

Introduction:

The rapid development of digital dentistry has gained wide attention. The use of CAD-CAM technology is becoming more favorable in different aspects of dentistry than conventional methods. The commonly used technique for prosthetic fabrication is subtractive manufacturing using CAD-CAM[1,2]. Implant-supported crowns are one of the frequently used prosthetic treatments with 90a % success rate. Implant-supported ceramic restorations restore esthetics, phonetics, nd masticatory function [3].

Ceramics were the material of choice in esthetic dentistry for a considerable duration]. They have high strength, superior esthetics, nd increased brittleness [5]. However, the development of reinforced ceramics has improved their brittleness [6]. Lithium disilicate-based glass ceramics (LD) were used as esthetic restoration due to their high strength, various chemical and processing properties, along with high esthetic outcome. However, one of their major flaws is crack propagation [7].

In 2021, advanced lithium disilicate (Cerec Tessera, Dentsply Sirona) was introduced as a new type of lithium disilicate diminishing crack propagation feature. Tessera is constituted from 90% lithium disilicate (Li2Si2O5) crystals and 5% virgilite (Li0.5AI0.5Si2.5O6) crystals by volume of 0.5-µm-long needle-like shaped crystals embedded in a 40-45% zirconia glass matrix. The decreased crack propagation is due to virgilite crystals [7,8]. These crystals are formed at a temperature of 800˚C to 850˚C and are ofofanometers in size [9]. Virgilite and lithium disilicate crystals show distinct thermal expansion coefficients, leading to microcrack formation upon cooling, resulting in crack tip shielding which increases material toughness [9,10].

Other materials were introduced to overcome crack propagation, including high-performance polymer polyether-ether ketone (PEEK) [11]. PEEK has high mechanical strength, superior thermal and chemical stability, anti-corrosiveness, nd increased elasticity nearly similar to human bone and dentin, thus it is used in both biomedical fields and is considered an alternative to ceramics [12].

BioHPP is PEEK PEEK-based material, which is a partially crystalline high-performance thermoplastic polymer with a low melting temperature of 343°C. It is used in prosthetic dentistry either by pressing or milling techniques [13]. However, the use of PEEK as a monolithic dental restoration is limited due to its opaque and grayish color. Thus, CAD/CAM high-impact polymer composite veneering material was developed to improve esthetics [14].

The main factors of success of any prosthetic treatment are assessed by marginal adaptability along with the fracture resistance [15,16]. Lack of readaptability causes plaque accumulation leading to caries development, periodontal diseases, implant screw loosening, microleakage, nd cement dissolution [17-19]. In order to mimic intraoral conditions during in-vitro studies, thermal-aging is done by exposing the specimens to extremes of temperature, [20 °C].

The main mechanical property to be considered in an intra-oral prosthesis is the ability to resist fracture during function [21]. Fracture resistance is affected by physical and mechanical properties and is considered a key factor for the longevity of restorations. This test is done inin vitropplying vertical loading at different cross-head speeds using a stainless-steel sphere at the center of the object [22].

Hence, this in-vitro study was planned to assess marginal adaptation and fracture resistance of ALD in comparison with BioHPP in the the fabrication of implant-supported prosthesis. The null hypotheses of this study were that no difference would be found in marginal adaptability and fracture resistance of implant-supported crowns fabricated using ALD and BioHPP.

Material And Methods

Twenty titanium bases of 4 mm diameter and 7 mm height were screwed to implant fixtures (Vitronex implant system) of 3.7 mm diameter and 10 mm length using a torque wrench with 35 Ncm torque.

Each implant fixture was embedded in an epoxy resin mold of height 1.8 cm and diameter 1.5 cm. Afterwards, specimens were divided into two groups of ten each. (Table 1)

Direct scanning was done using an extra-oral scanner by spraying the abutments. A full contour maxillary first premolar was designed in standard tessellation language (STL) with a height of 9 mm buccally and 8.5 mm palatally. The restoration thickness was 2 mm in the proximal surface, 2.5 mm in the buccal and palatal surfaces, and 1.5 mm minimum occlusal thickness. The cement space was set at 25 µm, while the extra cement spacer was set at 50 µm in both groups [23]. All crowns were fabricated using the same milling unit and milling strategy. Before the milling process of each group, a new set of burs wewas inserted. Designing crowns using the two materials is illustrated in Figure).

