EGYPTIAN
DENTAL JOURNAL
www.eda-egypt.org

VOL. 68, 1655:1664, APRIL, 2022

PRINT ISSN 0070-9484 • ONLINE ISSN 2090-2360

EDJ
EGYPTIAN DENTAL JOURNAL

FIXED PROSTHODONTICS AND DENTAL MATERIALS

Submit Date : 2022-01-25 • Accept Date : 2022-03-26 • Available online: 2022-03-30 • DOI : 10.21608/edj.2022.117767.1962

INTERNAL ADAPTATION AND MARGINAL GAP OF SPLIT-FILE VERSUS SCANNED WORKFLOWS OF THREE TYPES OF NON-METALLIC SUPER-STRUCTURES ON ZIRCONIA ABUTMENTS

Khaled Elbanna* *and* Alaa Waleed Alqutub**

ABSTRACT

The aim of this study was to compare marginal and internal adaptation of non-metallic implant supported crowns fabricated using split-file and scanning workflows.

Materials and methods: A total of 30 crowns were fabricated and divided into two equal groups: Group I: where the master abutment was used virtually as a split-file workflow and Group II where the master abutment was scanned. Each group was subdivided into three equal subgroups according to material: subgroup A: zirconia, B: lithium disilicate, and C: polyetherketoneketone (PEKK). Margin and internal adaptation were evaluated using replica technique with a digital microscope.

Results: Group II had lower marginal and internal gap means (71.55, 94.66 μm respectively) than Group I (85.44, 103.73 μm respectively). Zirconia had better margin and internal adaptation (69.27, 82.48 μm respectively) followed by PEKK (82.14, 105.4 μm respectively) then lithium disilicate which had the largest margin and internal gaps (84.08, 109.7 μm respectively).

Conclusions: 1. Despite the better fit of the scanned abutment group, split-file technique has shown acceptable marginal and internal adaptation. 2. Milled zirconia showed better fit than PEKK and lithium disilicate, however the three materials had acceptable marginal and internal adaptation.

KEYWORDS: Split-File, Internal Adaptation, Margin gap, Zirconia, PEKK

---

* Assistant Professor, Fixed Prosthodontics Division, Department of Oral and Maxillofacial Surgery and Diagnostic Sciences, Faculty of Dentistry, Umm Al-Qura University, KSA

** Assistant Professor, Implantology Division, Department of Oral and Maxillofacial Surgery and Diagnostic Sciences, Umm Al-Qura University, KSA

INTRODUCTION

Custom-made non-metallic implant prosthodontics is highly indicated for replacement of missing anterior teeth due to the customized emergence profile and esthetic outcome gained from such type of restoration. Custom-made implant restorations could come as screw-retained or cement-retained, depending on the requirements of the case, cost, technical factors, and the prosthodontist's preference. One way of fabrication of cement-retained implant restoration is the split-file workflow where the implant level impression is taken conventionally or digitally then the abutment is designed on the CAD software and at this point, the crown is designed at the same time on the virtual design of the abutment. later, they can be both fabricated together and delivered on the same time. This technique was first introduced by commercial agents.[1]

In addition to avoiding human errors in identifying the abutment margin, the significant time saved can be tempting to the dental technician, the prosthodontist, and the patient. Nevertheless, this technique is limited to cases where complete healing of the gingival tissues has resulted in the final desired gingival architecture. On top of that, there is no enough evidence of its efficiency in the literature to support its use.[1]

Different non-metallic materials were recommended for use to fabricate the meso and super structures. Zirconia is one of the most popular materials in the dental market due to its superior strength, low corrosion potential, high biocompatibility, low thermal conductivity, and esthetic properties. It can be used for the fabrication of the custom abutment material and/or the superstructure on top of the abutment as monolithic or veneered crown.[2, 3, 4]

Lithium disilicate has been used as an esthetic superstructure over implants and is known for having superior translucency in addition to their biocompatibility, mechanical strength and chemical stability.[5, 6, 7] CAD/CAM milling and subsequent crystallization of lithium disilicate incurs a 0.25% volumetric shrinkage, whereas sintering of milled zirconia leads to 22-25% volumetric shrinkage which may affect the fit of the restoration if this shrinkage is not well compensated in the software.[8-10]

The high-performance polymers PEEK and PEKK both belong to the family of polyaryletherketones, referred to in short as PAEK. PAEKs are high-performance thermoplastics which demonstrate high strength, stiffness and resistance to hydrolysis over a wide temperature range and are suitable for extreme loads. When processing thermoplastics, only the shape is changed, but not their chemical properties. Furthermore, the material shows no porosity and is free of monomers. PEKK is positioned at the top of the polymer pyramid and is available as base material in semi-crystalline and amorphous structure. Whereas PEKK, which is based on an amorphous structure, behaves flexibly, PEKK, which is based on a crystalline structure, is distinguished by high strength values.[11]

