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Effect of two Blocking Reverse Taper Preparation Methods on the Internal Fit of CAD/CAM Monolithic Zirconia Crowns (An In-vitro study)

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ABSTRACT

Background: Limited data is present on the accuracy of algorithms present inside CAD/CAM software regarding its effect on reverse taper blocking and, furthermore, on its effect on the internal fit. ***Aim****:* To evaluate the effect of two blocking methods of reverse taper preparation (conventional wax blocking and digital software's algorithm) on the internal fit of CAD/CAM monolithic zirconia crowns, and to compare the internal fit between zirconia crowns constructed over blocked preparation, and 12º Total Occlusal Convergence (TOC). ***Material and methods:*** Thirty CAD/CAM monolithic zirconia crowns were constructed over 3D printed dies. They were divided into three groups, each (n=10) according to the degree of TOC ;12 º, -4 º and -8 º reverse taper. Group II and Group III will be further subdivided into 2 sub-groups (n=5) according to the method of reverse taper blocking: A, conventional wax blocking technique, and B, digital method. 3D models were created to simulate a reduced upper molar. All dies were scanned to create STL files. Internal fit was assessed with the silicone replica technique. The Kruskal-Wallis test was used to compare between the groups. Dunn's test was used for pair-wise comparisons when Kruskal-Wallis or Friedman's test was significant. ***Results:*** There was no statistically significant difference between internal gap distance measurements of the five groups and between methods. ***Conclusion:*** Under the conditions of this study, the internal fit of the zirconia crowns constructed over reverse tapered preparations were within the clinically accepted values (300µ) except for -8º digitally blocked specimen (315.6µ).

Keywords: 3D printed dies, internal fit, reverse taper, undercut, zirconia.

INTRODUCTION

Digitalization, obtaining a digital impression, and utilizing computer aided design/computer-aided manufacturing (CAD/CAM) techniques are the future-oriented alternative in the manufacture of dental restorations.[1] Direct CAD/CAM procedures

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and techniques using intraoral scanners (IOS) encompass fewer steps in the impression-making process, consequently eliminating possible error sources.[1,2] With this progression, the usage of zirconia ceramics in the creation of aesthetic restorations expanded quickly.

Zirconia-based restorations may eventually replace metal-ceramic fixed dental prostheses (FDP) because of their great biocompatibility and similar mechanical characteristics.[3,4,5] The higher mechanical properties are due to the smaller grain size and the tetragonal-monoclinic transformation toughening process of zirconia, which results in compressive stresses in the material and decreases fracture propagation.[6,7]

Furthermore, the digital construction method of zirconia gave better control and manipulation over the designing and fabrication of the prosthesis, as well as a superior overall prosthesis than the metal ceramic prosthesis.[8] The superiority came in not only in the form of strength but also in accuracy of fit.

According to the previous literature, multiple factors affect the fit of zirconia copings which include the finish line design, preparation angles, accuracy of the final impression, the master cast fabrication, and the prosthesis fabrication procedures. Also, the process of sintering of zirconia after milling results in shrinkage rates of 30% for zirconia, which affects the accuracy of fit of Zirconia restorations.[9,10]

One of the factors which affects the internal fit of the fixed restorations is the preparation angle.[11] The term 'angulation' refers to the angle of preparation or to the total occlusal convergence (TOC).[12–14] For zirconia-based ceramic restoration, the most desired (TOC) is set to be 12^o.[15] This TOC of 12^o provides the final zirconia-based restoration with favorable path of insertion and facilitates impression taking with precision, and accuracy, whether digitally or conventionally besides, 12^o TOC provides the final restorations with optimal resistance and retention forms.[13,14,16,17]

On the other hand, reverse taper preparation presents multiple complications, such as distortion of the final impression, uneasy seating of the final restoration. It requires overpreparation of the tooth in order to eliminate it.[18,19] As a result, conserving dental structure without jeopardizing the integrity of the final restoration is preferable.[20] Hence, different methods of undercut blocking were introduced starting with conventional wax blocking until the updated ability of the algorithms within different CAD/CAM software.

Internal fit measures the virtual gap created for the cement to be applied. This created gap is set to parameters to control how the crown fits and how the cement flows inside the crown. Seating, fracture resistance, retention, and resistance to displacement forces are all known to be affected by this feature.[21,22]

Different techniques were used to measure the internal gap of fixed restorations, among these techniques is silicone replica technique or the replica method (RT).[23] Many researchers [24–28] have used this approach because it is a very simple, low-cost method that allows measurements to be taken both directly in the mouth cavity and in vitro studies since it does not need specimen destruction.[9] Silicone replica technique is carried out in the same way that a prosthesis is cemented. However, instead of cement, a silicone light body is injected into the prosthesis and then picked up using either heavy or medium silicone bodies. This replica was then sectioned, resulting in a modest number of marginal gap measurements but a wealth of internal gap data.

