10.21608/adjc.2023.192712.1252 Advanced Dental Journal
Volume 6 (2024) | Issue 2| Pages 208 - 215

Original Article

Marginal and Internal Gaps Evaluation of Endocrown Restoration Fabricated of Different CAD/CAM Materials using CBCT: An In vitro Study

Ahmed Ismail Taha [1], Nour Hatata [2]

[1] Prosthodontics Department, Faculty of Dentistry, Kafr Al Sheikh University.

[2] Radiology Department, Faculty of Dentistry, Kafr Al Sheikh University.

Email: dentnet20@hotmail.com

Submitted: 8-2-2023
Accepted: 31-5-2023

Abstract

Aim: The purpose of this in vitro study was to compare marginal and internal gaps of endocrowns fabricated from 3 different CAD-CAM materials.
Subjects and methods: Thirty human mandibular third molars were divided into 3 groups (n=10) according to the material used: e.max CAD, Shofu HC, and Brilliant Crios (n=10). The I-CAT Next Generation scanner was used to obtain cone beam computed tomography (CBCT) images. Gaps were measured at the marginal and axial walls and at the pulpal floor. All data were statistically analyzed by using 2-way mixed ANOVA and post hoc Tukey HSD tests for pairwise comparisons (α=.05).
Results: The gaps at both margin and pulpal surface were significantly different among the 3 groups (P<.001) Significant difference were also found among the in marginal, axial, and pulpal surfaces in each of the 3 groups (P<.001). The lowest mean ±standard deviation marginal gaps were found for e.max CAD (92 ±15.5) μm and the lowest pulpal gaps for Brilliant Crios (144 ±15.1 μm).
Conclusion: All materials had clinically acceptable margin gaps (<160 μm) but the internal gaps were not clinically acceptable except for Brilliant Crios.

Keywords: e.max, resin, hybrid,fitting,CBCT

I. *INTRODUCTION*

The endocrown was introduced as an alternative method for restoring posterior endodontically treated teeth, with the advantage of conservative tooth preparation. A preparation for an endocrown is composed of a circular butt-joint occlusal margin and tapered walls in the pulp chamber for retention. Endocrowns preserve tooth structure, restore function, and use esthetic materials, in addition to providing biomechanical integrity for extensively damaged endodontically treated posterior teeth.[1]

Endocrowns are monoblock restorations with the extended pulp chamber portion and anatomically shaped coronal portion formed as a single piece.[2] Bindl and Mormann[3] suggested that this single piece restoration provides both retention and stability through the advantages of the extension into the pulp chamber and adhesively bonding. Endocrowns can be milled from different materials and their clinical survival has been mainly related to their mechanical properties, adequate bonding, meticulous adaptation, and acceptable esthetics.[4-7] Marginal and internal gaps are affected by factors such as the design of preparation,[8-11] production technique,[12,13] gaps measurement technique,[14-16] and the materials used.[17,18] Computer-aided design and computer-aided manufacturing (CAD-CAM) techniques offer access to new restorative materials and chairside fabrication that could enhance esthetics and adaptation.[19]

Different techniques have been used to measure internal gaps, including direct measurement under a microscope of sectioned tooth-restoration specimen. The drawback of this method is that some data could be missed because of the sectioning approach, and the number of sections are limited. Therefore, nondestructive methods have been developed to preserve the specimen for additional evaluation. The model approach is the most widely non-destructive method, by using a tooth replica. however, the number of 2-dimension sections, and the correct reproducibility of sectioning alignment is hard to achieve, furthermore, the approach lacks precision because of detachment of the intaglio surface of the restoration after sectioning.[20]

Different three dimensional (3D) digital methods were raised to afford 3D reconstructed images for assessment of marginal gaps and evaluation of internal gaps in several directions and sections, making it possible to assess a great number of reference points and easy identification of critical distances non-destructively.