Crystalline PEKK is reported to function as crown and bridge material which can withstand high temperatures, resistant to chemical wear, and have high mechanical properties.[12] Biocompatibility and easy adjustments were also reported to be advantages of PEKK, however, its grayish color and low translucency makes it better to be used as a part of a framework not as a monolithic restoration.[13] Unlike zirconia and lithium disilicate, apart from the external veneering, milled PEKK is used directly without any further processing of the framework and with no subsequent dimensional changes on the fitting surface which may have impact on the overall fit of the restoration.[12]

The precise fit of the superstructure is essential for a long-term success of a restoration. The marginal gap between the abutment and the restoration could lead to bacterial infiltration causing inflammation of the soft tissues[14], besides decementation of the restoration.[15] On top of that, improper fit can lead to fracture of the all-ceramic restoration.[16] Internal gap is the perpendicular distance between the framework and the abutment on the axial and occlusal/incisal surfaces. Too much space lost as a result of a large internal gap especially on the occlusal/incisal area can decrease the interarch distance available for the restoration, which, eventually, will lead to decreased strength of the crown-cement system.[17] Different methods were described to measure the fit of crowns including but not limited to direct viewing, sectioning, replica techniques. [18, 19]

The aim of this study is to evaluate the internal and margin adaptation of non-metallic crowns milled after being designed either directly on the abutment design by the split-file workflow or after scanning of the abutment. The null hypotheses are that neither the technique nor the material of fabrication have effect on the internal and margin adaptation of the implant supported crowns.

MATERIALS AND METHODS

A total number of 30 crowns were used in this study which were divided into two equal groups (n=15) according to the fabrication protocol; two fabrication protocols were used: Split file protocol (Group I) and Scanned protocol (Group II). Each group was further subdivided into three equal subdivision (n=5) according to the material of the crown. The three materials used were Zirconia (Ceramill Zolid HT, Ammann Girrbach, Austria), lithium disilicate (e.max CAD, Ivoclar Vivadent, Lichtenstein) and polyetherketoneketone PEKK (Pekkton Ivory, Cendres$^+$ Metaux Medtech, Biel, Switzerland). (Table 1)

Internal Hex implant with 4 mm width and 10 mm length (Classic Sky, Bredent GmbH, Germany) was inserted vertically into epoxy resin using dental surveyor until 2 mm from the face of the implant were left uncovered and the resin was left to set for 24 hours. Scan body was fixed to the implant and scanned (Swing HD, DOF, Seoul, South Korea) to acquire the implant position and to start the design of one master abutment using a CAD software (Exocad GmbH, Darmstadt, Germany). The abutment was designed with the dimensions of a prepared upper left central incisor with deep chamfer finish line with significant gingival curvature extending from the labial to the interproximal and back to the palatal, with the screw hole on top of the palatal surface.

The generated design had two uses: first, it was saved to be used for the split file protocol and second it was used for milling of abutment. The designed abutment was milled in a 5-axis CNC milling machine (ED5X, Emar, Egypt) from Zirconia (Ceramill Zolid HT, Ammann Girrbach, Austria). The abutment was later sintered in zirconia sintering furnace (Ceramill Therm 3, Ammann Girrbach, Austria) and screwed to the implant with a torque wrench at 25 Ncm. (Figure 1)

TABLE (1): Sample Grouping.

	Subgroup A	Subgroup B	Subgroup C
Group I	Split File Zirconia n=5	Split File Lithium Disilicate n=5	Split File PEKK n=5
Group II	Scanned Zirconia n=5	Scanned Lithium Disilicate n=5	Scanned PEKK n=5

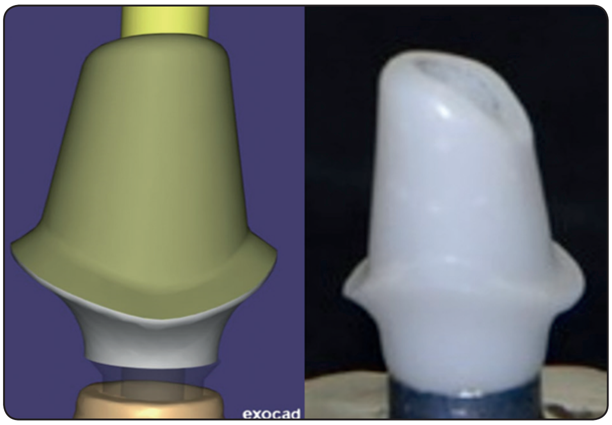

Fig. (1): Designed (left) and milled (right) master abutment.

