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RESEARCH AND EDUCATION

Fracture strength and three-dimensional marginal evaluation of biocompatible high-performance polymer versus pressed lithium disilicate crowns

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ABSTRACT

Statement of problem. Despite the acceptable physical properties of biocompatible high-performance polymer (BioHPP), little is known about the marginal accuracy and fracture strength of restorations made from this material.

Purpose. This in vitro study assessed the marginal and internal adaptation and fracture strength of teeth restored with lithium disilicate (LD) ceramics and BioHPP monolithic crowns.

Material and methods. Twenty-four extracted premolars were prepared for complete coverage crowns and divided into 2 groups to receive pressed IPS e.max LD, or computer-aided design and computer-aided manufacturing (CAD-CAM) BioHPP monolithic crowns. After adhesive cementation, the marginal and internal adaptations of the restorations were evaluated by microcomputed tomography at 18 points for each crown. Specimens were subjected to 6000 thermal cycles at 5 °C and 55 °C and 200 000 load cycles of 100 N at a frequency of 1.2 Hz. The fracture strength of the restorations was then measured in a universal testing machine at a crosshead speed of 0.5 mm/min. Data were analyzed via an independent-sample *t*-test (α=.05).

Results. The mean ±standard deviation of marginal gap was 138.8 ±43.6 μm for LD and 242.1 ±70.7 μm for BioHPP groups (P=.001). The mean ±standard deviation value of absolute marginal discrepancy was 193.8 ±60.8 μm for LD and 263.5 ±97.6 μm for BioHPP groups (P=.06). The internal occlusal and axial gap measurements were 547.5 ±253.1 μm and 197.3 ±54.8 μm for LD (P=.03) and 360 ±62.9 μm and 152.8 ±44.8 μm for BioHPP (P=.04). The mean ±standard deviation of internal space volume was 15.3 ±11.8 μm^3 for LD and 24.1 ±10.7 μm^3 for BioHPP (P=.08). The mean ±standard deviation of fracture strength was 2509.8 ±680 N for BioHPP and 1090.4 ±454.2 MPa for LD groups (P<.05).

Conclusions. The marginal adaptation of pressed lithium disilicate crowns was better, while BioHPP crowns displayed greater fracture strength. Marginal gap width was not correlated with fracture strength in either group. (J Prosthet Dent 2023;■:■-■)

The demand for esthetics has driven dentists to provide restorations made from tooth-colored materials.[1] IPS e.max (Ivoclar AG), a lithium disilicate-reinforced ceramic (Li_2O-SiO_2), is currently the toughest, most durable, and most widely used glass-ceramic.[1,2] Heat-pressed (IPS e.max Press) and computer-aided design and computer-aided manufacturing (CAD-CAM) (IPS e.max CAD) lithium disilicate (LD) restorations both have 70% of crystal content and differ only in crystal size. Therefore, their mechanical characteristics, such as the

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Clinical Implications

CAD-CAM BioHPP restorations exhibited acceptable marginal adaptation and fracture strength, suggesting they are suitable for clinical application.

modulus of elasticity, coefficient of thermal expansion, and chemical solubility, are similar.[2] Although ceramics are better than composite resins, metals, and polymers in terms of esthetics, their crystalline structure makes them brittle and more susceptible to fracture.[3] Because of the limited application of glass-ceramics[4] and the chipping risk of porcelain-veneered zirconia ceramics,[4] research has turned toward fiber and glass-reinforced polymers.[5,6]

Polyetheretherketone (PEEK) is a high-strength, synthetic, tooth-colored polymeric material with a semicrystalline structure that has been used as a biomaterial in different medical and dental applications.[7] Despite its advantages, the stiffness of PEEK is insufficient to withstand loads (tensile strength=110 MPa), which can be addressed by blending PEEK with glass or carbon fibers.[8] Biocompatible high-performance polymer (BioHPP) is a PEEK subgroup with an additional 20% of 0.3- to 0.5-μm ceramic fillers.[5,9,10] BioHPP has a flexural strength of 150 MPa, making it less prone to bulk fracture,[11] and its Young modulus of approximately 4 MPa is similar to that of human bone, allowing the material to distribute the forces and transfer them to the underlying structures more favorably.[12,13] The lower stiffness gives BioHPP an advantage over metals and ceramics.[11]

