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IN VITRO INVESTIGATION OF MARGINAL & INTERNAL ADAPTATION OF TWO SCREW-RETAINED IMPLANT SUPPORTED CROWNS: A COMPARATIVE ANALYSIS OF DIRECT OPTICAL & SUBTRACTIVE REVERSE ENGINEERING TECHNIQUES

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ABSTRACT

Objectives: The aim of this in-vitro study was to investigate the marginal and internal adaptation of two screw-retained crowns; lithium disilicate and BioHPP using direct optical and subtractive reverse engineering techniques and to calculate the degree of agreement between them.

Materials & Methods: Twenty-eight implant analogs were embedded perpendicularly in an auto-polymerizing resin. Implant-supported restorations were designed then milled with CAD wax and divided into 2 groups according to material (n=14): Lithium disilicate and BioHPP. Each group was pressed according to the manufacturer's instructions. The marginal and internal adaptation of the specimens were analyzed using DOT & subtractive RET. Data were explored for normality using Shapiro-Wilk's and Levene's tests and were analyzed using independent and paired t-test for inter and intragroup comparisons respectively with a significance level of $p<0.05$. Agreement analysis was done using intraclass correlation coefficient (ICC).

Results: BioHPP screw-retained implant-supported crowns showed higher marginal gap than lithium disilicate, yet the difference was non-significant when measured using DOT, while it was significant when measured using sRET. Calculated agreement between the two techniques at the marginal level showed that there was a statistically significant moderate agreement between both methods. Regarding internal adpatation, BioHPP had a statistically significant higher internal gap than lithium disilicate group.

Conclusions: Supra-structure material affected marginal and internal adaptation of implant-supported restorations. Pressed lithium disilicate crowns showed better marginal and internal adaptation than BioHPP crowns, however, both groups showed clinically acceptable results. DOT and RET were both relevant and showed moderate agreement between them.

KEYWORDS: BioHPP, Lithium Disilicate, Titanium base, implant-supported crowns, reverse engineering technology.

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INTRODUCTION

The success of implant restorations relies not only on successful osseointegration but also significantly on the success of the implant suprastructure. [1,2] Advances in ceramic and polymer-based materials have expanded their use in restoring single implants.[3] The selection of implant abutments plays a significant role on the success of implant-supported restorations from the functional, biological and esthetic perspectives. [4–7]

All-ceramic abutments have gained a wide popularity owing to the high esthetic requirements demanded by both prosthodontists and patients. However, technical complications have been encountered such as wear and brittle fracture at the implant-abutment connection.[8] This was overcome by using a hybrid abutment where a ceramic abutment is bonded to a titanium base (Ti-base). This design replaces the connecting part with a titanium-to-titanium connection, while preserving the benefits of esthetics, tissue biocompatibility and possibility of customizing the whole restoration design using digital technology. [9,10]

Different ceramic and polymer-based materials have been used over the Ti-Base. Such as zirconia, reinforced glass ceramics, hybrid ceramics, polyetheretherketone (PEEK) and biocompatible high-performance polymer (BioHPP). [11–15] Lithium disilicates are characterized by their favorable esthetics, high refractive index, good gingival response and mechanical properties. [8,16–18] Its use as a hybrid abutment has been investigated by some studies. [14,15,19,20]

PEEK is a synthetic, tooth-colored polymeric material with a semicrystalline structure used in different medical and dental applications.[21] The tensile strength of PEEK, 110 MPa, is insufficient to withstand loads, thus pure PEEK has been frequently used as provisional implant abutments.[12,22] BioHPP is a PEEK variant strengthened with ceramic fillers; aluminum oxide and zirconium oxide occupying 20% of its volume and with a grain size of about 0.3-0.5 microns. [23,24] It has a flexural strength of 150 MPa and modulus of elasticity 4 GPa which is close to the human bone. [25,26] Its low stiffness provide a distinct advantage over metals and ceramics. It enables the material to distribute the forces and transfer them to the underlying structures, reducing the risk of fracture particularly in implant-supported restorations. [23,27,28] Additionally, its low density 1.32g/cm3, makes it well perceived by patients and a commonly used implant framework. [23,29,30] BioHPP is available in the form of blocks for milling using computer aided design/computer aided manufacturing (CAD/CAM) techniques and pellets and granules for pressing using heat-press techniques. BioHPP crowns can be used as a fully anatomic restoration or it can be veneered, however, due to its opaque gray or whitish color, it is usually veneered with special composite resin. [23,28]