The samples of Group I (split-file protocol) were designed with the dimensions of an upper left central incisors in the software (Exocad GmbH, Darmstadt, Germany) directly on the previously saved abutment design with 30 μm cement gap until 1 mm from the abutment margin. Samples of Group I at this point were ready to be milled.

The sintered zirconia abutment was then scanned (Swing HD, DOF, Seoul, South Korea) and imported to the CAD software then a copy of the previously designed crown was applied to the abutment scan with the same parameters to fabricate the samples of Group II (scanned protocol).

The samples of subgroups A, B and C were milled from the same zirconia used for the abutment, lithium disilicate (E.max CAD, Ivoclar Vivadent, Lichtenstein) and PEKK (Pekkton, Cendres+Metaux, Biel/Bienne, Switzerland) respectively for both groups using the same milling machine used to mill the master abutment. The zirconia samples were then sintered (Ceramill Therm 3, Ammann Girrbach, Austria) whereas the lithium disilicate samples were crystallized (Programat P300, Ivocalr Vivadent, Lichtenstein). (Figure 2)

The screw hole of the abutment was blocked with pink wax and replica technique was used to measure the internal adaptation of the crowns by us-

Fig. (2): Seated crowns on master abutment; upper: split-file group, lower: scanned abutment group, left: zirconia, middle: lithium disilicate, right: PEKK.

ing fast setting light body addition silicone impression material (Elite HD+, Zhermack, Italy) which was mixed according to manufacturer's instructions and applied to the fitting surface of the crown. The crown was then seated on the abutment with constant finger pressure. After setting of the light body, the crown was removed and heavy body addition silicone impression material (Elite HD+, Zhermack, Italy) was injected on the light body to stabilize the whole assembly and then removed after setting.

Margin and internal adaptation were evaluated by cutting the rubber index using a razor blade buccolingually and mesiodistally to obtain four parts. The thickness of the light body was measured at 4 predetermined points for each part on the margin, the internal part of the chamfer finish line, the middle of the axial surface, and the incisal surface (Figure 3). Measurements were done by a single operator using a calibrated digital microscope (Hotviewer, China) at 100x magnification (Figure 4).

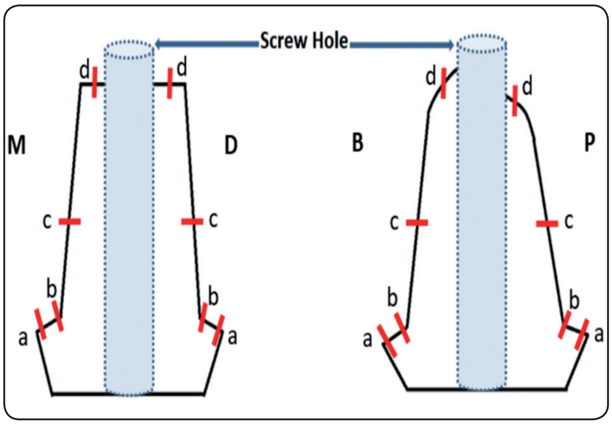

Fig. (3): Predetermined points for measuring marginal and internal adaptation: a=margin, b=chamfer, c=axial, d=incisal.

The data were tabulated and analyzed using statistical analysis software (SPSS 28.0, IBM, Chicago, USA). The data were tested for normality using Shapiro Wilk test and normal distribution was not found. Mann-Whitney U test was used for comparison between each two groups and Kruskall Wallis test was used to compare between the subgroups and group/subgroup interactions with Tukey HSD test used for post-hoc comparisons. The confidence interval was set at 95% to test for statistical significance.

RESULTS

The results of this study showed that the technique of fabrication has a significant effect on the margin and internal gap where Group II (Scanned abutment) had better margin and internal adaptation across all the areas measured. A statistical significant difference is shown in all measured sections except the incisal section. (Table 2, Figure 5) Whereas the material of construction has shown to significantly impact the margin and internal gap