A combination of high mechanical properties, biocompatibility, shock absorption, abrasion resistance, low density, and color stability makes this material suitable for prosthetic applications.[5,12-15] BioHPP is currently being used in the fabrication of removable partial denture frameworks, removable dentures, obturators, crowns, fixed partial dentures, endocrowns, post-and-cores, and individual implant abutments.[5,10,12,16] BioHPP blocks, pellets, and granules are available for CAD-CAM and heat-press techniques, with restorations made from the blocks reported to have optimal marginal adaptation.[17] An anatomic contour BioHPP restoration is an option.[11] However, this opaque and radiolucent material has a gray or whitish color in limited shades, making it much less esthetic than glass-ceramics[17] unless it is veneered with composite resin.[8] Therefore, to create a complete anatomic, functional, and esthetic restoration, specially developed laboratory composite resins have been used to veneer BioHPP.[14,16,18] Despite its ceramic content, BioHPP has not been reported to abrade the opposing tooth.[12] Other advantages of BioHPP include improved stress modulation through plastic deformation, high color stability, and excellent polishing properties, which make it an alternative to zirconia.[12] BioHPP prostheses are a suitable option for people with parafunction because they have been reported to be associated with significantly reduced maximum masticatory forces.[12]

Factors affecting the durability of an indirect restoration include adaptation and fracture strength.[19] Marginal misfit could lead to cement dissolution, marginal microleakage, discoloration, plaque accumulation, secondary caries, dental sensitivity, pulp exposure, periodontal diseases, and even alteration in oral microflora.[17,20-22] A ceramic restoration with poor internal adaptation has been reported to be more liable to fracture under occlusal loads.[20,23] Clinically acceptable marginal gaps for ceramic restorations have been reported to range from 120[24] to 500 μm.[25] The most accurate method of measuring a restoration gap is still controversial. Microcomputed tomography (μCT) is an innovative and accurate method for evaluating marginal adaptation that can provide high-resolution images of the space between the crown and the tooth.[26,27]

Inconclusive results have been reported on the marginal fit and fracture strength of BioHPP and LD cemented crowns.[9,17,18,28-34] It has been reported that the marginal fit of PEEK and BioHPP copings is within an acceptable range for clinical use.[17,34] Baciu et al[29] reported that pressed ceramics had a better marginal fit than pressed resins , while Bae et al[21] reported that polyetherketoneketone (PEKK) copings had a better fit than zirconia. According to Beleidy and Ziada,[18] the marginal fit and fracture strength of CAD-CAM PEEK cores veneered with CAD-CAM or nanohybrid composite veneers were clinically acceptable. In one study, milled BioHPP and zirconia veneered crowns were found to exhibit similar mechanical behavior, marginal integrity, and patient satisfaction.[28] However, another study reported that patient satisfaction with BioHPP crowns was less than with metal-ceramic crowns.[9]

Data regarding the marginal precision and fracture strength of CAD-CAM BioHPP are lacking. Therefore, the aim of this study was to compare the marginal fit and fracture strength of CAD-CAM BioHPP and pressed LD monolithic crowns. The null hypotheses were that no difference would be found in the marginal adaptation or fracture strength of crowns made from these two materials.

MATERIAL AND METHODS

Twenty-four intact human mandibular premolars free of caries, fractures, and cracks and extracted because of orthodontic treatment or periodontal disease were collected after ethical approval (IR.TUMS.DENTISTRY.REC.1399.189 and IR.TUMS.DENTISTRY.REC.1399.190). Based on Neves et al,[27] and by using the equal variance tab in a software program (PASS 15; NCSS, LLC) and considering α=.05 and β=.8, the

minimum sample size for each group was determined to be 12. Dental plaque, calculus, and residual tissues were removed with an ultrasonic scaler (UDS-A LED ultrasonic scaler; Guilin Woodpecker Medical Instrument Co, Ltd), and the teeth were disinfected in 0.5% chloramine-T (Chloramine T Trihydrate; Merck KGaA) for 24 hours and stored in normal saline for a maximum of 2 months.

Silicone indexes (PANASIL PUTTY; Kettenbach GmbH & Co KG) were made from each tooth, prepared for ceramic crowns using a diamond rotary instrument (No. 852 standard diamond; JOTA AG), and finished with tungsten carbide burs (No. 284 Torpedo; Microdont). The preparations were standardized with 1.6 ±0.2 mm occlusal reduction, 1.2 ±0.2 mm uniform axial reduction with a minimum of 4 mm height and total axial convergence of 12 to 16 degrees, and a 1-mm wide circumferential deep chamfer finish line 1 mm occlusal to the cementoenamel junction (CEJ).[35,36] The specimens were divided into 2 groups by block randomization (n=12): LD in A3 shade (IPS e.max Press HT ingots; Ivoclar AG) and BioHPP in white shade (breCAM.BioHPP; Bredent GmbH & Co KG). An experienced dental laboratory technician performed all the laboratory procedures. The prepared teeth were scanned with an extraoral scanner (AutoScan-DS-EX Dental Scanner; Shining 3D Tech Co).