Three-dimensional images can be obtained from optical scanners,[21] or with X-rays, such as from microcomputed tomography (μCT) or cone beam computed tomography (CBCT) that provide high quality images for measuring the gaps between the preparation surface and the intaglio surface of the restoration.[22-24] However, to perform an accurate analysis, there must be a clear distinction between the prepared surface, the restoration, and the internal gaps which can be achieved by performing the scanning procedure before cementation.[25]

This in vitro study aimed to assess the accuracy of marginal and internal adaptation of endocrowns by CBCT and detect significant difference in precision of marginal and internal adaptation among the restorations produced with 3 different CAD-CAM materials (lithium disilicate glass ceramic, resin-modified ceramic, and resin nanoceramic). The null hypotheses were that no significant difference would be found between marginal and internal gaps values among the 3 groups and no significant difference between margin and internal gaps within each group.

II. SUBJECTS AND METHODS

This in vitro study was approved by the ethical committee of the Faculty of Oral and Dental Medicine and Surgery, Kafr Al Sheikh University, Kafr Al Sheikh, Egypt (MKSU/22-11-2). Thirty human mandibular third molars had been extracted because of impaction problems and were gathered for this research. The inclusion criteria were sound, free of caries, and without cracks, and within a range of 7 to 8 mm buccolingually and 9 to 10 mm mesiodistally measured 3-mm above the cementoenamel junction (CEJ). The height of the pulp chamber was 5 to 7 mm starting from the central groove to the floor pulpal chamber. measured with a periodontal probe through an access cavity.

Selected teeth were divided into 3 groups (n=10) according to CAD-CAM material used (Table 1). The sample size had been determined to be adequate for a statistical power of 80% (G*Power 3.1.9.2.; Heinrich Heine University Düsseldorf)[26] : Group EM (restored with lithium disilicate glass ceramic, e.max CAD; Ivoclar AG), Group SH (restored with resin-modified ceramic, zirconium silicate interpenetrating with composite, HC; Shofu), and Group BC (restored with resin nanoceramic, Brilliant Crios; Coltène) (n=10).

Endodontic treatments were performed by single operator (A T) for all specimens. A cylindrical mold was used to place each specimen centrally in a non-shrink epoxy resin material (Kemapoxy 150; CMB) and was inserted to a level of 2 mm apical to the most apical buccal point of the CEJ, with the help of dental surveyor (unident; Unident Instruments Pvt. Ltd) to simulate the normal biological width. The acrylic resin block allowed all specimens to be positioned from the center of rotation of the CBCT scanner at fixed distances, which, providing a standardized image quality.

A straight handpiece was attached to the surveyor device, so that a low-speed double sided diamond disk (NTI Serrated; Kerr Corp), was attached in the handpiece. All specimens were decoronated 3-mm occlusal to the highest point of pulpal floor and perpendicular to their long axis, under copious water coolant. The wall of pulp chamber was prepared with a tapered diamond rotary instrument with rounded end (TR-13 (ISO 198/018); Mani)[27] held perpendicular to the floor and guided by the surveyor.

All optical scans were performed with a wireless intraoral scanner (Mdeit i700; Medit corp) by a single operator (A T). Standard tessellation language (STL) file was exported and transferred to a software program (DentalCAD 3.0 Galway

2021; exocad) that was used to design the endocrown restoration. The virtual images of the restorations were designed with a cement space of 40 µm and were transferred to a 5-axis milling machine (Coritec 250i; imes-icore GmbH). The endocrown restorations were milled from the 3 CAD-CAM materials used in the study. After milling, a diamond wheel (DCB; Schleifer) was used to finish the remaining part of sprue. Endocrown restorations for group EM were placed on crystallization tray for crystallization in a furnace (Programat P310; Ivoclar AG) following the manufacturer instructions.

After milling, endocrown restorations were evaluated on the prepared teeth, and pressure areas were identified by using a water-soluble pressure indicating paint (PIP; Keystone Industries). A finishing green diamond point (DCB; Schleifer) was used to remove all detected pressure areas until complete seating was verified, as being when clinically acceptable marginal adaptation was detected. Improvement of marginal gaps were noticed by 2 clinicians using sharp explorer at different marginal points. Then alcohol moistened cotton pellet was used to clean all specimens and restorations were seated before CBCT scanning.