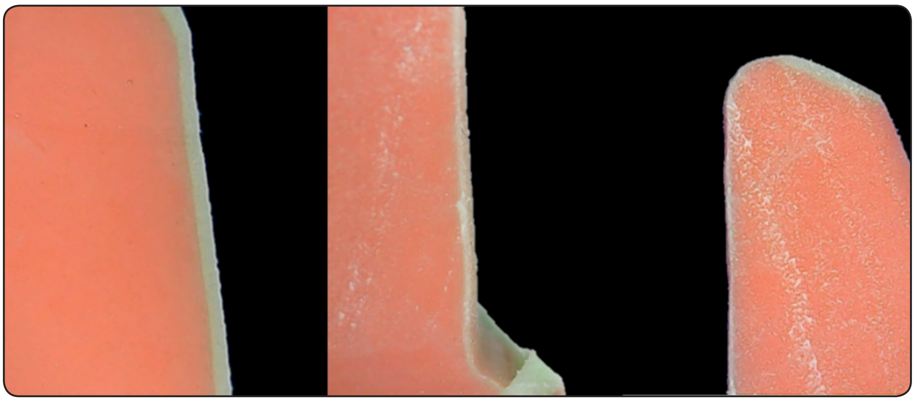

Fig. (4): Samples of axial (right), margin and chamfer (middle), and incisal (left) gap represented by the thickness of the light body (green) also with zirconia (subgroup A) showing better adaptation than lithium disilicate (subgroup B) and PEKK (subgroup C). The interaction between the technique and material of fabrication showed that scanned zirconia samples had the best margin followed by scanned PEKK, split-file zirconia, scanned lithium disilicate then the split-file PEKK and lithium disilicate had the largest marginal gap (Table 3, Figure 6). Whereas for the overall internal adaptation, scanned zirconia and split-file zirconia had the best adaptation followed by scanned PEKK and lithium disilicate then the split-file PEKK and litium disilicate (Table 4, Figure 7)

TABLE (2) Means (Standard Deviations) of each section according to technique of fabrication.

	Group I Split-File	Group II Scanned
Margin	85.44 µm (32.87)^{b}	71.55 µm (24.24) ^{a}
Chamfer	93.11 µm (32.25) ^{b}	82.53 µm (26.91) ^{a}
Axial	77.65 µm (22.67) ^{b}	72.27 µm (21.3) ^{a}
Incisal	177 µm (67.18) ^{a}	175.57 µm (76.44) ^{a}
Overall internal adaptation	103.73 µm (54.81) ^{b}	94.66 µm (57.31) ^{a}

Rows with different letters ^{a,b,c} indicates a statistically significant difference $p \leq 0.05$

TABLE (3) Means (Standard Deviations) of each section according to material of fabrication.

	Zirconia	Lithium Disilicate	PEKK
Margin	69.27 µm (34.73) ^{a}	84.08 µm (26.11) ^{b}	82.14 µm (25.2) ^{b}
Chamfer	92.33 µm (32.75) ^{a}	81.94 µm (28.2) ^{a}	88.92 µm (28.67) ^{a}
Axial	73.75 µm (15.54) ^{a}	77.92 µm (25.41) ^{b}	73.21 µm (24.08) ^{a}
Incisal	107.78 µm (36.5) ^{a}	220.49 µm (61.05) ^{c}	200.6 µm (56.67) ^{b}
Overall internal adaptation	82.48 µm (35.17) ^{a}	109.7 µm (66.15) ^{b}	105.4 µm (58.84) ^{b}

Rows with different letters ^{a,b,c} indicates a statistically significant difference $p \leq 0.05$

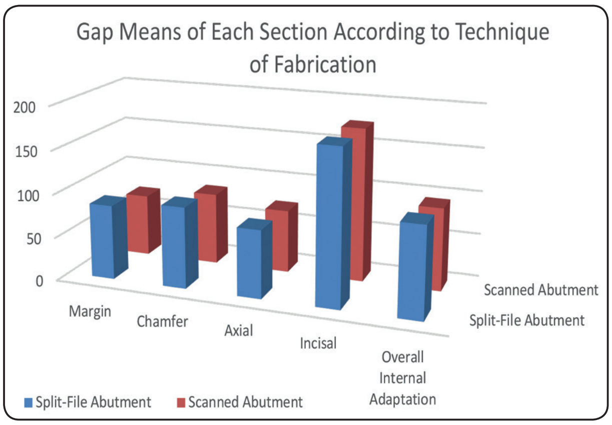

Fig. (5): Means of each section according to technique of fabrication.