The LD crowns were fabricated according to the manufacturer's instructions. Wax patterns were designed with a software program (SUM3D Dental; CIM System). The minimum thickness of the occlusal surface was defined as 1.5 mm,[35,36] and the minimum thickness of the axial surfaces was defined as 1 mm with a 20-μm virtual cement space[37,38] and a 1-mm marginal ramp.[23] The wax patterns (POLYWAX; Bilkim Co, Ltd) were milled (DWX-51D 5 Axis Dental Milling Machine; Roland DGA), sprued, and invested (IPS PressVEST Speed; Ivoclar AG). Twelve monolithic crowns were pressed (EP 600 Combi Press Furnace; Ivoclar AG). After cooling, the refractory materials were airborne-particle abraded (125 μm aluminum oxide particles; Protechno) at 0.1 MPa pressure. The sprues were separated with a diamond-cutting rotary disk (separating diamond disc; DFS Diamon), and crowns were glazed in 1 firing cycle. The BioHPP crowns were milled with the exact dimensions as the previously described CAD-CAM LD wax patterns. Finally, the crowns were steam cleaned (Dental laboratory steam generator EGV 18; Eurocem Srl) for 2 minutes and left to dry for 10 minutes before evaluation.

The crowns in both groups were seated on their respective teeth. No adjustments were made to the intaglio surfaces.[38,39] Following the manufacturer's guidelines, the crowns were cemented with dual-polymerizing resin cement (PANAVIA V5; Kuraray Noritake Dental Inc). The intaglio surface of each BioHHP crown was airborne-particle abraded (Pneumatic sandblaster ESB 2; Eurocem Srl) (110 μm aluminum oxide particles; Protechno) at 0.25 MPa pressure. The intaglio surfaces of the LD crowns were etched (K-etchant; Kuraray Noritake Dental Inc) for 5 seconds, rinsed, and dried. Silane (Ceramic Primer Plus; Kuraray Noritake Dental Inc) was applied to the intaglio surfaces of both groups and dried. The tooth surfaces were prepared with primer (PANAVIA V5 self-etch tooth primer; Kuraray Noritake Dental Inc), left for 20 seconds, and dried. Cement was applied to the intaglio surfaces, the crowns seated on their preparations, and light polymerized for 5 seconds. After the excess cement had been removed, the crowns were lightly polymerized again (Fig. 1). A standardized load of 49 N was applied during cementation.[40]

The specimens were mounted in scanning tubes in groups of 3 and scanned with μCT (LOTUS NDT; Behin Negareh Co, Ltd). The X-ray tube voltage was 50 kV and its current was 150 μA to obtain the best possible image quality, as specified by the manufacturer. The exposure time was 1 second at ×3.5 with a processing software program (LOTUS-inVivo; Behin Negareh Co, Ltd). The slice thickness of the images was set to 16.5 μm (Fig. 2). For measurements, nine areas were appointed for each sagittal and coronal plane. Eight measurements for marginal gap (MG) and absolute marginal gap (AMD) in each specimen and 10 measurements for axial gap (AG) and occlusal gap (OG) were recorded by an examiner (S.H.) (Fig. 3).[41-43] Internal space volume (ISV) was measured by using a reconstructed μCT image of the crown-cement-tooth complex (Fig. 4).

To simulate the periodontal ligament, the roots of the teeth were covered with additional silicone (Esthetic Mask; DETAX GmbH & Co) with a thickness of 0.2 to 0.3 mm apical to the CEJ. The specimens were mounted to the same height in autopolymerized pink acrylic resin (UNIFAST Trad; GC Inc). To simulate the equivalent of a 1-year clinical service, specimens were subjected to artificial aging. The simulation of aging was performed by thermal cycling and mechanical loading (200 000 mechanical loads of 100 N and 6000 thermal cycles of 2 minutes each with distilled water at 5 °C and 55 °C) using a mastication simulator (CS-4.4 chewing simulator; SD Mechatronics).[44-47] Load was applied at a 90-degree angle to the central fossa of the teeth.

The specimens were loaded in a universal testing machine (Z050; Zwick Roell) to determine the fracture strength perpendicular to the central fossa at 0.5 mm/min crosshead speed. A Ø3-mm stainless-steel ball served as the antagonist (Fig. 5). The load at fracture was recorded in N for the two groups. The failure mode was examined visually and recorded based on the Burke classification[48] immediately after specimen fracture. Class I had a minimal fracture or crack in the crown. In class II, less than half of the crown was lost. Class III crown fracture occurred in the midline (half of the crown was displaced



Figure 1. Biocompatible high-performance polymer and lithium disilicate crowns after cementation.

or lost). In class IV, more than half of the crown was lost, and in class V, a severe fracture of the crown or tooth occurred.