Marginal and internal fit are vital to the long-term success of any dental restoration.[31] Marginal gap is the vertical distance between the finish line and the restoration, while internal fit is the distance between the axial and occlusal walls of the abutment and inner surface of restoration. Lack of adequate fit is potentially detrimental to the implant, supporting tissues and supra-structure.[32] A wide gap at the abutment level results in faster cement dissolution, creating recesses for plaque accumulation and bacterial adherence which leads to bone resorption around implants.[33] Additionally, a thicker cement layer will increase polymerization shrinkage and interfacial stresses, which may reduce the fracture resistance of restorations. [34] Consequently, adequate fit between implant components is crucial to minimize mechanical and biological complications. [35] No consensus has been reached regarding the acceptable marginal gap width.[34,36] Clinically acceptable marginal gap has been reported to be within 50-120μm.[37–44] One of the most referenced studies by McLean and Von Fraunhofer in 1971, [43] concluded that a marginal gap of no more than 120μm was clinically acceptable after clinical examination of more than 1000 crowns at 5 years.

Several methods have been used to investigate marginal and internal adaptation of restorations such as: direct optical technique (DOT), which is a non-invasive, time-saving technique and has less chance of error accumulation as it doesn't require multiple steps. However, it can measure the vertical marginal gaps only using light, stereo- or scanning electron microscopes.[45,46] Silicon replica technique; is a more technique sensitive method that replicates the cement space to measure the marginal and internal gaps.[47,48] However, most of these techniques are 2-dimensional, have limited measuring points and are sometimes also destructive.[49] Reverse engineering technique (RET), on the other hand, has the advantage of using computer softwares for 3-dimensional (3D) non-destructive analysis where 3D image data is created by connecting more than a thousand points of data in the form of a triangular mesh and the subsequent 3D image data can be analyzed qualitatively and quantitatively without losing data of the overall surface. [50–53] sRET, is a 3D superimposition analysis technique which depends on subtractive analysis of abutment scan and cement space scan; represented by polyvinyl siloxane. A 3D difference analysis of the matched scans represents the thickness of the cement. This technique has been considered a reliable method by many previous studies.[51,54–57] There is still no standard protocol used to assess the fit of dental restorations. [51,52]

The aim of this in-vitro study was to:

1. Investigate the marginal and internal adaptation of two screw-retained implant-supported crowns; lithium disilicate and BioHPP using direct optical and subtractive reverse engineering techniques.
2. Calculate the degree of agreement of both techniques when measuring the marginal gap. The null hypothesis was that the material will not influence the marginal and internal adaptation of screw retained crowns and that there will be no agreement between both measuring techniques.

MATERIALS AND METHODS

Twenty-eight implant analogs (Zimmer Biomet Implant System, Aston Ave., Carlsbad, USA.), 3.5mm in diameter were embedded perpendicularly in an auto-polymerizing resin (Technovit 4,000; Heraeus Kulzer, Wehrheim, Germany) using a dental surveyor (Ney, DeguDent GmbH, Germany). The upper edges of the analogs were extended 2 mm above the level of the surrounding material to simulate crestal bone resorption.[58] According to the previous results of Anadioti and Evanthia[59], Park et al[60], Silva et al [61] and Urhenbacher et al[62] in which the effect size (f) was (0.67) and by adopting an alpha (α) level of 0.05 (5%), a Beta (β) level of 0.20 (20%) i.e. power=80%. The predicted sample size (n) was 28 specimens i.e. 14 for each group. Sample size calculation was performed using G*Power version 3.1.9.2.

Screw-retained crown simulating a maxillary first premolar was designed using CAD software (DentalCAD; exocad, Darmstadt, Germany). The general outline was as follows: 11.5 mm occluso-cervical height, 8.5 mm bucco-lingual width, 8 mm mesio-distal width. [14] The Ti-base (Zenotec Titanbasis System F, Wieland Dental, Pforzhei, Lindenstraße, Germany) used was 3 mm in height with 0.5 mm wide shoulder.

