



A Comparative Evaluation of Marginal and Internal Fitness of Zirconia Monolithic Crown Fabricated with Different CAD\CAM Systems: (In Vitro Study)

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Keywords:

CAD\CAM, zirconia, marginal gap, internal gap.

Article Info.:

Article History:

Received: 14/8/2023

Received in revised form: 10/9/2023.

Accepted: 13/9/2023

Final Proofreading: 13/9/2023

Available Online: 1/6/2024

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Citation: Assi TK, Ibraheem AF. A Comparative Evaluation of Marginal and Internal Fitness of Zirconia Monolithic Crown Fabricated with Different CAD\CAM Systems: (In Vitro Study). Tikrit Journal for Dental Sciences 2024; 12(1): 1-10

<https://doi.org/10.25130/tjds.12.1.1>

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Abstract

The precision of computer-aided design/computer-aided manufacturing (CAD/CAM) systems is reliant upon their technical attributes and reliability in producing the designated restorations. The evaluation of this precision is primarily conducted through the examination of the marginal and internal fitness of said restorations. Consequently, the objective of this research endeavor was to analyze and compare the marginal and internal fitness of zirconia crowns fabricated using various CAD/CAM systems. The samples were categorized into four groups, each consisting of 10 samples, based on the specific CAD/CAM equipment employed for crown fabrication as follows: Group I fabricated using Sirona CAD\CAM milling machine, Group II fabricated using Dentium CAD\CAM machine, Group III fabricated using XTCERA CAD\CAM machine and Group IV fabricated using IMES-ICORE CAD\CAM machine. Tooth preparation done following the guidelines recommended by KATANA TM Zirconia (Kurary Noritake Dental Inc., Japan). To ensure standardization, one CAD/CAM program designed parameters was selected to be used for all CAD/CAM machines. Cement thickness was directly measured using sectioning technique to assess the crown's internal and marginal fitness. After performing sectioning, measurements were conducted using a digital microscope with a magnification of 230x. Eleven predetermined measuring locations were selected for each sample, representing four distinct areas: two marginal points, two chamfer points, four axial points, and three occlusal points. Results showed that none of four CAD\CAM machines tested was able to accurately reproduce the designed cement space parameter except Group I (Sirona) showed the closest results. As a conclusion, no CAD\CAM system is 100% accurate however, crowns fabricated using Sirona CAD\CAM milling machine showed the closest recordings to selected parameters among other CAD\CAM milling machines tested.

Introduction:

Marginal adaptability, biocompatibility, esthetics, and durability are four distinctive characteristics of a successful restoration of the tooth ⁽¹⁾. Internal and marginal fit are critical factors in the continuing effectiveness of indirect restorations ⁽²⁾. The presence of marginal misfit has been found to be a contributing factor in the accumulation of plaque, which in turn can lead to the development of cavities or periodontal disease. This association is particularly evident in dental restorations that have sub-gingival borders. Moreover, an inadequate fitting might potentially lead to the deterioration of cement and subsequent entry of bacteria ⁽³⁾. Internal space is particularly crucial since it is closely related to restoration retention and resistance ⁽⁴⁾. A suitable cement gap is necessary for a homogenous stress distribution under masticatory stresses ⁽⁵⁾; however, an excessive cement thickness minimizes the amount of load required for fracture to occur ^(6,7).

Holmes et al. ⁽⁸⁾ introduced a classification for marginal and internal adaptation in 1989, marginal gap (MG) can be defined as the perpendicular distance between the internal surface of the restoration and the axial wall of the preparation butt at the margin. The internal gap (IG) is operationally defined as the vertical distance between the internal surface of the restoration and the axial wall of the preparation.

Based on the available scientific information, there is no agreement on the maximum clinically tolerable marginal discrepancy (MD), with reported values ranging from 50 to 200 μm ⁽⁹⁻¹¹⁾. Increased MD values lower crown fracture resistance ⁽¹²⁻¹⁵⁾. Regarding the internal gap, 100 μm is regarded as clinically suitable ⁽¹⁶⁾, with maximal acceptable ranges that vary from 200 to 300 μm ⁽¹⁷⁻¹⁹⁾. Zirconia has witnessed a significant growth in use in dentistry because of its white hue and functional effects ⁽²⁰⁾. In modern dentistry, the only method for creating zirconia restorations is through the use of computer-aided

design/computer-aided manufacture (CAD/CAM). The soft-milling process is the most often used method for creating zirconia prostheses, and the blank must be sintered to attain the ultimate density and maximal strength of the material. This sintering process results in a rather high sintering shrinkage of 20%-30% ⁽²¹⁾. To compensate for sintering shrinkage, the software is instructed to mill a larger crown by an appropriate factor ⁽²²⁾. As a result, some mismatches are to be expected when trying-in a crown on the original preparation.