Data were analyzed with a statistical software program (IBM SPSS Statistics, v25; IBM Corp) to obtain the mean, standard deviation, and range. Marginal adaptation and fracture strength data were tested for normality by the Shapiro-Wilk test and equality of variances by the Levene test. Both conditions were met (P>.05). To determine whether there were any significant differences between the groups, the independent-sample t-test was conducted. The Pearson correlation coefficient was used to analyze the fracture strength data correlation to MG and the mean of OG/AG (as internal fit) data (α=.05 for all tests).

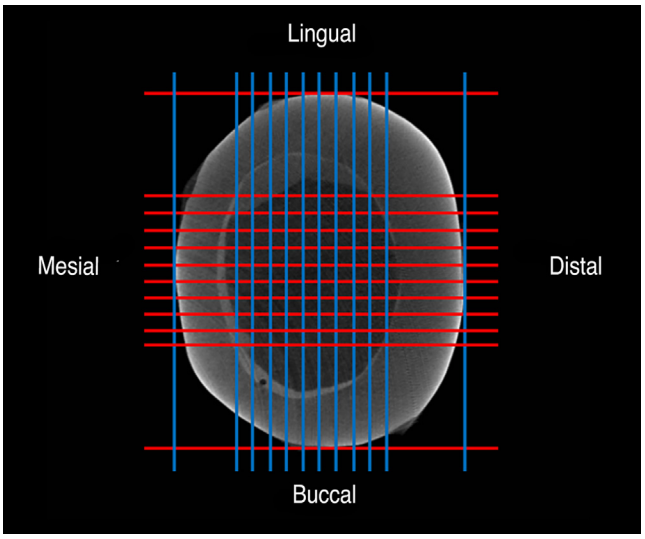


Figure 2. Microcomputed tomography scan image. Using the ImageJ software, 10 equidistant vertical cuts made in buccolingual and mesiodistal directions, with average of 14 slices between these cuts depending on slice numbers of each specimen. Vertical cuts made in middle third of each specimen.

RESULTS

The statistical results for the MG, AG, OG, AMD, and ISV are summarized in Table 1. The independent-sample *t*-test showed that MG was significantly smaller in the LD compared with the BioHPP group (P=.001). However, no significant differences were found in the AMD and ISV between the two groups (P=.06 for AMD, P=.08 for ISV). The results revealed that the AG and OG values for the BioHPP group were significantly smaller than those of the other group (P=.049 for AG, P=.03 for OG).

All specimens survived the cyclic loading without fracture. The mean fracture strength of BioHPP monolithic crowns was significantly higher than that of LD crowns (Table 2) (P<.05). The frequency of each failure mode is summarized in Table 3. There were 66% irreparable catastrophic failures in the LD group; in contrast, 66% of the failures in the BioHPP group were not catastrophic (Fig. 6). The correlation between the fracture strength, marginal gap, and internal fit was not significant (P=.764 for MG, P=.695 for internal fit).

DISCUSSION

This study compared the MG, AMD, OG, AG, ISV, and fracture strength of cemented LD and BioHPP monolithic crowns. The null hypothesis, that no difference would be found in the marginal adaptation and fracture strength of crowns made from 2 groups, was rejected.

Better marginal adaptation has been reported for ceramic than for BioHPP restorations.[17,29] Baciu et al[29] reported a better fit for e.max inlays than pressed BioHPP, and Emad et al[34] reported significantly higher marginal gap values for PEEK than zirconia crowns. In the current study, the marginal fit of LD crowns was better than that of BioHPP crowns. The improved fit may be explained by the semicrystalline structure of the BioHPP, containing fillers embedded in a resin matrix, and the shrinkage of the material during polymerization compared with ceramic sintering.[8] The range of MG of BioHPP crowns was 160 to 360 μm. The clinically acceptable MG for ceramic crowns has been reported to be <120 μm,[24] while cemented restorations may have an MG of 70 to 320 μm.[40,49] Therefore, in the current study, the marginal gap values of BioHPP cemented crowns were within the acceptable range, suggesting they are suitable for clinical application. Previous studies have reported similar results for PEEK copings and crowns.[9,16]

According to Holmes et al,[43] AMD is characterized by the combination of MG and extension errors. Therefore, AMD is generally higher than MG. AMD in the present study ranged from 110 to 370 μm for LD crowns and 120 to 380 μm for BioHPP crowns. MG and AMD may also be influenced by preparation designs.