Twenty-eight screw-retained crowns were milled from CAD wax blocks (Telio CAD, Ivoclar Vivadent; Schaan, Liechtenstein) using a 5-axis milling machine (Roland Dwx50, Tokyo, Japan). A cement space was set to 60 μm at the axial and occlusal surfaces to avoid the need for manual adjustments after milling. [63] The specimens were divided into two main groups (n = 14) according to material: lithium disilicate (IPS e.max Press; Ivoclar Vivadent, Schaan, Liechtenstein) and BioHPP (Bredent GmbH & Co. KG, Senden, Germany). Each group was pressed according to the manufacturer's instructions of each material. Specimens were seated to their respective Ti-base, and finishing and polishing of the pressed screw-retained crowns was carried out as shown in Figure 1.

Marginal gap was measured using DOT and sRET. For the DOT, four equidistant points were marked on each side (buccal, mesial, distal, and palatal) of the Ti-base, resulting in 16 reference points. A stereomicroscope (Olympus SZ61; Olympus Corp, Tokyo, Japan) under ×40 magnification was used to measure the marginal gap. Images were analyzed using an image analysis software (Olympus DP2-SAL; Olympus Corp, Tokyo, Japan). [34] Vertical gaps between the cervical margin of the abutment and the Ti-base were calculated automatically with phase analysis. Collected data was tabulated using Microsoft Excel (Microsoft Office 2013). Vertical gap mean (in microns) for each specimen was calculated and tabulated for statistical analysis.

For the sRET group, a subtractive technique was used for 3D analysis of both the marginal and internal adaptation of the screw-retained crowns. The Ti-base surface was scanned using a digital scanner (E4, 3Shape, Copenhagen, Denmark) after coating its surface with a light spray to reduce reflectivity. The exported STL scan was named "Reference model." Then the internal surface of the crown was coated with a thin layer of silicone oil and dried with a cotton swab and high-pressure air. The crown was filled with light-body polyvinyl siloxane (3M Express VPS, MN, USA) and seated on its corresponding Ti-base. A 20 N load was equally applied on the crown for 10 minutes. After complete polymerization, excess silicone was carefully removed with a scalpel and the crown was quickly removed from the abutment, leaving a thin layer of light-body polyvinyl siloxane simulating the cement space firmly adhered to the Ti-base. The Ti-base covered with the silicon replica was scanned using the same optical scanner, and the exported STL file was named "Test model." The Reference and Test models were imported into reverse engineering software (Geomagic Control, 3D Systems, NC, USA). The two STL files were superimposed using the corresponding base part of the Ti-base, and then the gap space was extracted by subtracting the Test model from the Reference model, Figure 2. [51,52,54–57]

Color-coded difference images were used to examine the similarilty of Ti-base surface and internal surface of restoration qualitatively. However, quantitatively dimensional differences between reference and test model were computed for every data point captured during digitalization. The root mean square (RMS) was calculated by the following formula:

$$RMS = \frac{\sqrt{\sum^{n}_{i=1}(x_{1,i} - x_{2,i})^2}}{n}$$

where $x_{1,i}$ is the measuring point i on reference, $x_{2,i}$ is the measuring point i on test, and n is the total number of measuring points.

RMS serves as a measure of how different the two datasets vary from zero. RMS measurements were split into two distinct areas: marginal, which is 0.4 mm horizontally from the finish line and axial, representing the middle third of the axial wall, Figure 3. RMS data was recorded and used for statistical analysis. The agreement of DOT and sRET in measuring marginal gap was also calculated using statistical agreement analysis.

Data were presented as mean and standard deviation (SD) values. Shapiro-Wilk's and Levene's tests were used to test normality and variance respectively. Marginal and internal gaps were measured using independent and paired t-test for inter and intragroup comparisons. Agreement analysis was done using intraclass correlation coefficient (ICC). Significance was set at $p < 0.05$ in all tests. R statistical analysis software version 4.3.1 for Windows was used for statistical analysis. [64]