ALD crowns were fabricated by wet milling using Cerec Tessera blocks (Dentsply Sirona) with an average time of 13-16 minutes for each crown [8]. After sprue removal, crowns were finished thandn polished using ceramic finishing diamond stones. Glaze was applied to the crown's external surface to complete both glazing and crystallization process at 760 ˚c and took an average of 9-12 minutes per cycle.

As for the fabrication of BioHPP crowns, the design was divided virtually on Exocad using the digital cutback technique into two parts: the core part of uniform thickness of 0.5 mm and 4 mm height, and the veneered anatomic part in the previously mentioned parameters, with cement space set at 25 µm. Wet milling of the core part was done using BreCAM.BioHPP blanks (Bredent, GmbH) followed by wet milling of the anatomic part using BreCAM.HIPC blanks.

In order to cement the veneering to the core, the outer surface of the PEEK core was air abraded with 110µm aluminum oxide grit at a distance of 3 cm and 3 bar pressure with a 45˚ angle using a sand blasting device, followed by application of visio. Link primer and light curing for 30 seconds [24,25]. Cementation of HIPC Veneers to PEEK cores was done using sta atic load device under 3 kg weight, ensuring equal application of force to all crowns, followed by removal of excess cement and curing for 40 sec on each surface [24,26].

Different crowns with intaglio surface treatments were done for each group, and Ti-based implants were used before cementation. Etching of intaglio surfaces of ALD crowns was done using 9.5% hydrofluoric acid gel for 30 seconds, then cleaned in a distilled water bath ultrasonically, and finally, silane coupling agent was applied to the dried fitting surface for 60 seconds, and [8,27]. Regarding BioHPP crcrcrowns 'ntagliourface, air

Abrasion was done using 110µm aluminum oxide grit at a distance of 3 cm and 3 bar pressure, followed by application of Visigo. Link primer and light curing for 30 sec [24,25]. Eventually, Implant Ti-bases were air abraded using 110µm aluminum oxide at a pressure of 4 bar after securing the abutment margins with baseplate wax and surface treated using MKZ metal primer, then light cured for 30 seconds [24,25]. Teflon tape was embedded in abutment screw access holes before cementation in order to simulate a clinical situation, and the same operator cemented one crown at a time. Crowns were cemented using Total C-ram (Itena) self-adhesive dual-cure resin cement and seated on implant abutments under finger pressure, followed by removal of excess cement. Afterwards, each crown was placed under a static load of 3 kg using a static load device, followed by light curing of each aspect (buccal, palatal, mesial, and distal) for 40 seconds [26]. Glycerin gel was applied to the crown's margins before light curing to limit the formation of oxygen oxygen-inhibiting layer (2) [27]. Crowns were unscrewed and inspected for the presence of excess cement, then margins were finished and polished. Abutments were re-screwed to implant fixtures, followed by securing the screw access hole with Teflon tape and flowable composite.

Identification of cervical marginal gaps between crown margins and Ti-bases margins on each surface was measured during three stages (before and after cementation, and after thermocycling) and recorded in microns using a stereomicroscope (Olympus, Japan) with fixed x40 magnification. During measurement before cementation, all crowns were fixed to Ti-bases using a clamp jig. Regarding the measurement of marginal gaps for the third time, all specimens were exposed to 5000 thermal cycles, which is equivalent to six months of intraoral exposure with a range of temperature between 5 to 55 ˚c, and dwell time was 60 seconds with a pause time of 10 seconds [29]. Four equidistant points were identified on each surface, with a total of sixteen points for each crown. These points were verified by numbering the specimens, then calibrating the images digitally each time from one line angle to the other on each surface using the same ruler tool used for measuring the gap to ensure equal distance and measurement of the same points during the three phases [30]. Images were obtained using digital image microscopy software (Toup View, Version 3.7).