The BioHPP group had a lower mean average of internal occlusal and axial gaps than the LD group, but ISV differences were not significantly different. In both groups, internal OG values were significantly higher than AG. The AG reduction indicated that the crown's axial surface was close to the tooth's surface. Although digital technology is capable of creating minimal axial spacing, a uniform thickness regardless of the cement space defined by the CAD-CAM software program cannot be achieved.[20] In the present study, the cement space was set at 20 μm.[37,38] However, according to some reports, increasing the spacer parameter setting led to decreased internal gaps with indirect restorations.[23,50] Lower spacer thicknesses could result in interferences in the CAD-CAM crowns, thus impairing the seating of the cemented restoration, explaining why, in the current study, the mean marginal gap was higher and the internal gap was lower for BioHPP. Conversely, the internal gap values may not correspond well with marginal adaptation values.[26] Internal misfits can be reduced with clinical adjustments, making it less critical than vertical marginal gaps, which cannot be adjusted and determine cement exposure.[23]

μCT analysis has been reported to be one of the most reliable, nondestructive, and high-resolution techniques for evaluating the integrity of crowns.[26,40] μCT offers a 3D investigation of the marginal and internal gaps within a few micrometers at multiple sites and directions and is more time-efficient than other techniques. However, artifact formation because of different radiation absorption coefficients of materials is a limitation.[23] Cement type, its viscosity and radiopacity, application steps, micromechanical etching of the intaglio surface of the crown, and the sharpness of μCT images could all affect

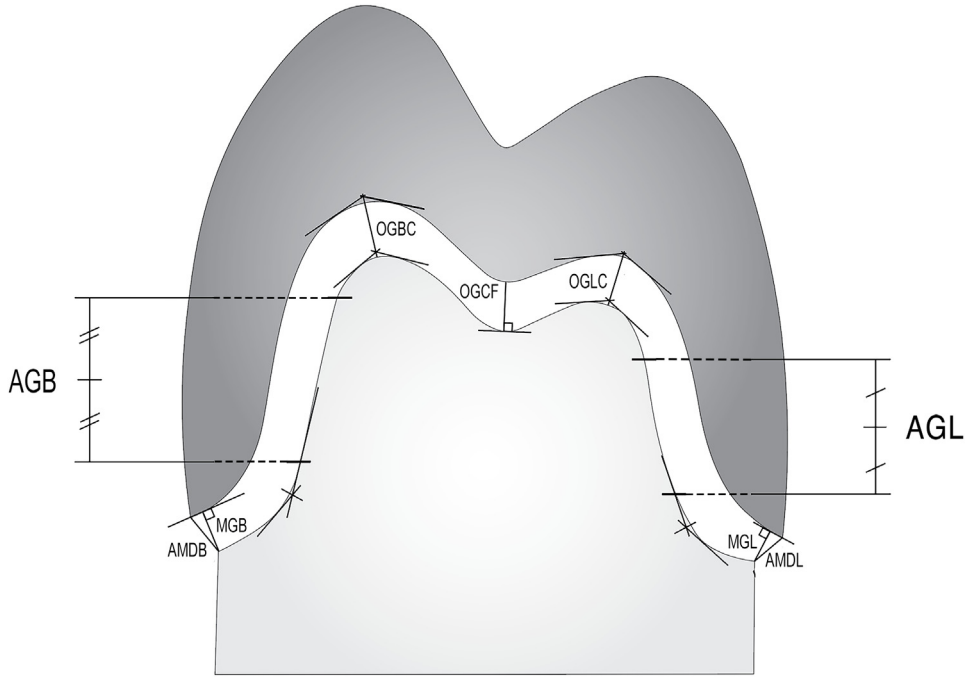


Figure 3. Illustration of sagittal cross-section of specimen and measurement points. MG defined as vertical discrepancy between margin preparation and crown.[2] AMD defined as distance between cavosurface of preparation margin and cervical edge of crown.[2] AG defined as distances perpendicular to crown and internal axial space of tooth at selected points.[41] OG defined as distances perpendicular to crown and internal occlusal space of tooth at selected points.[23] AGB, internal axial gap at buccal; AGL, internal axial at lingual; AMDB, absolute marginal discrepancy at buccal; AMDL, absolute marginal discrepancy at lingual; MGB, marginal gap at buccal; MGL, marginal gap at lingual; OGBC, occlusal gap at buccal cusp; OGCF, occlusal gap at central fossa; OGLC, occlusal gap at lingual cusp.

the values of internal and marginal gaps.[40] Although studies have used resin cement in conjunction with μCT scanning,[31,40] the radiopacity of the luting agent might alter the outcome of the μCT analysis.[23]