Up to date, very limited data is present on the accuracy of algorithms within different CAD/CAM software's on its effect on undercuts blocking. Also, on its effect on the internal fit of the fixed restoration. So, the aim of the present study is to evaluate the effect of blocking methods of reverse taper preparation (conventional wax blocking and digital software's algorithm) on the internal fit of CAD/CAM monolithic zirconia crowns, and to compare the internal fit between zirconia crowns constructed over blocked preparation, and 12^{o} TOC. The initial null hypothesis claimed that there was no difference in the internal fit of the zirconia crowns between the two blocking methods (digital and conventional wax blocking) of reverse taper preparation. The second null hypothesis stated that there was no difference in internal fit between zirconia crowns built over blocked Reverse taper and 12^{o} total convergence angle.

MATERIALS AND METHODS

All materials' brand names, description, manufacturers, shade, and lot numbers are shown in **Table (1).**

Samples grouping

Sample grouping is presented in **Figure (1**). Thirty CAD/CAM monolithic zirconia crowns were constructed over 3D printed dies. They were divided into three groups (n=10) according to the degree of total occlusal angle (TOC); Group I (control group): 12 ^{o} TOC, Group II: - 4 ^{o} reverse taper TOC, and Group III (n =10): - 8 ^{o} reverse taper TOC. Group II, and group III were further subdivided into 2 sub-groups (n=5) according to the method of reverse taper blocking: A, conventional wax blocking technique and B digital blocking technique.

Table (1): List of brand names, description, manufacturers, shade and size blocks, and lot numbers used in this study.

Brand name	Description	Manufacturer	Lot number
Zhermach Addition silicone Elite HD+ (putty soft & light body consistencies	Polyvinyl siloxane hydrophilic impression material	Badia Polesine (Rovigo) Italy	390483
ProShape Model Resin	3D print strong, precise grey resin liquid for models fabrication and prototypes	Turkey	
Zirconia Disk Sagemax NexxZr+	(4Y-TZP)	Federal Way, WA98003 USA	
Blocking wax GEO Classic Avantgarde (Renfert)	Grey Opaque Modelling wax	Germany	495-0200

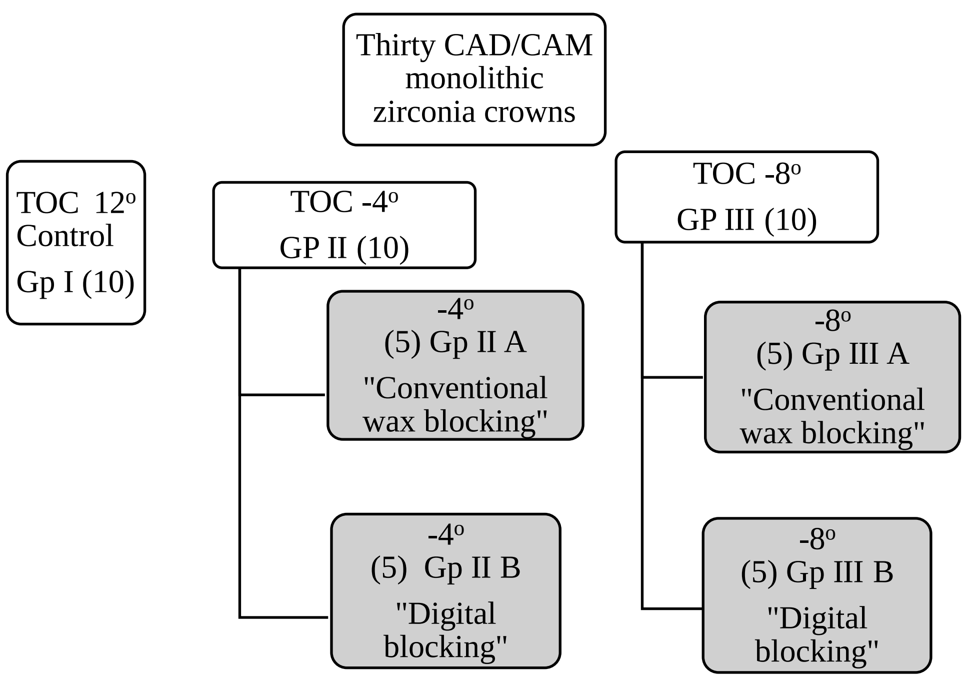
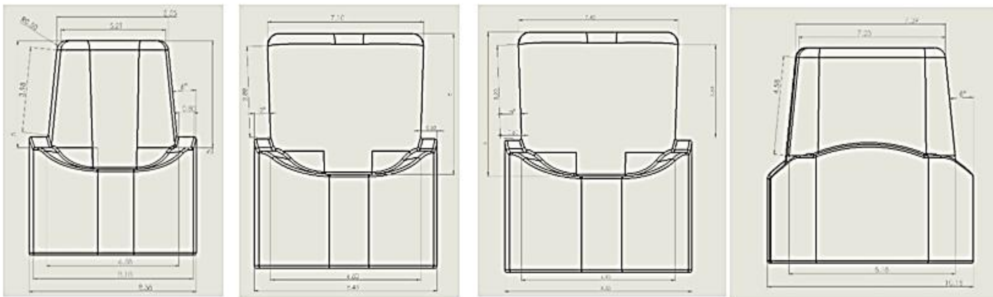


Figure (1): Sample Grouping.