Numerous CAD/CAM systems, designed for both in-office and in-lab use, have been developed and are currently available in the commercial market. These devices have the capability to produce anatomically accurate contour restorations and copings for ceramic veneer applications. Numerous studies have demonstrated that the marginal fitness of CAD/CAM restorations is influenced by a wide range of parameters such as marginal configuration, thickness of die spacer, cement used, and the cementation procedure ⁽²³⁻²⁸⁾. There have also been suggestions that scanning, software, and machining all have a negative impact on the fit of CAD/CAM restorations ⁽²⁹⁻³³⁾.

The misfit of prostheses has been well proven as a result of numerous clinical and laboratory variables, including divergence from suggested criteria for tooth preparation, inaccuracy of the imprint made, and/or firing cycles. The marginal and internal fit of the prosthesis has been measured to assess the post-sintering dimensional change in zirconia in dentistry. Inadequate crown fitting is typically addressed by accepting a longer cement line and/or making post-sintering bur modifications to the crown to compensate for inconsistencies ⁽³⁴⁾.

Therefore, the objective of this study was to assess the marginal and internal fit of zirconium crowns manufactured using four distinct computer-aided design and computer-aided manufacturing (CAD/CAM) systems. This study presents two null hypotheses. The first of which asserts that there would be no discernible variation in zirconium crown marginal and internal fitness across the four CAD/CAM

methods under evaluation, while the second hypothesis states that: the cement space setting parameters of the four used CAD\CAM machines will match the cement thickness measured following cementation.

Material and Method

Forty sound first premolars from the human maxilla of comparable size and shape were gathered. Any abnormal teeth with cavities, cracks, or enamel defects⁽³⁵⁾. In order to facilitate holding of the sample and imitate the level of the supporting alveolar bone, collected teeth were stabilized in acrylic resin blocks with their top border 2 mm lower than the cement-enamel junction. To ensure that the long axis of the teeth will be perpendicular to the horizontal plane of the acrylic block, a dental surveyor was used⁽³⁵⁾. To ensure that the bur's long axis remains parallel to the tooth's long axis throughout the preparation process and obtain a constant taper degree in accordance with the taper of the preparation and finishing burs used, a modified dental surveyor with a high-speed turbine and air/water coolant was adapted to the surveyor horizontal arm. To ensure that each tooth's long axis is parallel to the bur during preparation, an acrylic block was fastened to the horizontal dental surveyor table⁽³⁶⁾. To prevent inter-examiner discrepancies, the preparation was done by one operator⁽³⁷⁾. Following the recommendations made for KATANA TM Zirconia (Kurary Noritake, Japan), teeth were prepared to receive full contour zirconia crowns. The preparation features included: axial reduction (1mm-1.5mm), chamfer finishing line (0.8mm) in depth and (1.5mm) above the cemento-enamel, the occluso-gingival height (4mm), and 6 convergence angle of axial walls. Trapezoid diamond burs (Lusterdent, France) (No. 126-M) and football-shaped burs (Lusterdent, France) (No. 211-M) were used for occlusal surface preparation, round end tapered fissure burs (Lusterdent, France) (No. 165-SC) were used for axial wall preparation, and (No. 302-F) were used for finishing.

Sample grouping: The teeth were categorized into four main groups according to the different CAD/CAM machines used in milling zirconia crowns (each group consisted of 10 teeth) as follow: **Group I:** crowns fabricated using Sirona milling machine. **Group II:** crowns fabricated using Dentium milling machine. **Group III:** crowns fabricated using XTCERA milling machine. **Group IV:** crowns fabricated using IMES-ICORE milling machine.

The fabrication methods, which comprised model scanning, software designing, milling, and sintering protocols, were performed in strict adherence to the manufacturer's specifications for zirconia KATANA TM Zirconia (Kurary noritake, Japan) and the CAD/CAM milling systems employed.

Scan phase: To ensure standardization all teeth were scanned using InEos X5 (Dentsply Sirona, USA), three dimensional digital models for all samples were produced and exported as STL file images.