The null hypothesis that BioHPP monolithic crowns have the same fracture strength as LD crowns was rejected. The findings showed that the mean load to failure of BioHPP crowns was significantly higher than that of LD crowns (2509.76 ±196.29 N versus 1090.36 ±454.17 N). These results were consistent with those of Mohamed,[33] Beleidy and Ziada,[18] and Elashmawy et al.[10] The higher fracture strength values for BioHPP could be explained by the mechanical properties of the material. Having a Young modulus of 4 MPa, similar to that of human bone and dentin, BioHPP distributes forces more favorably than metal alloys and ceramics.[8,12,13] Moreover, BioHPP offers a higher shock absorption capacity than LD, reducing the risk of fractures and cracks when forces are applied. Subcritical fractures created during ceramic fabrication can also lead to subsequent fractures.[47] Patients with parafunction may be able to benefit from BioHPP prostheses since they have been reported to reduce the maximum masticatory forces significantly.[12] In the present study, 66% of the specimens had an irreparable catastrophic failure in the LD group (class V Burke classification). In contrast, in the BioHPP group, 66% of the failures were not catastrophic. The same rationale for fracture strength could account for these results.

The fracture behavior of crowns is affected by factors such as crown thickness, cusp angle, notch design, crown height, taper, and margin design, as well as the material type of the crown and cement properties.[36] According to the manufacturer's instructions, the minimum thickness of LD crowns is 1.0 mm; however, Shillingburg et al[35] recommended an occlusal reduction of 1.5 to 2.0 mm for ceramic crowns. For BioHPP crown preparation, the manufacturer does not provide any instructions. Shahmoradi et al[36] reported that HPP crowns with a 1.0-mm margin and 1.5-mm occlusal thickness exhibited the highest crack initiation load. In the present study, tooth preparation was standardized across both groups to avoid bias. Accordingly, 1.0 mm of marginal thickness and 1.5 mm of occlusal thickness were used.

The correlation among the fracture strength, marginal gap, and internal fit in the current study was not significant. No clear correlation has been established between the marginal accuracy and fracture strength of restorations, and one variable rarely has a significant impact on another.[19] Internal adaptation, in contrast, plays an influential role in the retention and resistance of restorations. For homogeneous stress distribution under masticatory loads, adequate cement space is required. A

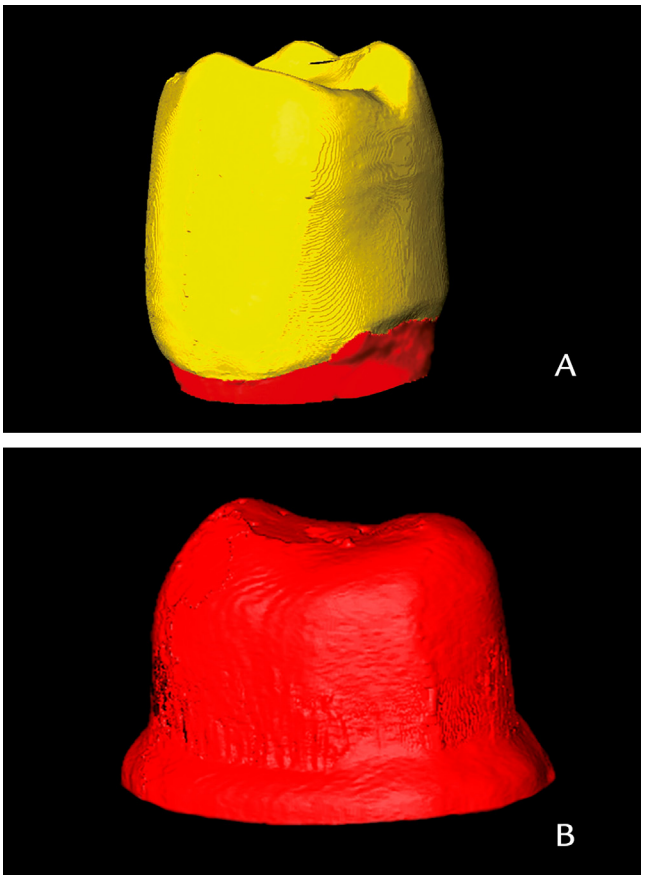


Figure 4. A, Microcomputed tomography image of reconstructed crown-cement-tooth complex using LOTUS inVivo-REC by standard Feldkamp, Davis, Kress (FDK) algorithm. B, Cement reconstruction showing internal space volume between crown and tooth.