The prepared specimen blocks were organized on the occlusal plate of a CBCT machine in a circular pattern. The I-CAT Next Generation scanner was used to obtain CBCT images, using same parameters for all specimens. The Digital Imaging and Communications in Medicine (DICOM) format was exported to a software program (Invivo Dental 5.4; Anatomage) which was used for gaps measurements. 2 Mesiodistal and 2 buccolingual X-ray virtual sections, clear of any artifacts, were selected for gaps measurements to ensure accurate measurements. Gaps were measured in all specimens at 3 different sites (M; marginal, A; axial wall, and P; pulpal floor) as shown in (Fig. 1A-C) and (Fig. 2A-C)

According to previous publications,[8,9] eleven measurements were selected on each virtual section: Mg: 1 measurement on the marginal gap, 3 measurements on axial wall, Cg; measurement on the cervico-axial angle, and Ag1 and Ag2, which divided the axial wall into 3 equal parts; and 2 measurements on the pulpal floor, Pg1 on the axiopulpal angle and Pg2 in the center of the pulpal site. Mg represented the marginal fit, whereas Cg, Ag1, Ag2, Pg1, and Pg2 represented the internal fit of the endocrown. Mg, Cg, Ag1, Ag2, and Pg1 measures were Picked twice in each virtual section; that is why it is eleven measurements. A total of 1320 gaps measurements were collected from the 3 groups.

Statistical analysis

All data were collected and statistically analyzed with a statistical software program (IBM SPSS Statistics, v20.0; IBM Corp) (α=.05).

The 2-way mixed ANOVA was run to determine whether there were differences in gaps (µm) between the 3 independent groups at different sites. There were no outliers, as assessed by boxplot. The data was normally distributed, as assessed by Shapiro-Wilk test of normality (P>.05). There was homogeneity of variances (P>.05) and covariances (P>.05), as assessed by Levene test of homogeneity of variances and Box M test, respectively. The Huynh-Feldt test was reported as Mauchly Test of Sphericity revealed a P =.011, and Epsilon value of .772. There was a statistically significant interaction between the group and site on gaps (µm), F=5.868, P=.001, partial η^2=.303, and Cohen f=.6593332. Accordingly, simple main effect of group was run comparing gaps (µm) between the 3 groups at each time point, and simple main effect of site was run comparing gaps (µm) between the 3 sites in each group as shown in Figure 3.

III. RESULTS

Table 2 showed that, margin and pulpal sites had statistically significant differences in mean gaps among the 3 assessed groups, however there was no statistically significant difference among the 3 groups at the axial site. Post Hoc Tukey HSD tests were performed for pairwise comparisons. Group SH displayed the largest mean marginal and pulpal gaps (marginal=133 and pulpal=222 µm) compared to BC group (marginal=113 and pulpal=144 µm) and EM group (marginal=92 and pulpal=193 µm) (P<.001). All mean marginal gaps of 3 groups were within clinical acceptable range.

When mean gaps were compared across the sites as shown in table 3, all tested groups showed a statistically significant difference in mean gaps between 3 sites (margin, axial, and pulpal), except between the mean axial and pulpal sites in both group EM and group SH. Pairwise comparisons with Bonferroni adjusted P-values showed that smallest mean gap (µm) was observed at the margin for all tested groups; group EM (92 µm), and group SH (133 µm), and group BC (113 µm), where the axial site displayed the largest gap in group EM (200 µm) and group BC (172 µm), but group SH showed the largest gap at pulpal site (222 µm).

Table (1): Materials were used in the present study

Group	Block used	Manufacturer	Composition	
EM	e.max	Ivoclar AG	Lithium disilicate glass ceramic	70 vol% lithium disilicate and glass ceramic
SH	Shofu Block HC (SH)	Shofu	Resin-modified ceramic	zirconium silicate (61%) is embedded in a high temperature/high pressure polymer matrix, creates a skeleton.
BC	Brilliant Crios	COLTENE	Resin nanoceramic	Crosslinked methacrylates 29.3 wt% Amorphous silica 70.7 wt%