Crown fabrication: To standardize crown design for all four CAD\CAM systems, EXOCAD software system V2.4 was used to designate crown restoration:

- 1. Design phase:** maxillary first premolar was selected as an abutment tooth; the specific restoration type and type of material was defined in this phase. These crown designs were then exported as STL files and sent to all four CAD\CAM systems.
- 2. Model phase:** all of these parameters were detected to be standardized to all four CAD\CAM systems used in this study which include: spacer (radial): 80 μm , spacer (occlusal): 80 μm , minimal occlusal thickness: 700 μm , minimal radial thickness: 500 μm , margin thickness: 50 μm .
- 3. Milling phase:** each 10 crowns were milled with a different CAD\CAM machine with the following properties to standardize milling process: 5-axis milling machine, dry milling, milling cycle of (10-15mins) for each zirconia crown and milling bur diameters used were of 2.5 and 1.0 mm respectively.

Following milling 40 crowns were sintered with three different sintering machines with temperature range of (1450-1500C°).

A custom made holding and cementation device was used to maintain seating force as well as secure zirconia crowns during cementation⁽³⁸⁾.

The evaluation of the fitness of each crown was conducted through the direct measurement of cement thickness using a technique known as crown-sectioning. This method minimizes the potential for software and repositioning mistakes⁽³⁹⁾ and provides an uninterrupted view of the gap⁽⁴⁰⁾.

This process involves the tooth sample to be submerged in acrylic resin so that there is less risk of the sample being destroyed⁽⁴¹⁾. A 1mm thick sectioning blade was employed to section these specimens.

A digital microscope was utilized to evaluate the cement gap between the zirconia crown and tooth. This study used a magnification of 230X as it provided a clear vision of marginal and internal gap for accurate readings. For each sample, eleven different planned measuring points were chosen, and these points represent the four separate measuring areas: (two occlusal, two marginals, two chamfer and four axial).

Results

Table (1) contains descriptive statistics about the gap in each of the four groups various areas, measured in micrometers (μm). The gap's maximum mean value was noticed at the occlusal area (164.23 ± 6.445) of Group II, while the lowest mean value was recorded at marginal area (53.22 ± 6.179) of Group I. Table (2) showed that the highest marginal (111.87 ± 6.061) and internal (136.01 ± 3.796) gap recorded was in Group II. Meanwhile, lowest marginal (53.22 ± 6.179) and internal gap (85.94 ± 1.987) were recorded in Group I.

The One-way Analysis of Variance (ANOVA) test was employed to compare the gap among the various areas within each group, as presented in Table (2). The results indicated that there was no

statistically significant difference in the gap among the different areas within each of the four CAD/CAM groups tested ($P > 0.05$).

Discussion

The main purpose of this study was to evaluate marginal and internal fitness of zirconium CAD\CAM restorations fabricated using four different CAD\CAM machines. The overall statistical results showed no significant difference between marginal and internal gap among four CAD\CAM machines tested hence first hypothesis is accepted, however this study also indicated that the spacer design settings values differed from the measured cement thickness except in Group I (Sirona) that had the closet results to the predesigned spacer setting of ($80 \mu\text{m}$) and so the second hypothesis is rejected for the remaining three CAD\CAM machines.

Despite the fact that the operator can select a preferred marginal and cement gap in the CAD program, the milling machinery do not appear to provide the requested parameters⁽⁴²⁻⁴⁴⁾. There have been reports of discrepancies on the same system (ranging from 24 to $634 \mu\text{m}$ for similar settings)⁽⁴⁵⁾ and extreme mismatches that reaches ($1316 \mu\text{m}$)⁽⁴³⁾. An accurate CAD-CAM system, according to Boitelle et al.⁽⁴⁶⁾, has to be able to mill various restorative materials effectively and accurately for the creation of high-quality restorations.

A number of studies^(47,48-53), Several studies have investigated the adaption of different CAD/CAM systems and have identified variances between the values programmed into the system and the values observed in the final restoration. The observed discrepancies may be attributed to factors such as the efficacy of digital data collection and processing⁽⁵⁴⁾, the geometry of tooth preparation, the specific type of restoration fabricated, dental laboratory protocols⁽⁵⁵⁻⁵⁸⁾, and the grinding technique employed.⁽⁵⁴⁾

Another possible cause of these results is the cementation procedure as according to many studies⁽⁵⁹⁻⁶²⁾ cementation process increases the marginal and internal gap substantially. The results of this study

resembled that of Rodiger et al. ⁽⁶³⁾, Zentler et al. ⁽⁶⁴⁾, Scotti et al. ⁽⁶⁵⁾, Borba et al. ⁽⁶⁶⁾, in which all of these studies measured an internal gap larger than the CAD\CAM software settings that were selected.