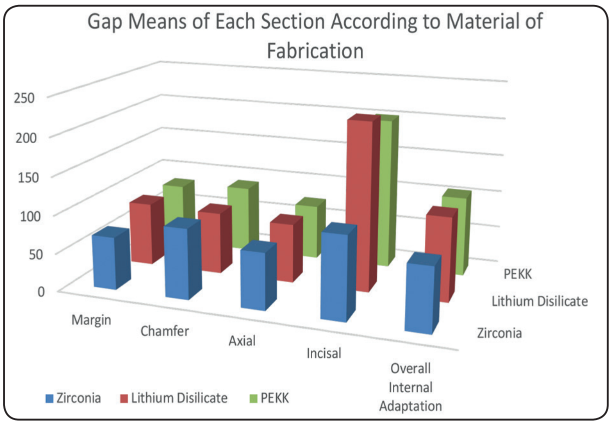

Fig. (6): Means of each section according to material of fabrication.

TABLE (4): Means (Standard Deviations) of each section according to technique and material of fabrication.

	Split-File Zirconia	Split-File Lithium Disilicate	Split-File PEKK	Scanned Zirconia	Scanned Lithium Disilicate	Scanned PEKK
Margin	74.29 μm (40)^{b}	91.13 μm (29.76)^{c}	90.9 μm (24.34)^{c}	64.25 μm (27.8)^{a}	77.03 μm (19.66)^{b}	73.38 μm (23.04)^{b}
Chamfer	98.5 μm (38.39) ^{a}	85.83 μm (25.48) ^{a}	95 μm (31.13) ^{a}	86.17 μm (24.98) ^{a}	78.06 μm (30.54) ^{a}	82.83 μm (24.94) ^{a}
Axial	76.17 μm (17.64) ^{a}	71.29 μm (30.5) ^{a}	75.17 μm (17.45) ^{a}	71.33 μm (12.91) ^{a}	74.22 μm (18.73) ^{a}	71.25 μm (29.38) ^{a}
Incisal	120.33 μm (43.59) ^{b}	218.66 μm (48.43) ^{c}	192 μm (65.06) ^{c}	95.22 μm (21.88) ^{a}	222.3 μm (72.17) ^{c}	209.19 μm (46.14) ^{c}
Overall internal adaptation	88.72 μm (41.14) ^{b}	113.67 μm (62.47) ^{c}	108.79 μm (55.66) ^{c}	76.24 μm (26.65) ^{a}	105.73 μm (69.57) ^{b}	102.01 μm (61.82) ^{b}

Rows with different letters ^{a,b,c} indicates a statistically significant difference $p \leq 0.05$

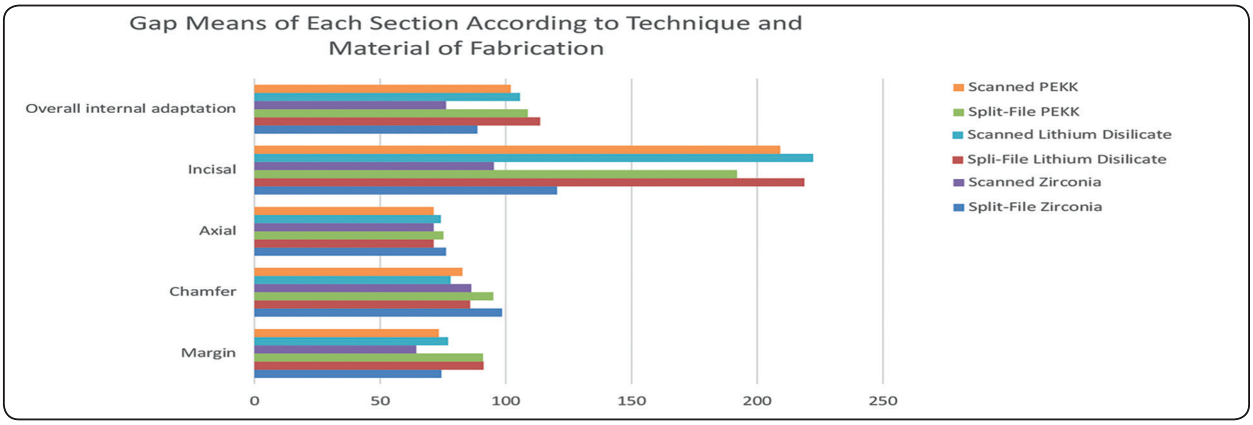

Fig. (7): Means of each section according to technique and material of fabrication.