Table 1. Results of marginal adaptation, absolute marginal discrepancy, internal adaptation, and internal space volume between groups (n=12)

Parameter	Group	Mean	Standard Deviation	Minimum	Maximum	P
MG (μm)	LD	138.8	43.6	79.5	242.7	.001
	BioHPP	242.1	70.7	162.1	362.4	
AMD (μm)	LD	193.8	60.8	113.9	311.4	.06
	BioHPP	263.5	97.6	127.0	383.5	
AG (μm)	LD	197.3	54.8	131.5	340.2	.049
	BioHPP	152.8	44.8	90.8	241.7	
OG (μm)	LD	547.5	253.1	209.9	917.0	.03
	BioHPP	360.0	62.9	287.3	458.7	
Volume (mm^3)	LD	15.3	11.8	4.9	39.7	.08
	BioHPP	24.1	10.7	5.0	37.9	

AG, axial gap; AMD, absolute marginal discrepancy; BioHPP, biocompatible high-performance polymer; LD, lithium disilicate; MG, marginal gap; OG, occlusal gap.

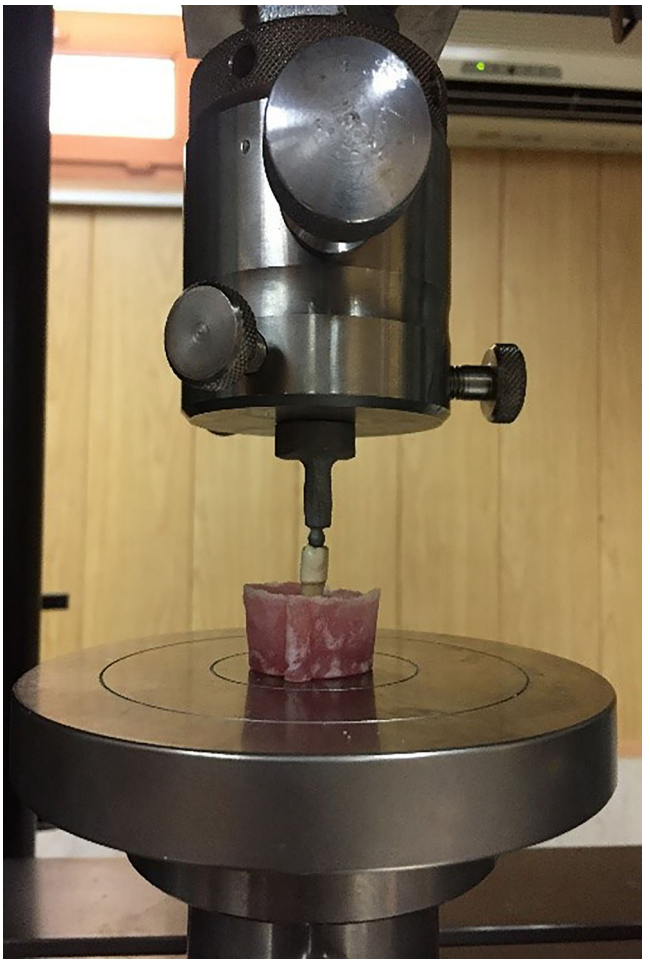


Figure 5. Specimens loaded in universal testing machine (Z050, Zwick Roell) at 0.5 mm/min speed to determine fracture load.

Table 2. Results of load at fracture between groups (n=12)

Parameter	Group	Mean	Standard Deviation	Minimum	Maximum	P
Fracture strength (N)	BioHPP	2509.8	680.0	1516.9	3905.8	<.001
	LD	1090.4	454.2	625.4	1995.7	

BioHPP, biocompatible high-performance polymer; LD, lithium disilicate.

Table 3. Frequency of failure mode in experimental groups (n=12)

Group	Class I	Class II	Class III	Class IV	Class V
BioHPP	8	2	0	0	2
LD	0	2	1	1	8

BioHPP, biocompatible high-performance polymer; LD, lithium disilicate.

large resin cement thickness causes different load concentrations, which reduces the fracture strength.[22]

Limitations of the study included that, although thermocycling in combination with cyclic loading was used, the results obtained from an in vitro study may not be representative of clinical practice. It has been recommended that 1 200 000 mastication cycles be performed to simulate 5 years of clinical service,[46] but, in the present study, only 1 year of clinical service was simulated. This study measured the fit of the restorations only after cementation. Therefore, the clinical reliability of discrepancies before and after cementation was not