Fracture test was conducted by fixing all specimens in a brass jig and applying vertical load using a universal testing machine (Tinius Olsen) to crowns using a 4 mm stainless-steel ball stylus at a crosshead speed of 1 mm/min. Perpendicular to the occlusal plane and centralized at the occlusal cuspal slopes of the crowns. A

A Rubber sheet was positioned between the stylus and occlusal surface of the crown to uniformly distribute the loads applied and avoid chipping of the veneering material (3). A crack sound and a sharp decline in the deflection curve were indications of load failure. Load failure was recorded in Newton (N) using computer software. Finally, the mode of fracture was inspected visually using a stereomicroscope (Olympus, Japan) at x20 magnification and was classified according to Bruke's classification [28]. (Table 2)

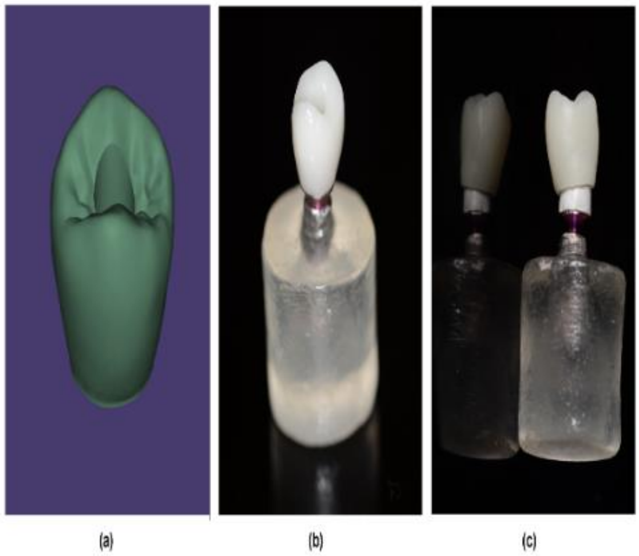

Figure (1): (a) designing of crowns and fabricated from (b) ALD and (c) BioHPP

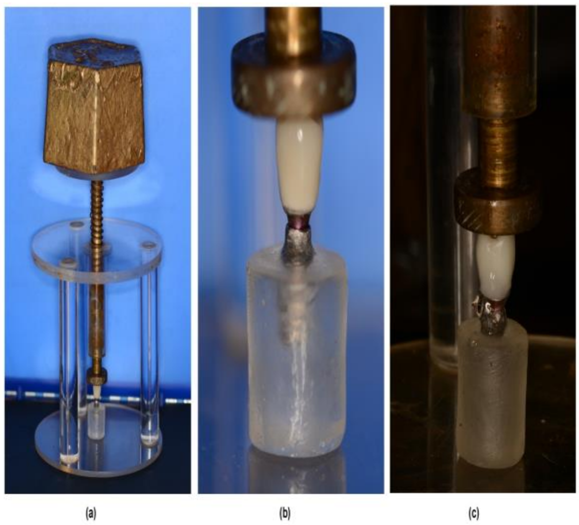

Figure (2): (a,b) Cementation under 3 kg load using static load device and (c) application of glycerin to prevent oxygen inhibiting layer formation

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Table 1. Groups listed with different materials used for crowns fabrication (N=10)

Group	Material used
I	**Crowns fabricated using CAD-CAM milled advanced lithium disilicate material (CEREC Tessera).**
II	**Crowns fabricated using CAD-CAM milled PEEK core from high performance polymer blanks (BreCAM.BioHPP) veneered with high impact polymer composite (BreCAM.HIPC).**

Table 2. Burke's classification for modes of crown fracture (Burke, 1999)[28]

Class	Pattern of fracture
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 or crown

Figure (3): Universal testing machine used to measure the fracture resistance (Tinius Olsen)

Mann-Whitney U test, along with the Friedman test, was used for statistical analysis, followed by a post hoc test with Bonferroni correction. The mode of failure was analyzed using Chi chi-square test. All tests were two-tailed, and the significance level was set at $p < 0.05$.