3D Printed Dies Construction

Thirty 3D Printed dies were engineered utilizing SolidWorks **(Figure 2)**.

SolidWorks is developed to create 3D CAD software. The application enables the development and imitation of a reduced tooth (upper molar) with 0.8mm finish line and height of 6mm, as well as the addition of the requisite design characteristics (taper, finish line design, internal surface design and height.[29]

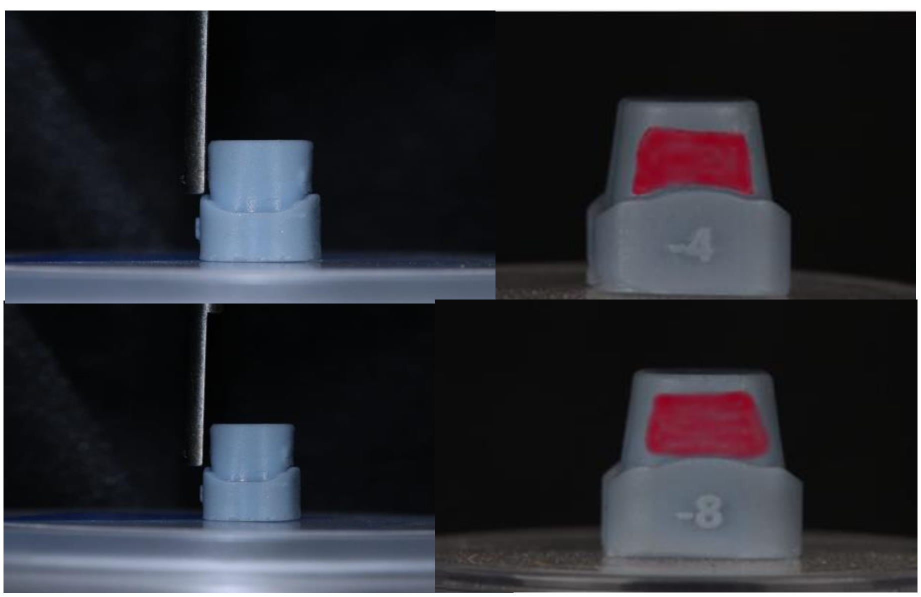


12°	-4°	-8°	Mesial & Distal 12°

Figure (2): Solid works design blue print.

Blocking of Undercuts

Conventional wax blocking was implemented on the 3D printed dies of groups IIA, and IIIA. The dies were placed on the surveyor **(Figure 3)**. The undercut area was then located using the parallel arm and 0° taper tool, and blocked with the wax and the wax trimmer tool.[30] On the other hand, digital blocking undercut was processed for groups II B and III B, 3D printed dies were scanned intraoral scanner Omni cam, and the EXO - CAD software designing program was used to identify and block the undercuts **(Figure 4)**. After conventional blocking of the printed dies of subgroups IIA, and IIIA, the blocked printed dies were scanned with Omni CAM from CEREC intra oral (IO) scanner to create



(A)

(B)

Figure (3): Conventional wax blocking using Surveyor, red areas represent the area blocked by wax. **A;** represents TOC -4° and **B;** Represents TOC -8°.