DISCUSSION

Intimate fit between the superstructure and the abutment is important for the long-term success of the dental restoration, therefore precision of the manufacturing process is required to guarantee optimum results otherwise microleakage, periodontal diseases, and loss of the restoration could result.[20] Replica technique has been utilized frequently as an accurate, non-destructive method to record the fit between different components of implant supported restorations.[19, 21-23] It is reported that if a proper type of silicone is used, replication of the cement space regardless of the location can be recorded accurately.[22] Short production time, low cost and absence of need for special equipment has made the replica technique adopted for pre-cementation studies.[24] No significant difference was found between sectioning and replica techniques in measuring marginal gap.[25]

The gap was measured at four predetermined points on the margin, the inner surface of the chamfer finish line, the middle of the axial surface, and at the incisal surface with a total of 16 points for each sample. This was in accordance with Park et al[23], Kim et al[26] and Park et al[27] who used 14-18 points to measure marginal and internal gaps of different CAD/CAM crowns and fixed partial dentures fabricated from different CAD/CAM materials.

In this study, the incisal gap was the largest in all the tested groups as reported in previous studies with gaps ranging from 95-222 μm, whereas the axial gap was the smallest gap in all tested groups (71-76 μm) except those made from zirconia where the marginal gap means were the smallest (64-74μm).[23,28-31]

Both null hypotheses were rejected as there was a statistically significant difference between the marginal and internal gap means of the two fabrication protocols besides the three materials used in this study. There aren't enough data regarding the split-file workflow, nevertheless, the results of this study were in accordance with Sheridan et al[1] who found that split-file workflow yielded higher mean gap values compared to scanned abutment. This was found for all the areas measured for Group I and Group II; the margin (85.44 μm and 71.55 μm respectively), the chamfer (93.11 μm and 82.53 μm respectively), the axial (77.65 μm and 72.27 μm respectively), the incisal (177 μm and 175.57 μm respectively) and the overall internal adaptation (103.73 μm and 94.66 μm respectively). There was a statistically significant difference for all the measured areas except the incisal area. This significant difference may be caused by the effect of removing of the milling attachments and finishing of the zirconia abutment post milling, in addition to the post sintering shrinkage. These factors may have affected the overall dimension of the abutment causing the scanning of the abutment to get a more accurate version of the master abutment than the split-file version that was not accommodated for these alterations.

With regards to the materials used in this study, zirconia has shown the least marginal and overall internal gap distance (69.27 μm and 82.48 μm respectively) followed by PEKK (82.14 μm and 105.4 μm respectively) whereas lithium disilicate had the largest marginal gap and overall internal adaptation (84.08 μm and 109.7 μm respectively). These results were in accordance with the study performed by Park et al [23] in which they found that zirconia and PEKK yielded better adaptation than lithium disilicate on the margin (77.06, 66.83, and 96.49 μm respectively), deep chamfer (161.85, 137.8 and 161.85 μm respectively), and occlusal areas (178.59, 173.52, and 204.73 μm respectively). However, they found that PEKK had better adaptation than zirconia which was not the case in this study.

This may be explained by the effect of veneering composite used in the other study which may have improved the marginal adaptation of the samples whereas in this study no veneering material was used to standardize the dimensions of the samples in all groups. Another reason may be a different milling technique of PEKK as it is recommended by the manufacturer to use either wet milling or a special bur supplied by the manufacturer to obtain accurate fit of the PEKK restoration. In this study a wet milling protocol was used for the milling of the PEKK restorations. Finally, the use of an anterior abutment with significant gingival curvatures from the facial to the proximal surfaces and back to the palatal in this study in contrast to the molar flat-contoured finish line used in the other study may have caused some difficulties in the crown fabrication. [1, 32-34]

On the contrary to the results of this study, Al Hamad et al [31], Huang et al [35], and Seelbach et al [36] found no significant difference in the marginal fit between CAD/CAM fabricated zirconia and lithium disilicate crowns. Whereas Freire et al [37] found better margin fit of lithium disilicate (27.95 μm) than with zirconia (58.05 μm).

The interaction between the technique and material of fabrication showed that zirconia crowns of Group II had the lowest marginal gap (64.25 μm) followed by PEKK crowns of Group II (73.38 μm), zirconia crowns of Group I (74.29 μm), while the largest marginal gap was recorded for Group I lithium disilicate crowns (91.13 μm). Similarly, Group II zirconia crowns showed the least internal adaptation mean value (76.24 μm), however, it was followed by Group I zirconia crowns (88.72 μm) then Group II PEKK crowns (102.01 μm). Group I lithium disilicate crowns still showed the largest internal adaptation mean value (113.67 μm).

The results obtained in this study were well in the range of the acceptable gap values reported by previous studies for the margin and internal adaptation (50-200 μm) [38-42] and the mean values for margin gap of all groups were lower than that reported by McLean and Fraunhofer [41] of 120 μm. It is worth mentioning that the intaglio of the restorations was not touched in this study and the measurements of the gaps were done for the restoration as received from the milling process. A better adaptation is anticipated after fit adjustment especially for lithium disilicate and PEKK as adjustment of zirconia particularly may lead to surface phase transformation on the fitting surface.[38]

Lack of cementation and veneering of the different materials are considered limitations of this study. Moreover, post-adjustment gap measurements may have revealed different level of seating and could affect the gap values reported in this study.