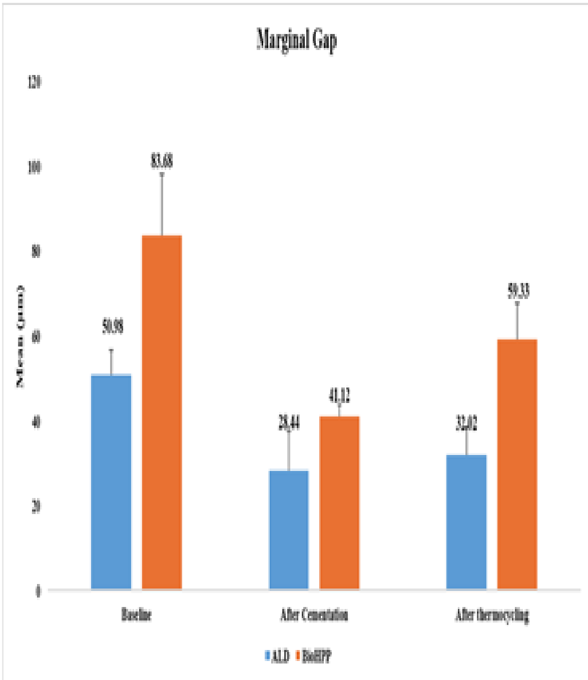

Figure (4): Bar chart showing a comparison of overall marginal adaptation between the two

Results

The median overall marginal gaps between ALD and BioHPP at different phases are summarized in Figure 4,5. At baseline, ALD exhibited a median marginal gap value of 52.50 µm, while BioHPP's was

86.09 µm. Mann-Whitney U test indicated ALD had statistically significantly lower median marginal gap value than BioHPP ($p < 0.05$) before cementation. After cementation, ALD still maintained a lower median marginal gap of 26.04 µm than BioHPP, with a median marginal gap of 40.06 µm. According to the Mann-Whitney U test, ALD showed statistically significantly lower median marginal gap than BioHPP after cementation ($p<0.05$). After thermocycling, ALD recorded a median marginal gap of 31.12 µm, compared to BioHPP's of 60.67 µm. Mann-Whitney U test revealed ALD maintained significantly lower marginal gaps after thermocycling compared to BioHPP ($p < 0.05$). Friedman test for overall marginal gap differences across the steps was also statistically significant for both ALD (FM value of 8.400, $p = 0.015$) and BioHPP (FM value of 10.00, $p = 0.007$), indicating significant variations across the steps within each material. Pairwise comparison of marginal gaps between different stages within ALD and BioHPP is summarized in Figure 4. Regarding pairwise comparison, ALD showed significantly lower marginal gap after cementation than at baseline ($p = 0.013$), and BioHPP showed significantly lower marginal gap after cementation than at baseline ($p = 0.005$). On the other hand, no significant differences were found between the other stages within each material group. Thus, ALD encountered lower marginal gaps in comparison with BioHPP across different stages, indicating superior marginal integrity.

The comparison of fracture resistance between ALD and BioHPP is summarized in Figure 6. Mann-Whitney U test recorded statistical significance between ALD and BioHPP ($p < 0.05$). ALD demonstrated higher statistical significance regarding fracture resistance with a median value of 837.68 N in comparison with BioHPP, which recorded a median value of 641.41 N. Thus, superior performance of ALD in comparison with BioHPP was suggested regarding fracture resistance.

Regarding mode of failure, there was a huge contrast between (ALD) and BioHPP groups across different classes, with a significant difference between the groups (p=0.001) (figures 7, 8). According to Bruke's classification, 30% of BioHPP samples were categorized as class I, 40% as class II, 10% as class III, and 20% as class V. While 100% of ALD samples showed class III midline fracture

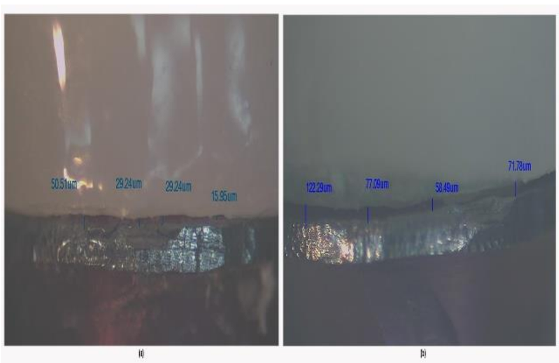

Figure (5): Measurement of the marginal gap under stereomicroscope at (x40) magnification for (a) ALD and (b) BioHPP

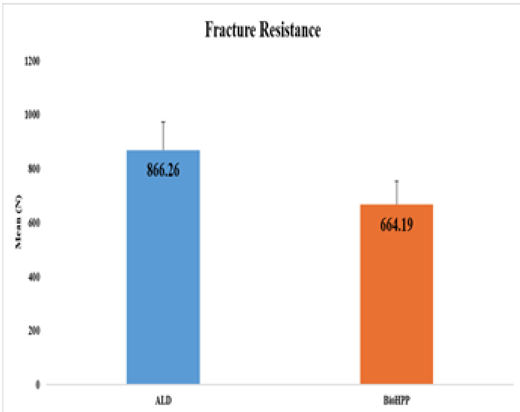

Figure (6): Bar chart showing a comparison between the two studied groups regarding fracture resistance