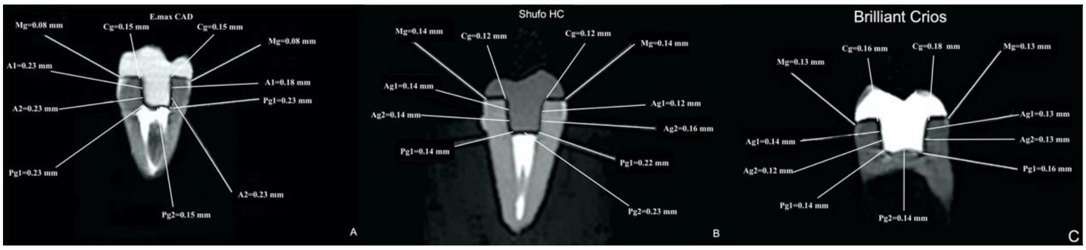

Figure (1): A-C, virtual measurements of marginal and internal gaps for CAD-CAM, computer aided design and computer-aided manufacture endocrown restorations in 3 groups (EM, SH, and BC) using CBCT, cone beam computed tomography: (a, b, and c are showing measurements in bucco-lingual cross-section). Mg; marginal gap, Cg; cervico-axial angle gap, Ag1; axial gap1, Ag2; axial gap2, Pg1; axiopulpal angle gap and Pg2; gap on the center of pulpal wall.

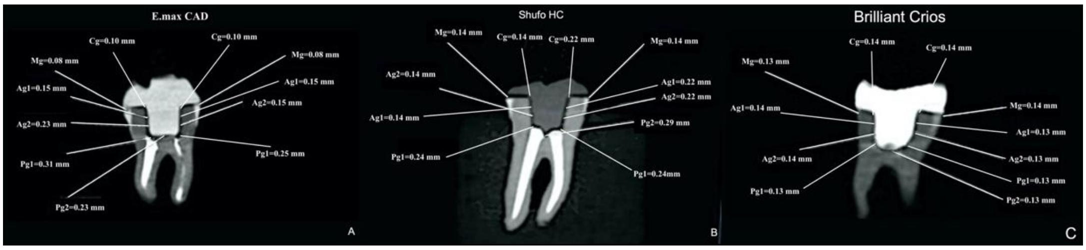

Figure (1): A-C Virtual measurements of marginal and internal gaps for CAD-CAM, computer-aided design and computer aided manufacture endocrown restorations in 3 groups (EM, SH, and BC) using CBCT, cone beam computed tomography: (a, b, and c show measurements in mesio-distal cross-section). Mg; marginal gap, Cg; cervico-axial angle gap, Ag1; axial gap1, Ag2; axial gap2, Pg1; axiopulpal angle gap and Pg2; gap on the center of pulpal wall.

Table (2): Mean values, standard deviations, and group comparison of gap thickness (values in micrometer) at various sites across 3 tested groups (n=30)

Site	Group			Test of significance				Group Comparison *P*-value		
	EM	SH	BC	F	*P*-value	Partial η^2	Cohen's *f*	EM/ SH	EM/ BC	SH/ BC
M	92 ±15.5	133 ±16.4	113 ±17.7	15.378	<.001	.533	1.068329	<.001	.025	.035
A	200 ±54.6	192 ±37.7	172 ±25.3	1.239	.306	.084	.3028251	.901	.294	.527
P	193 ±25.8	222 ±32.2	144 ±15.1	24.105	<.001	.641	1.336232	.050	.001	<.001

Notes: Data is mean ± SD. The test of significance is 2-way mixed analysis ANOVA. Partial η^2 and Cohen's *f* represent the effect size. Sites (M=margin, A=axial, P=pulpal)

Table (3): Mean values, standard deviations, and group comparison of gap thickness (values in micrometer) at various sites across 3 tested groups (n=30)

Group	Test of significance				Site Comparison *P*-value		
	F	*P*-value	Partial η^2	Cohen's *f*	M/A	M/P	A/P
EM	26.559	<.001	.747	1.718304	<.001	.001	1.00
SH	24.080	<.001	.728	1.635992	.009	<.001	.200
BC	22.678	<.001	.716	1.587806	.001	.006	.031