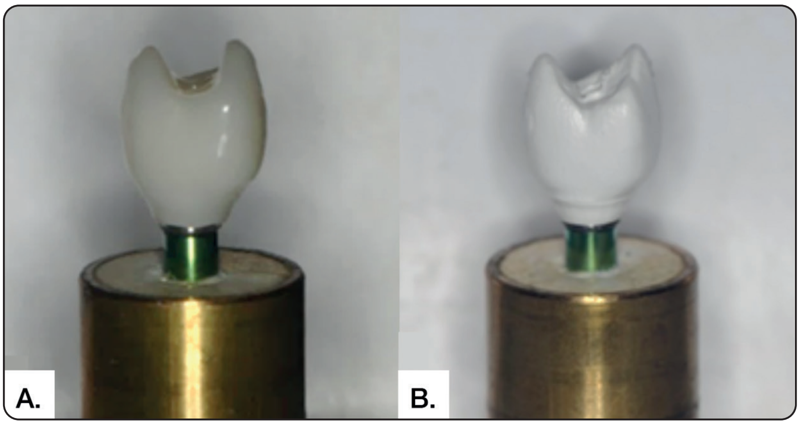

Fig. (1): Screw-retained crowns after pressing. A: Lithium Disilicate. B: BioHPP.

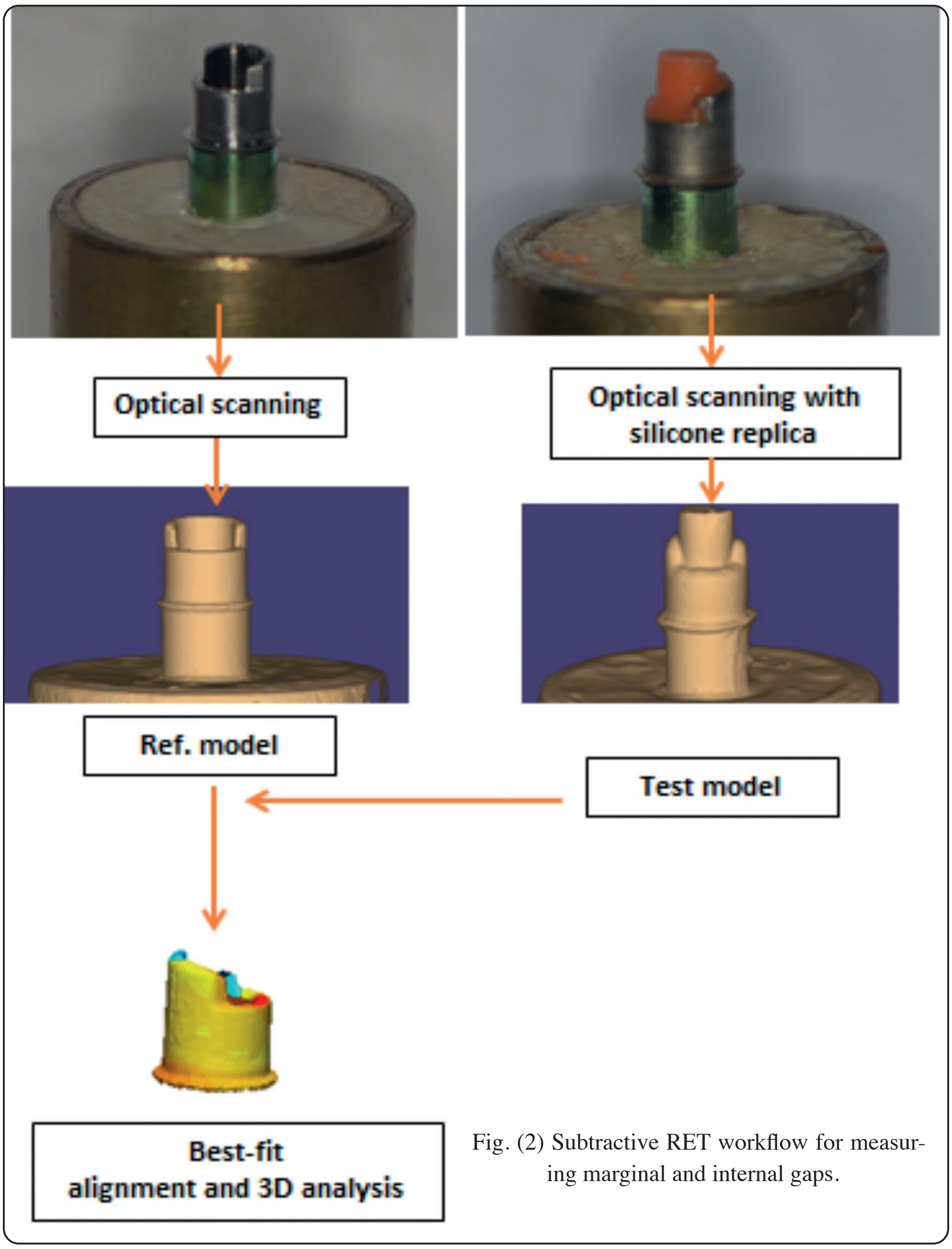

Fig. (2) Subtractive RET workflow for measuring marginal and internal gaps.