CONCLUSIONS

Within the limitations of this study, the following conclusions can be drawn from the current study:

1. Despite the better fit of the scanned abutment group, split-file technique has shown acceptable marginal and internal adaptation.
2. Milled zirconia showed better fit than PEKK and lithium disilicate, however the three materials had acceptable marginal and internal adaptation.

REFERENCES

1. Sheridan R, Verrett R, Haney S, Schoolfield J. Effect of split-file digital workflow on crown margin adaptation. J Prosthodont 2017;26:571-580.
2. Binon PP. Implants and components: entering the new millennium. Int J Maxillofac Implants 2000;15:76-94.
3. Prestipino V, Ingber A. Esthetic high-strength implants abutments. Part I. J Esthet Dent 1993;5:29-36.
4. Meijer H, Stellingsma K, Meijndert L, Raghoebar G. A new index for rating aesthetics of implant-supported single crowns and adjacent soft tissues-The implant crown aesthetic index. Clin Oral Implants Res 2005;16:645-649.
5. Ueda K, Güth JF, Erdelt K, Stimmelmayr M, Kappert H, Beuer F. Light transmittance by a multi-coloured zirconia material. Dent Mater J 2015;34:310-4.
6. Thieme K, Rüssel C. Nucleation and growth kinetics and phase analysis in zirconia-containing lithium disilicate glass. J Mater Sci 2015;50:1488-99. 7.
7. Almeida e Silva JS, Erdelt K, Edelhoff D, Araújo É, Stimmelmayr M, Vieira LC, Güth JF. Marginal and internal fit of four-unit zirconia fixed dental prostheses based on digital and conventional impression techniques. Clin Oral Investig 2014;18:515-23.
8. Komine F, Blatz MB, Matsumura H. Current status of zirconia-based fixed restorations. J Oral Sci 2010;52:531-9.
9. Kang SH, Chang J, Son HH. Flexural strength and microstructure of two lithium disilicate glass ceramics for CAD/CAM restoration in the dental clinic. Restor Dent Endod 2013;38:134-40.
10. Oh GJ, Yun KD, Lee KM, Lim HP, Park SW. Sintering behavior and mechanical properties of zirconia compacts fabricated by uniaxial press forming. J Adv Prosthodont 2010;2:81-7.
11. PEKK brochure Esthetic.line Pekkton Ivory brochure. Cendres+Metaux Medtech; 1016.03.01.01 | 02.2019:1-16.
12. Fuhrmann G, Steiner M, Freitag-Wolf S, Kern M. Resin bonding to three types of polyaryletherketones (PAEKs)-durability and influence of surface conditioning. Dent Mater 2014;30:357-63.
13. Stawarczyk B, Beuer F, Wimmer T, Jahn D, Sener B, Roos M, Schmidlin PR. Polyetheretherketone-a suitable material for fixed dental prostheses? J Biomed Mater Res B Appl Biomater 2013;101:1209-16.
14. Att W, Hoischen T, Gerds T, Strub JR. Margin adaptation of all-ceramic crowns on implant abutments. Clin Implants Dent Relat Res 2008;10:218-225.
15. Karl M, Graef F, Wichmann M, Beck N. Microfractiures in metal-ceramic and all-ceramic implant-supported fixed dental prostheses caused by super -structure fixation. Dent Mater J 2012;31:338-345.
16. Reich S, Wichmann M, Nkenke E, Proesschel P. Clinical fit of all-ceramic three-unit fixed dental prostheses, generated with three different CAD/CAM systems. Eur J Oral Sci 2005;113:174-179.

17. Nakamura T, Dei N, Kojima T, Wakabayashi K. Marginal and internal fit of Cerec 3 CAD/CAM all-ceramic crowns. Int J Prosthodont 2003;16:244-248.

18. Kersten S, Tiedemann C. Strength and marginal fit of full and partial porcelain crowns on Branemark Implants. Clin Oral Implants Res 2000;11:59-65.

19. Elbanna K, Alqutub A, Salem S. Evaluation of Internal Fit of CAD/CAM Implant Abutments with Hybrid and Internal Hex Connections Using Different Materials ID: EDJ-2110-1824

20. Yildrim B, Paken G. Evaluation of the marginal and internal fit of implant-supported metal copings fabricated with 3 different techniques: an in vitro study. J Prosthodont 2019;315:315-320.