Notes: Data is mean ±SD. The test of significance is one-way repeated measures ANOVA. Partial η^2 and Cohen's *f* represent the effect size. Sphericity was assumed for each group (Mauchly's Test of Sphericity, p-values are 0.089, 0.316, and 0.527 for EM, SH, and BC groups, respectively. Sites (M=margin, A=axial, P=pulpal)

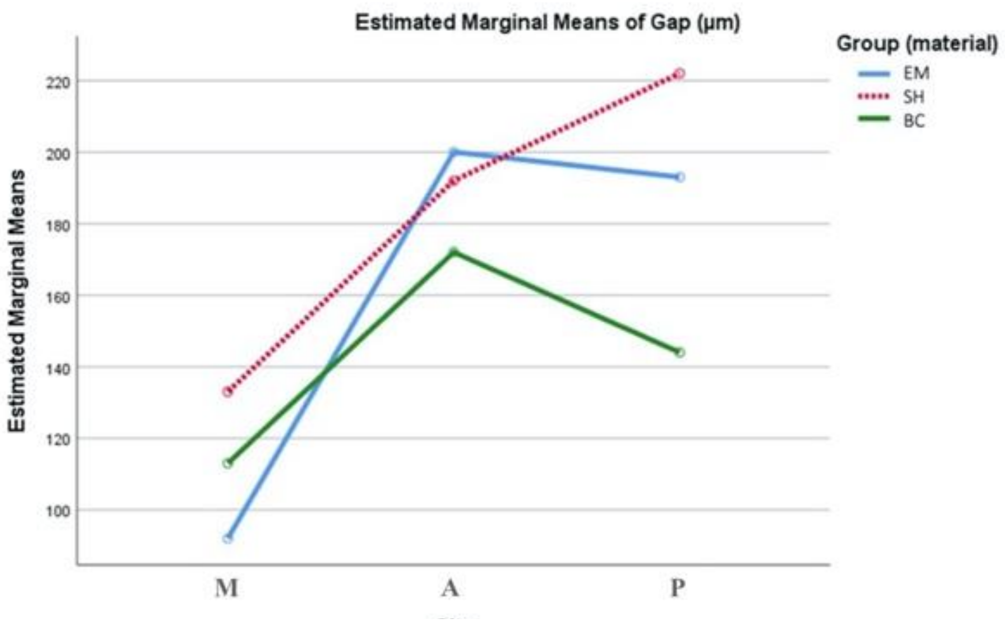

Figure (3): Group by Site interaction effect on gap (µm). (M=margin, A=axial, P=pulpal)

IV. DISCUSSION

Clinical success of endocrown restoration depends on the marginal and internal adaptations of restorations. As improper marginal adaptation of restoration would inversely increase the thickness of cement and in turn results in dissolution of adhesive cement, with consequent discoloration of margin and recurrent caries or accumulation of food debris and plaque and finally tooth destruction, ginigival and periodontal inflammation and pockets formation.[10]

Although natural human teeth were used, similarity range of the teeth size was the choice to standardize the assessments of gaps and to provide great clinical relevance, all preparations were done using the same diamond rotary instrument type mounted on a surveyor. To eliminate clinical errors, CAD-CAM scanner and milling machine were used for precise procedure. So, it was feasible to compare the marginal and the internal gaps with elimination of other variables and just concentrating on the effect different tested materials.

Previously, to assess the internal fit, some techniques had been used to evaluate the marginal and internal integrity of indirect restoration both qualitatively and quantitatively. In the present study, 3D qualitative and quantitative accurate measurement in various directions, the assessment method of CBCT was performed for precise 3D qualitative and quantitative measurement from various directions. The internal gaps measurement using CBCT was carried out for restoration over the tooth being held on acrylic resin block, to help accurate positioning on tray to allow accurate capture of image. This procedure gives a 3D evaluation of the internal gaps at distinct points: marginal, axial, and pulpal floor in bucco-lingual and mesio-distal sections. Therefore, the internal gaps of all the endocrown restorations were evaluated from all sides that allow to estimate the exactness of a restoration fit. All the virtual measurements were done by single clinician to verify the uniformity of the attained data and to exclude statistical variance as much as possible. In addition, images were taken at the proper identical parameters to standardize the cuts at which measurements were taken and minimize human error.[24]