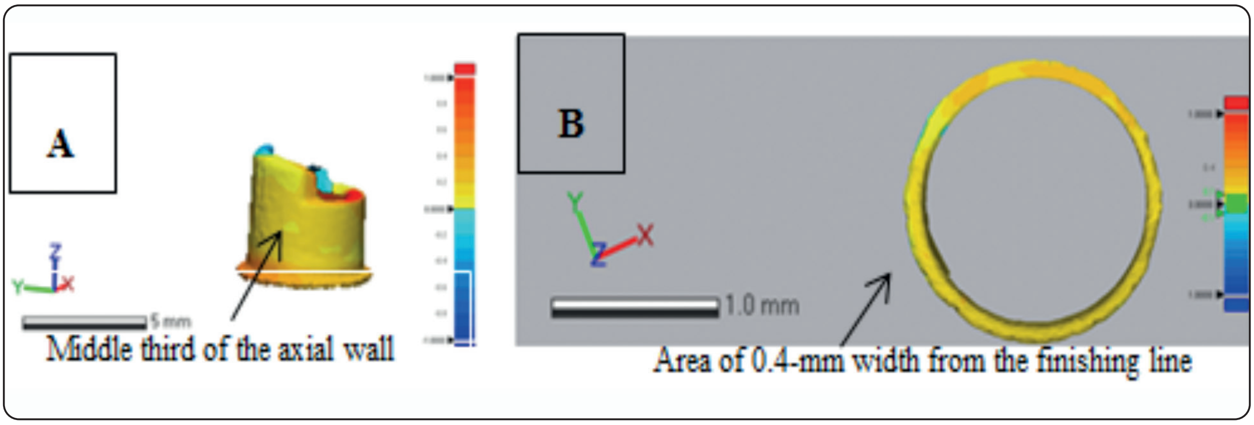

Fig. (3) Subtractive RET showing color coded maps using Geomagic analysis. A: Internal fit, B: Marginal fit.

RESULTS

Data explored for normality showed parametric distribution. Intergroup comparisons for marginal gap values are presented in Table 1. For marginal gap values measured using DOT, BioHPP had higher marginal gap values than lithium disilicate group, however, there was no significant difference ($p = 0.060$). While for sRET, BioHPP had a significantly higher gap value than lithium disilicate ($p < 0.001$). Mean and standard deviation values for marginal gap in different groups are presented in Figure 4.

Agreement of marginal gap measuring techniques is presented in Table 2. Results showed that there was no significant difference between both measurements ($p = 0.936$) and there was a statistically significant moderate agreement between both methods (ICC = 0.681, $p = 0.024$). Mean and standard deviation values for marginal gap measurements using the two methods are presented in Figure 5.

As for the internal gap, independent t-test showed that BioHPP group also had a statistically significant higher internal gap values than lithium disilicate group ($p < 0.001$) as show in Table 3.

TABLE (1) Intergroup comparison of marginal gap.

Measurement method	Marsinalsap (μm) (Mean±SD)		t-value	p-vaiue
	Lithium disilicate	BioHPP		
Direct Optical technique	64.28±3.97	70.70±7.17	2.07	0.060
Subtractive RET	64.02±0.64	70.73±1.46	11.16	<0.001*

Significant (p<0.05)

TABLE (2) Agreement between marginal gap measuring techniques.

Marginal gap (μm) (Mean±SD)		Mean difference (95% CI)	t-value	p-value	ICC (95% CI)
Direct Optical Technique	3D Superimposition Analysis Technique				
67.49±6.49	67.37±3.65	0.12 (-2.95:3.19)	0.08	0.936	0.681 (0.037:0.897)*

CI= Confidence interval, *Significant (p<O.OS)

TABLE (3) Mean ± standard deviation (SD) of internal gap (μm) measured by subtractive RET.