Also, a possible cause is the CAD\CAM milling tools, accurately milling burs, as according to current research, The size of the milling bur is of utmost importance due to the potential occurrence of voids resulting from excessive material removal, commonly referred to as "over milling," when using a bur with a large diameter ^(67, 68). Conversely, when the edges being prepared are smaller than the diameter of the bur, the milling process does not yield the desired results ⁽⁶⁹⁾. In addition, the milling machine's ability to accurately replicate the desired design can have an impact on the thickness of the cement gap and its uniformity, thereby influencing the fit of the crown and perhaps affecting its longevity ⁽⁷⁰⁾.

Despite using real human teeth for this research, all the teeth used were of a comparable size to ensure measurement consistency and high clinical relevance. Additionally, every preparation was performed using the same kind of diamond rotary tool on a customized dental surveyor. All replicas were sectioned in the same location to observe the discrepancies from a straight perpendicular view. To eliminate various errors, a single CAD/CAM scanner, a

single type of crown, and a single type of cement material were all utilized. Because of this, the marginal and internal fit could be compared while concentrating just on the various CAD/CAM milling machines used to make each crown.

Also, this study has the advantage of being an in vitro study, which may differ from an in vivo study in that the scanning processing would be less accurate due to restrictions like saliva and the scanner's restricted access to the oral cavity. However, the preselected measure points were limited to the sectioned lines, which may not accurately reflect the overall fit, and the gap measurements were assessed using a sectioning technique which may not be 100% accurate.

As a conclusion, no CAD\CAM system had proven to be 100% accurate in literature, and it is difficult to study all aspects of each CAD\CAM systems available in the market due to large number of it, however Sirona CAD\CAM system had proven to be as close as possible to the cement gap setting parameters, while the other three CAD\CAM systems results remained within the clinically acceptable ranges of marginal and internal gaps.

Table 1: Descriptive statistics of the gap at the different areas of the four different groups measured in (μm)

Group	Area	N	Minimum	Maximum	Mean	Std. Deviation
Group I	Marginal	10	53.22	71.09	61.590 0	6.17924
	Chamfer	10	80.37	93.55	87.736 0	4.33117
	Axial	10	80.92	89.91	85.833 0	3.16962
	Occlusal	10	92.45	99.72	95.657 0	2.55097
	Internal	10	85.94	91.79	89.738 0	1.98751
Group II	Marginal	10	95.72	111.87	102.21 80	6.06156
	Chamfer	10	127.84	141.84	135.38 90	5.49197
	Axial	10	98.67	107.32	102.33 30	2.88562
	Occlusal	10	143.79	164.23	155.47 20	6.44543
	Internal	10	125.59	136.01	131.06 00	3.79640
Group III	Marginal	10	90.03	102.63	96.615 0	4.14068
	Chamfer	10	114.93	132.11	125.60 40	5.61400
	Axial	10	83.55	92.83	87.924 0	3.34634
	Occlusal	10	133.90	149.86	140.78 00	5.02574
	Internal	10	113.03	123.43	118.09 70	3.20253
Group IV	Marginal	10	87.99	96.51	91.671 0	2.87597
	Chamfer	10	118.51	130.41	124.68 90	4.61586
	Axial	10	98.45	110.45	103.65 30	4.63775
	Occlusal	10	133.74	150.31	143.38 70	5.32759
	Internal	10	120.85	128.57	123.90 60	2.33000

Table 2: One-way ANOVA test for comparison of the gap among the different areas of each group

Groups		ANOVA	d.f	Mean square	F-test	P-value
Group I	Between Groups	212.796	9	23.644	.128	.999
	Within Groups	7366.966	40	184.174		
	Total	7579.762	49			
Group II	Between Groups	482.515	9	53.613	.099	1.000
	Within Groups	21753.939	40	543.848		
	Total	22236.454	49			
Group III	Between Groups	385.430	9	42.826	.090	1.000
	Within Groups	18979.045	40	474.476		
	Total	19364.475	49			
Group IV	Between Groups	209.521	9	23.280	.056	1.000
	Within Groups	16771.807	40	419.295		
	Total	16981.328	49			

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