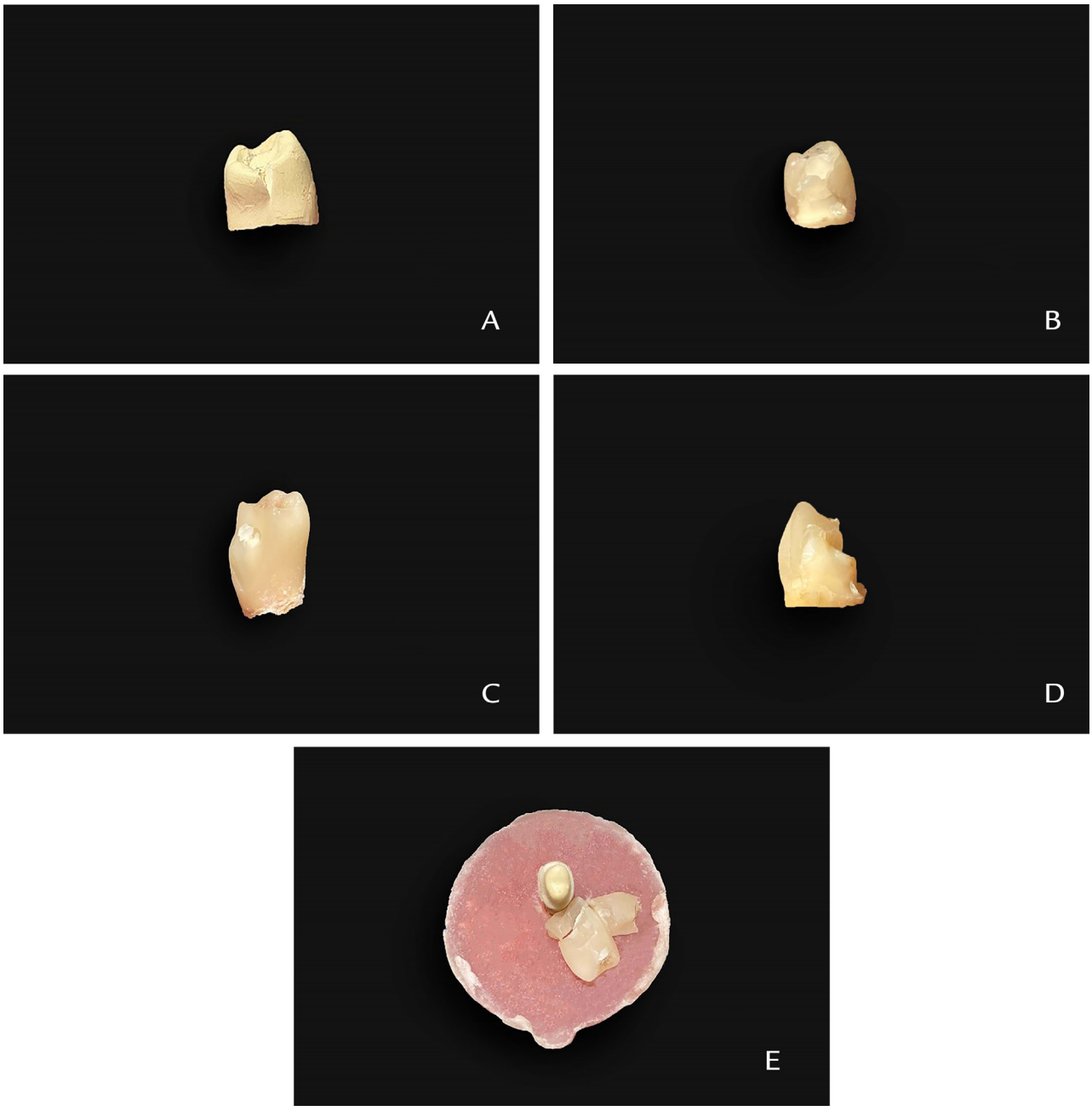


Figure 6. Burke classification for mode of failure. A, Class 1. B, Class II. C, Class III. D, Class IV. E, Class V.

evaluated. Furthermore, using a solid virtual cement space for the CAD-CAM system eliminated the influence of different cement spaces. This study also did not assess how software versions or parameter settings affected crown marginal or internal adaptation. To evaluate Bio-HPP for indirect restorations, clinical studies are required to assess biocompatibility, plaque resistance, water solubility, wear-resistance, color stability, bond strength, and especially the optical properties of this material. BioHPP is a new addition to dentistry, and clinical studies are necessary to examine its esthetic performance and overall patient satisfaction to validate its clinical use.

CONCLUSIONS

Based on the findings of this in vitro study, the following conclusions were drawn:

1. Despite the better marginal adaptation of LD crowns and the higher fracture strength of BioHPP crowns, both materials were within acceptable ranges for the adaptation and strength of cemented crowns.
2. Therefore, given that all other requirements are fulfilled, BioHPP monolithic crowns could be considered a possible alternative for clinical use.

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