Marginal and internal gaps are the fundamental affair of CAD-CAM endocrown restorations.[8] The accepted gaps for internal and marginal adaptation was demonstrated in previous studies between 75 and 160 µm.[16,21] In the present study, 3 types of CAD-CAM were compared; indirect endocrown esthetic restoration fabricated from ceramic blocks (e.max CAD), resin-modified ceramic disk (HC Shofu), and resin nanoceramic disk (Brilliant Crios). Ceramic blocks (Lithium disilicate ceramics) have been well known for their excellent esthetic, and mechanical properties, in addition to chemical stability, and biocompatibility. Nevertheless, some of their disadvantages are their brittleness and stiffness.[24]

CAD-CAM composite has been characterized over ceramic with the following chief advantages: it has less hardness and stiffness, which results in less wear of the opposing enamel clinically. Moreover, it can be fabricated and repaired easily. It is also less brittle.[28] Accordingly, less fatal collapse is anticipated in addition to less chipping and crack introduction during manufacturing.[5] Moreover, they are more consistent with milling machine and have better marginal quality.[6,7]

Recently, different categories of materials have been suggested such as ceramic-like materials, polymer infiltrated ceramics, CAD-CAM resin-based blocks, or nanoceramics.[29,30] CAD-CAM composites can be categorized depending on their microstructural build up into 2 main categories, resin with dispersed fillers and polymer infiltrated ceramic networks.[31]

The null hypotheses of this study were rejected. In the present in vitro study, the mean marginal, axial, and pulpal gaps for 3 tested groups (EM, SH, and BC) were compared. It revealed that, all the marginal gaps of 3 groups were within the clinical acceptable range of 75 to 160 µm.[16,21] The lowest mean ±standard deviation marginal gaps for EM group (92 ±15.5) µm followed by BC group (113 ±17.7) µm and the highest mean ±standard deviation marginal gaps for SH group (133 ±16.4) µm. And this may be due to low hardness and modulus of elasticity which results in removal of greater amount of material during milling.[7] This result agreed with previous research; as significant differences were observed between the ceramic-based and resin-based blocks at margin gaps, although, a negative relationship between hardness and adaptation.[17,32]

Group (BC) displayed the smallest internal gaps; the pulpal gaps (144 µm) and axial gap (170 µm). However, the mean gaps at pulpal and axial for other groups (EM and SH) were higher. This may be illustrated by the absence of post milling firing e.max CAD, in condition of SH and BC, that abolishes the occurrence of any dimensional changes.[33] Moreover, densification of "IPS e.max CAD" lithium disilicate ceramics during crystallization process. Consequently, 0.2% shrinkage occurs, due to microstructure transformation, in which lithium disilicate crystals grow in a controlled manner, resulting in material relocation.[34] In addition to that measures were done after adjustment of intaglio surface, which can make changes in the internal fit. The significant difference between mean pulpal gaps of SH and BC can be attributed to the fact about different resin-ceramic materials that exhibited differences in gaps values which may be the result of differences in the resin matrix composition, size, and type of the particles used as charge, these dispersed particles on the milled surface are easily cleared by sandblasting.[35]

To analyze internal fit in more detail, the measurements of the gaps in the present study were compared at 3 sites within each group, it was found that mean marginal gaps were the lowest value of 3 sites with significant difference. Data from previous studies suggest that the internal gaps exhibit greater values compared to marginal gaps which was consistent with result of the present study which may be due to adjustment of intaglio surface to improve restoration marginal adaptation.[34-36]

A limitation of this study that, it was an in vitro study, which may differ from a clinical study; where the clinical scanning processing would be less precise because of limitations such as saliva, and limited access of the scanner in the oral cavity. In addition to measuring the gaps with the virtual images need high resolution images. Also, the fact that the teeth which are selected doesn't represent the clinical situations of endcrowns. Moreover, the potential accuracy of milling machine may not be the best. It is also recommended for future studies to compare zirconia endocrown fit with those materials used in the present invitro study.