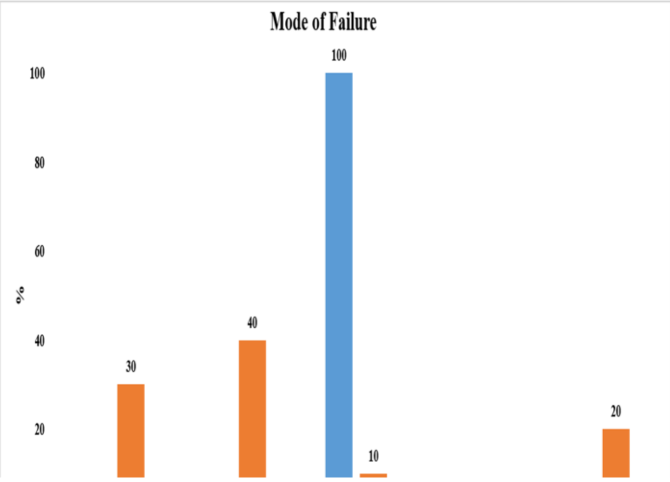

Figure (7): Bar chart showing a comparison between the two studied groups regarding mode of failure

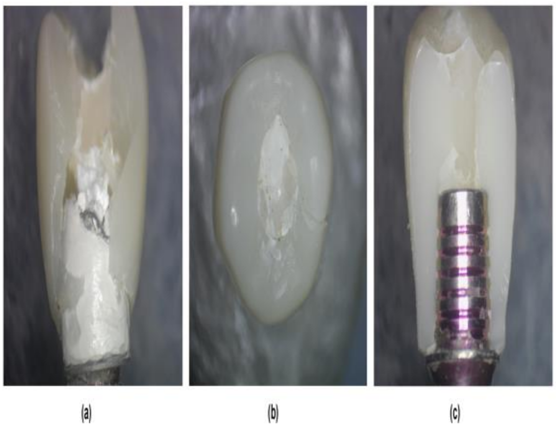

Figure (8): Different failure modes according to Bruke's classification under stereomicroscope at (x40) magnification

Discussion

The objective of the current study was to evaluate marginal adaptation during 3 stages and fracture resistance of implant-supported maxillary second premolars fabricated from ALD in comparison with BioHPP.

a. Marginal adaptation

The key factor of optimal success and longevity of any restoration is marginal adaptation [31]. Impaired marginal integrity leads to plaque accumulation, periodontal inflammation, screw loosening, and failure of fixed dental prosthesis [32-34]. The clinically acceptable values for CAD/CAM single restorations range from 23 µm to 110 µm [35,36]. However, McLean and Fraunhofer (1971) agreed that the acceptable marginal discrepancy is 120 µm [37].

Epoxy resin was used for implant molding due to their clear color, along with cementation with translucent resin cement for better visibility during marginal gap measurement using a static load device to ensure equal load application [38,39]. According to Rinke et al. (1995) and Groten and Pröbster (1997), a 3 Kg load was the proper load to prevent damaging or cracking the crowns [26,40].

On statistically analyzing both groups, it was found that a smaller marginal gap was encountered in ALD, which ranged from 44.94 µm to 61.47 µm, than in BioHPP, which ranged from 61.47 µm to 100.32 µm, before cementation. This was also noticed in the other two stages (after cementation and after thermocycling). The marginal gap of ALD after cementation ranged from 19.09 µm to 41.31 µm and from 25.42 µm to 42.69 µm after thermocycling. However, in the case of the BioHPP group, marginal gaps after cementation ranged from 38.23 µm to 45.31 µm and from 46.65 µm to 68.00 µm after thermocycling. All marginal gap values during different stages in both materials were within a clinically acceptable marginal gap (less than 120 µm) declared by McLean and Fraunhofer (1971) [37].

These findings were consistent with Zeighami et al. (2019)[41], Baran et al. (2022)[42], Meshreky et al. (2020)[43], Godil et al. (2021)[44], and El-Agwany et al. (2023)[45], whose results showed less marginal adaptation of BioHPP than zirconia, zirconia veneered using CAD-On lithium disilicate glass ceramics, and lithium disilicate restorations.