21. Tamac E, Toksavul S, Toman M. Clinical marginal and internal adaptation of CAD/CAM milling, laser sintering, and cast metal ceramic crowns. J Prosthet Dent 2014;112:909-13.

22. Laurent M, Scheer P, Dejou J, Laborde G. Clinical evaluation of the marginal fit of cast crowns-validation of the silicone replica method. J Oral Rehabil 2008;35:116-22.

23. Park JY, Bae SY, Lee JJ, Kim JH, Kim WC. Evaluation of the marginal and internal gaps of three different dental prostheses: comparison of the silicone replica technique and three-dimensional superimposition analysis.

24. Boitelle P, Tapie L, Mawussi B, et al: Evaluation of the marginal fit of CAD-CAM zirconia copings: comparison of 2D and 3D measurement methods. J Prosthet Dent 2018;119:75-81.

25. Rahme HY, Tehini GE, Adib SM, et al: In vitro evaluation of “replica technique” in the measurement of the fit of Procera crowns. J Contemp Dent Pract 2008;9:25-32.

26. Kim DY, Kim EB, Kim HY, Kim JH, Kim WC. Evaluation of marginal and internal gap of three-unit metal framework according to subtractive manufacturing and additive manufacturing of CAD/CAM systems. J Adv Prosthodont 2017;9:463-469.

27. Park JY, Lee WS, Kim HY, Kim WC, Kim JH. Accuracy evaluation of metal copings fabricated by computer-aided milling and direct laser sintering systems. J Adv Prosthodont 2015;7:122-128.

28. Bayramoglu E, Ozkan YK, Yildiz C. Comparison of marginal and internal fit of press-on-metal and conventional ceramic systems for three- and four-unit implant-supported partial fixed dental prostheses: An in vitro study. J Prosthet Dent 2015;114:52-58.

29. Kahramanoglu E, Ozkan YK. Marginal and Internal Adaptation of Different Superstructure and Abutment Materials Using Two Different Implant Systems for Five-Unit Implant-Supported Fixed Partial Dentures: An In Vitro Study. Int J Oral Maxillofac Implants 2013;28:1207-1216.

30. Ortorp A, Jonsson D, Mouhsen et al. The fit of cobalt chromium three-unit fixed dental prostheses fabricated with four different techniques: a comparative study. Dent Mater 2011;27:356-363.

31. Alhamad K, Al Quran F, AlJalam S, Baba N. Comparison of the accuracy of fit of metal, zirconia and lithium disilicate crowns made from different manufacturing techniques. J Prosthodont 2019;28(5):497-503.

32. Asavapanumas C, Leevailoj C: The influence of finish line curvature on the marginal gap width of ceramic copings. J Prosthet Dent 2013;109:227-233.

33. Azar MS, Lehmann KM, Dietrich H, et al: Effect of preparation depth differences on the marginal fit of zirconia crown copings: an in vitro study. Int J Prosthodont 2011;24:264-246.

34. Tao J, Yoda M, Kimura K, et al: Fit of metal ceramic crowns cast in Au-1.6wt% Ti alloy for different abutment finish line curvature. Dent Mater 2006;22:397-404.

35. Huang Z, Zhang L, Zhu J, et al: Clinical marginal and internal fit of crowns fabricated using different CAD/CAM technologies. J Prosthodont 2015;24:291-295.

36. Seelbach P, Brueckel C, Wostmann B: Accuracy of digital and ¨ conventional impression techniques and workflow. Clin Oral Investig 2013;17:1759-1764.

37. Freire Y, Gonzalo E, Lopez-Suarez C, Suarez M. The marginal fit of CAD/CAM monolithic ceramic and metal-ceramic crowns. J Prosthodont 2019;28(3):299-304.

38. Preis V, Schmalzbauer M, Bougeard D, et al: Surface properties of monolithic zirconia after dental adjustment treatments and in vitro wear simulation. J Dent 2015;43:133-139.

39. Karlsson S: The fit of Procera titanium crowns. An in vitro and clinical study. Acta Odontol Scand 1993;51:129-134.

40. Bjorn AL, Bjorn H, Grkovic B: Marginal fit of restorations and its relation to periodontal bone level. II. Crowns Odontol Rev 1970;21:337-346

41. McLean JW, von Fraunhofer JA: The estimation of cement film thickness by an in vivo technique. Br Dent J 1971;131:107-111.

42. Sulaiman F, Chai J, Jameson LM, et al: A comparison of the marginal fit of In-Ceram, IPS empress, and Procera crowns. Int J Prosthodont 1997;10:478-484.