V. CONCLUSION

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

1. Marginal, and internal gaps vary depending on the different materials used. EM showed the lowest marginal gaps followed by BC, and the largest marginal gaps was for SH.
2. Only BC showed acceptable internal gaps sizes, while EM, and SH however, was above the clinically acceptable range.
3. The largest gaps was observed at internal gaps for all tested groups.

Conflict of Interest:

The authors declare no conflict of interest.

Funding:

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors

Ethics:

This study protocol was approved by the ethical committee of the faculty of dentistry- kafr Al sheikh university on:2/11/2022, approval number: MKSU/22-11-2

VI. REFERENCES

1. Rink S Huls A and Jahn L. Marginal accuracy and fracture strength of conventional and copy milled all-ceramic all ceramic restorations. Int J Prosthodont 1995;8:303–10.

2. Nakamura T, Nonaka M, Maruyama T. In vitro fitting accuracy of copy-milled alumina cores and all-ceramic restorations. Int J Prosthodont 2000;13:189–93.

3. Bindl A. and Mörmann W H. Clinical evaluation of adhesively placed cerec endocrowns after 2 years: preliminary results. J Adhes Dent 1999;1:255–65.

4. Groten M, Girthofer S, Pröbster L. Marginal fit consistency of copy-milled all-ceramic all ceramic restorations during fabrication by light and scanning electron microscopic analysis in vitro. J Oral Rehabil 1997;24:871–81.

5. Tsitrou E A, Northeast S E, and van Noort R. Brittleness index of machinable dental materials and its relation to the marginal chipping factor. J Dent 2007;35:897–902.

6. Awada A, Nathanson D. Mechanical properties of resin- ceramic CAD-CAM restorative materials. J Prosthet Dent 2015;114:587–93.

7. Coldea A, Fischer J, Swain M V, and Thiel N. Damage tolerance of indirect restorative materials (including PICN) after simulated bur adjustments. Dent Mater 2015;31:684–94.

8. Shin Y, Park S, Park JW, Kim KM, Park YB, Roh BD. Evaluation of the marginal and internal discrepancies of CAD-CAM endocrowns with different cavity depths: An in vitro study. J Prosthet Dent 2017;117:109–15.

9. Gaintantzopoulou MD, El-Damanhoury HM. Effect of preparation depth on the marginal and internal adaptation of computer-aided design/computer- assisted manufacture endocrowns. Oper Dent 2016;41:607–16.

10. Topkara C, Keles A. Examining the adaptation of modified endocrowns prepared with CAD-CAM in maxillary and mandibular molars: A microcomputed tomography study. J Prosthet Dent 2022;127:744–9.

11. Seo D, Yi Y, Roh B. The effect of preparation designs on the marginal and internal gaps in cerec3 partial ceramic crowns. J Dent 2009;37:374–82.

12. Yun MJ, Jeon YC, Jeong CM, Huh JB. Comparison of the fit of cast gold crowns fabricated from the digital and the conventional impression techniques. J Adv Prosthodont 2017;9:1–13.

13. Kokubo Y, Nagayama Y, Tsumita M, Ohkubo C, Fukushima S, Vult von Steyern P. Clinical marginal and internal gaps of in-ceram crowns fabricated using the GN-I system. J Oral Rehabil 2005;32:753–8.

14. Abduo J, Lyons K, Swain M. Fit of zirconia fixed partial denture: A systematic review. J Oral Rehabil 2010;37:866–76.

15. Groten M, Axmann D, Pröbster L, Weber H. Determination of the minimum number of marginal gap measurements required for practical in-vitro testing. J Prosthet Dent 2000;83:40–9.

16. Boitelle P, Mawussi B, Tapie L, Fromentin O. A systematic review of CAD-CAM fit restoration evaluations. J Oral Rehabil 2014;41:853–74.

17. Coldea A, Swain MV, Thiel N. In-vitro strength degradation of dental ceramics and novel PICN material by sharp indentation. J Mech Behav Biomed Mater 2013;26:34–42.