Material	*Internal gap (μm) (Mean ± SD)*	*p-value*
Lithium Disilicate	65.96 ± 2.06	**0.027***
BioHPP	68.47 ± 1.64	

****Significant ($p < 0.05$)***

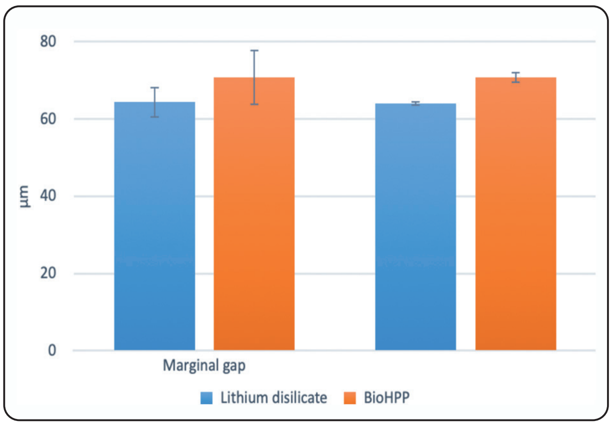

Fig. (4) Bar chart showing mean and standard deviation values of marginal gap (μm).

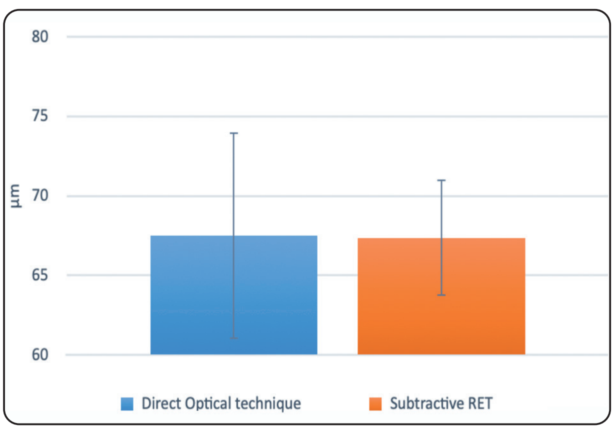

Fig. (5) Bar chart showing mean and standard deviation values of marginal gap measured using different techniques (μm).

DISCUSSION

The first null hypothesis that supra-structure material would not influence the marginal and internal adaptation values of the two screw-retained crowns was rejected. Screw-retained BioHPP crowns had higher mean gaps than lithium disilicate crowns at both the marginal and the internal levels. However, the mean marginal and internal gaps of both materials were less than 71 μm which lies within the clinically acceptable range of 50-150μm. [41,43,65,66]

Marginal and internal gaps can be assessed using multiple ways, there is no agreement yet on a standard method. In our study, marginal gap was assessed using DOT and sRET, agreement between both techniques was also evaluated. DOT, is one of the most commonly used techniques, however it's limited to certain measuring points. sRET, on the other hand, is a valid and reliable 3D technique to assess the marginal and internal adaptation of fixed restorations. The convenience of data handling and increased data utilization allows various applications, such as qualitatively showing discrepancies using color-coded maps and quantitatively calculating discrepancies in a specific region and the entire volume of the gap space. [54–57] Some studies have also used RETs [48,51–53,60,67–69], yet few have compared its reliability to other measurements techniques.[48,49,55,56,70]

According to our study, BioHPP had higher marginal gap values than lithium disilicate screw-retained crowns when measured using both techniques. However, the difference was statistically significant with the sRET and non-significant with DOT, thus the second null hypothesis was rejected. This could support what Groten et al (50) reported; that increasing the number of measuring points gains more data and thus, increase the level of significance, accuracy and reliability, which was obtained with the sRET. The agreement between both techniques according to the statistical calculation, found that both were considered reliable as there was no significant difference between them rather a significant moderate agreement. This supports the concept that sRET analysis can be a reliable measuring technique to gain more data. This was in agreement with El-Ashkar et al; [49] who compared 3 different techniques: direct optical, replica and 3D superimposition analysis and found similar results with DOT and 3D superimposition analysis.[48] Also, Hasanzade et al; [71] who compared replica and 3D analysis techniques and found that both measuring techniques had highly reliability, however, 3D superimposition provided higher values in axial and absolute marginal gap assessment.