According to previous studies' findings, the increased marginal gap in BioHPP than ceramic restorations might be due to different structured materials, different milling machines specifications, PEEK's semi-crystalline structure containing resin matrix embedded fillers, and the ceramics' stiffness leading to better adaptation [42-44].

On the other hand, the study results were contrasted by Osman et al. (2022)[46], (2020)[47], and Nagi et al. (2023)[48], who revealed that lithium disilicates had increased marginal gap values than BioHPP.

Their findings might be due to the use of the pressing method rather than milling..

b. Fracture resistance

The supreme success of any prosthesis is durability and resistance to fracture. In this in vitro study, fracture resistance was assessed for ALD and BioHPP.

Multiple studies evaluated the masticatory forces using different methods. Saridag et al. (2012) reported that the highest biting force was found at the posterior first molar area of 500 N thus, any posterior fixed prosthesis should withstand forces of more than the recorded value [of 49]. In addition, Heintze et al. (2011), stated a range of biting force at the second premolar region of 300-400 N [50].

It was found that ALD exhibited significantly higher fracture resistance, ranging from 755.09 to 1020.10, than that of BioHPP, ranging from 564.94 to 804.92 verifying superior performance. Besides, both materials manifested greater load-bearing capacity than normal oral masticatory forces, which range between 300 to 500 N in the posterior region [49,50].

It was proven by Jurado et al. (2024) [51] and Kassem et al. (2023) [52], who evaluated the fracture resistance of different CAD/CAM LD restorations using IPS. Emax CAD, Cerec Tessera, GC Initial LiSi CAD, and Mer Mill,tamo amongngchsera had the highest fracture strength among the compared groups, thus it was chosen in the current study.

The present study results were in accordance with Aher et al. (2023)[53] and Ghalawingy et al., (2021)[54], who reported higher fracture resistance in ALD than BioHPP. They interpreted that thermal aging of HIPC veneering caused water diffusion in its macromolecular network, leading to plasticization, followed by hydrolysis in the epoxy network by water sorption, leading to debonding of the veneering material [14].

This study finding came in contrast with Arshad et al. (2023), [55] and Aldhuwayhi et al. (2022), who detected higher fracture resistance in crowns fabricated using PEEK than those using lithium disilicate. Their findings were related to the material's plastic deformation under mechanical load [56].

Different studies disputes could be related to fabrication methods, use of diversity of luting cements with different compositions, and cementation protocols [26,40,57,58]. Crown parameters might also alter the fracture strength regardless of the material used [59].

Within the limitations of this study, the use of an extraoral scanner rather than intraoral scanners, which didn't reflect the clinical situation, the fabrication technique advocated in this study was CAD/CAM milling and not pressing, which might have affected the outcome and the assessment of marginal adaptation by measuring marginal gaps using only a stereomicroscope. Accordingly, further studies under alternative conditions, materials fabrication techniques, and using different evaluation techniques are required.

Conclusion

- According to the study's findings, the following was concluded:
  1. Better MA and FR were encountered in ALD in comparison with BioHPP during different cementation steps.
  2. The best MA was recorded after cementation in both materials and was within the acceptable clinical value of marginal gap (120 µm during different maneuvers.
  3. It was noticed that ALD crowns can't be repaired upon fracture; however, in the case of BioHPP crowns, the core part was still intact with no cracks in most cases, and can be repaired by changing the veneered part.

Declarations

Ethics approval and consent to participate

This research got ethics and research committee approval from the Scientific Research Ethics Approval Committee at the Faculty of Dentistry, Pharos University, Egypt, on 27 October 2024, with Serial Number #290.

Consent for publication

Not Applicable (Implants)

Availability of data and materials

Data available on request from the authors

Competing Interests

The authors declare no conflicts of interest. The authors declare that they have no significant competing financial, professional, or personal interests that might have influenced the performance or presentation of the work described in this manuscript.

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The authors received no specific funding for conducting this study.

Authors' contributions

S.H. and A. A conceived the presented idea. M.S. developed the theory.

- S.H. and A.A. verified the analytical methods and encouraged M.S. to interpret the results and supervised the findings of this work. All authors discussed the results and contributed to the final manuscript.

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