18. de Paula Silveira AC, Chaves SB, Hilgert LA, Ribeiro AP. Marginal and internal fit of CAD-CAM-fabricated composite resin and ceramic crowns scanned by 2 intraoral cameras. J Prosthet Dent 2017;117:386–92.

19. Ramirez-Sebastia A, Bortolotto T, Roig M, Krejci I. Composite vs ceramic computer-aided design/computer-assisted manufacturing crowns in endodontically treated teeth: analysis of marginal adaptation. Oper Dent 2013;38:663–73.

20. Nawafleh NA, Mack F, Evans J, Mackay J, Hatamleh MM. Accuracy and reliability of methods to measure marginal adaptation of crowns and FDPs: A literature review. J Prosthodont. 2013;22:419–28.

21. Sorensen JA. A standardized method for determination of all ceramic restoration margin fidelity. J Prosthet Dent 1990;64:18–24.

22. Gassino G, Barone Monfrin S, Scanu M, Spina G, Preti G. Marginal adaptation of fixed prosthodontics: A new in vitro 360-degree external examination procedure. Int J Prosthodont 2004;17:218–23.

23. Luthardt RG, Bornemann G, Lemelson S, Walter MH, Hüls A. An innovative method for evaluation of the 3-D internal fit of CAD-CAM all ceramic restorations fabricated after direct optical versus indirect laser scan digitizing. Int J Prosthodont 2004;17:680–5.

24. Ibrahim SH, Amr H, Hassan AA, Elzohairy A. Internal fit evaluation of indirect restorations fabricated from CAD-CAM composite blocks versus ceramic blocks in badly broken teeth using cone beam CT (CBCT): Double-blinded randomized clinical trial. Heliyon 2022;8:e09466.

25. Coli P, Karlsson S. Fit of a new pressure-sintered zirconium dioxide coping. Int J Prosthodont 2004;17:59–64.

26. EL Ghoul W A, Ozcan M, Ounsi H, Tohme H, Salameh Z. Effect of different CAD-CAM materials on the marginal and internal adaptation of endocrown restorations: An in vitro study. J Prosthet dent 2020;123:128–34.

27. Bornemann G, Lemelson S, R. Luthardt R. Innovative method for the analysis of the internal 3D fitting accuracy of Cerec-3 crowns. Int J Comput Dent 2002;5:177–82.

28. Ruse N D and Sadoun M J. Resin-composite blocks for dental CAD-CAM applications. J Dent Res 2014;93:1232–4.

29. Denry I, Kelly J R. Emerging ceramic-based materials for dentistry. J Dent Res 2014;93:1235–42.

30. Gracis S, Thompson V P, Ferencz J L, Silva N R F A, and Bonfante E A. A new classification system for all-ceramic and ceramic-like restorative materials. Int J Prosthodont 2015;28:227–35.

31. Mainjot A K, Dupont N M, Oudkerk J C, Dewael T Y, and Sadoun M J. From artisanal to CAD-CAM blocks: State of the art of indirect composites. J Dent Res 2016;95:487–95.

32. Goujat A, Abouelleil H, Colon P, Jeannin C, Pradelle N, Seux D, Grosgogeat B. Mechanical properties, and internal fit of 4 CAD–CAM block materials. J Prosthet Dent 2018;119:384–9.

33. Gold SA, Ferracane JL , Costa J. Effect of crystallization firing on marginal gap of CAD-CAM fabricated lithium disilicate crowns. J Prosthodont 2018;27:63–6.

34. Pradies G, Zarauz C, Valverde A, Ferreiroa A, Marinez-Rus F. Clinical evaluation comparing the fit of all-ceramic crowns obtained from silicone and digital intraoral impressions based on wavefront sampling technology. J Dent 2015;43:201–8.

35. Carbajal Mejia JB, Yatani H, Wakabayashi K, Nakamura T. Marginal and internal fit of CAD-CAM crowns fabricated over reverse tapered preparations. J Prosthodont 2019;28:e477–e84.

36. Ayse Gozde T, Metin S, Mubin U. Evaluation of adaptation of ceramic inlays using optical coherence tomography and replica technique. Braz Oral Res 2018;32:e005.