Regarding the material, Arshad et al; [28] found that BioHPP crowns had larger marginal gaps than lithium disilicate crowns when measured using microcomputer tomography. Kayikci et al;[72] found that 3-unit peek implant-supported restorations had higher marginal gap than titanium implant-supported fixed partial dentures regardless the method of fabrication. Other studies comparing marginal gap of BioHPP and crowns with different materials found that BioHPP had a larger marginal than other materials used. [73–75] Attia et al; [76] compared different forms of PEEK; pellets, granules and milled to zirconia copings and found that there was no difference in marginal gap between milled PEEK and zirconia, while there was a significantly higher marginal gaps for the pressed than the milled PEEK copings. In contrast, PEKK has shown better marginal gaps than lithium disilicates according to Park et al;[60] who found that milled PEKK crowns had lower marginal gaps than lithium disilicate crowns. They attributed this to the absence of the crystallization cycle with PEKK than lithium disilicate which undergoes slight contraction on crystallization causing a negative effect on marginal fit. Also, Bae et al;[77] found that PEKK had better marginal adaptation than zirconia copings.

Regarding internal adaptation, our results showed that pressed lithium disilicate screw-retained crowns had better internal adaptation than pressed BioHPP. This was in contrast to Park et al [78] who compared PEEK crowns with lithium disilicate and zirconia crowns using replica technique and 3D analysis. They found that PEEK had the lowest axial gap followed by lithium disilicate then zirconia. Arshad et al; [28] found that milled BioHPP crowns had lower axial gaps than pressed lithium disilicate crowns using mirco-CT analysis, however there was no significant difference in their internal volume. This was attributed to the lower cement space in milled crowns that can cause incomplete seating which is usually seen as low axial gaps with large occlusal gaps. Attia M et al; [79] found that milled PEEK crowns had better marginal and internal adaptation than pressed PEEK when measured using micro-CT. However, the mean internal gaps at the mid-axial walls were found to be close to the results of our study (71-72 μm) for PEEK pellets. The difference between our study and other studies Avon be attributed to the difference in the processing techniques (pressed or milled) and measuring tools used.

The increased marginal and internal gaps of BioHPP could be due to the semicrystalline structure of BioHPP which contains ceramic fillers embedded in resin matrix, the injection molding technique; which may cause degradation of the polymer, the preheating method, the vacuum pressing device and the shrinkage of the material during polymerization. [80] On the other hand, the higher grain size of lithium disilicate crystals and crystallization of lithium disilicate may potentially impact the mechanical performance and best fit of the material. [81,82]

Misfit between different implant prosthetics components is of major concern as it will not only cause mechanical problems, it also plays a crucial role on the biologic success of the implant-supported restorations. [41,83] The attachment of the peri-implant mucosa to the surrounding abutment, is what creates a mucosal seal to protect the underling peri-implant bone from the ingress of oral bacteria. The margin between the Ti-base and supporting structure is usually placed deep subgingival and close to the crest of the bone and although they are cemented and polished extra-orally, a large marginal gap can create a recess for bacterial colonization which may lead to peri-implantitis, crestal bone loss and eventually loss of osseointegration. [84,85] Limitations of this study can be attributed to miscalculations due to possible inaccuracy and overlapping of the scanned data, inability to apply this study clinically and that the crowns were not cemented.

CONCLUSIONS

Within the limitations of this study, it was found that supra-structure material affected marginal and internal adaptation of screw-retained crowns. Pressed BioHPP had higher marginal gap values than pressed lithium disilicate screw-retained crowns. However, the difference was non-significant when measured with DOT while significant with sRET. The use of adjunct 3D software technologies enables more detailed measurements for deeper analysis. DOT and RET were both relevant and showed moderate agreement between them. Pressed lithium disilicate screw-retained crowns showed better internal adaptation values than pressed BioHPP screw-retained crowns.

LIST OF ABBREVIATIONS

DOT —- Direct optical technique

sRET —- Subtractive reverse engineering technique

Ti-base — Titanium base

PEEK —- Polyetheretherketone

BioHPP —- biocompatible high-performance polymer

CAD/CAM —- computer aided design/ computer aided manufacturing

RET —- reverse engineering technique

3D —- 3-dimensional

RMS —- Root mean square

ICC —- intraclass correlation coefficient

PEKK —- Polyetherketoneketone

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