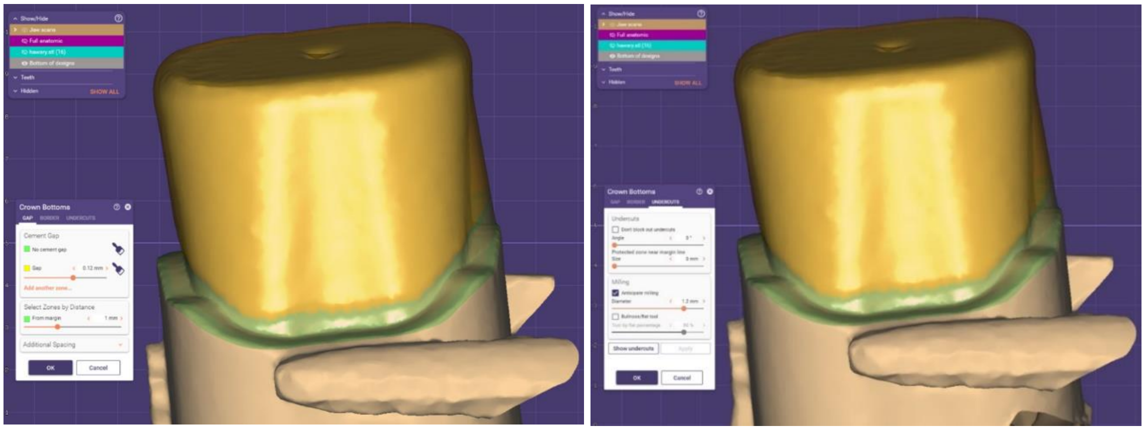


Figure (4): Digital Blocking of Undercuts Using EXO-CAD Software, Arrows mark the area blocked by Algorithm. A; represents TOC -4^o and B; Represents TOC -8^o.

a stereolithography (STL) file.

Construction of Monolithic Zirconia Crowns

Monolithic zirconia crowns were constructed using CAD/CAM technology from the STL files exported from scanning from Omni CAM IO. Full contour crowns were designed using EXO - CAD software. According to the CEREC manual, cement thickness was set to be 120 µm. All Zirconia crowns were milled from Sagemax NexxZr+ (4Y-TZP) disc utilizing Roland DWX-51D 5-Axis Dental Milling Machine.[31]

Internal Fit Assessment

The Silicone Replica Technique was used to assess the internal fit of the zirconia crowns. The zirconia crowns were filled with a light body silicone, and after adapting the crown on the oriented die, finger pressure was maintained until complete polymerization of light body silicone.[32] The zirconia crown was then removed. For the establishment of table cutting, putty body silicone was then loaded over the light body silicone.[23,33] A sharp #11 blade was used to section the silicon vertically and then measured using a digital microscope.[20,32,34–36] Measurements were taken as the mean of five equidistant 5 points of a single proximal wall **(Figure 5).**

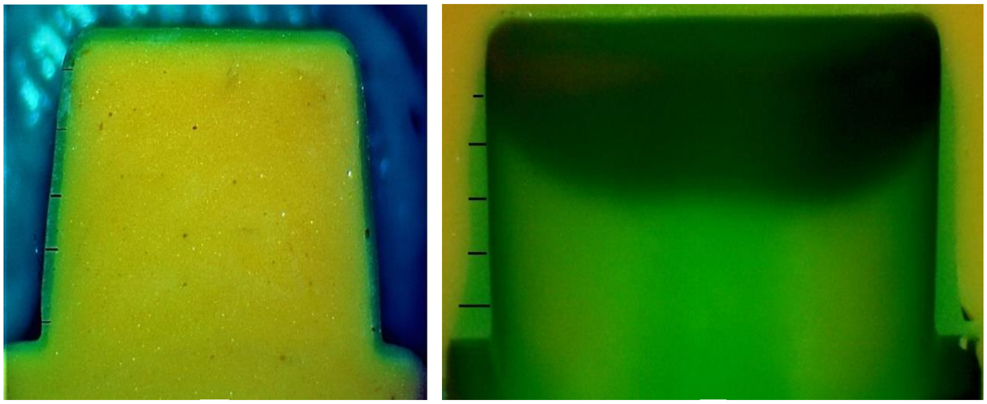
Statistical Analysis

Numerical data were explored for normality by checking the distribution of data and using tests of normality (Kolmogorov-Smirnov and Shapiro-Wilk tests). All data showed non-normal (non-parametric) distribution. Values for the median, range, mean, and standard deviation (SD) were used to show the data. The Kruskal-Wallis test was used to compare the groups. Dunn's test was used for pair-wise comparisons when Kruskal-Wallis or Friedman's test is significant. The significance level was set at $P \leq 0.05$.

Statistical analysis was conducted with IBM SPSS Statistics for Windows, Version 23.0. Armonk, NY: IBM Corp.

Internal fit (µm)

There was no statistically significant difference between gap distance measurements of the two techniques **(Table 3)** and **(Figure 7)**.



A B

Figure (5): Internal Fit Measurement. **A;** represents control group, and **B;** represents dies with undercuts.

RESULTS

There was no statistically significant difference between the internal gap distance measurements of the five groups. As shown in **Table (2)** and **Figure (6)** to compare between conventional (waxed) and digital (unwaxed) groups.

DISCUSSION

Digital dental advancements, particularly in the area of taking impressions, are growing rapidly, and producing more predictable and consistent results.[37,38] Now, the

Table (2): Descriptive statistics and results of Kruskal-Wallis test for comparison between internal gap distance (µm) measurements in different groups.

Group	Median	Min.	Max.	Mean	SD	*P*-value	Effect size *(Eta squared)*
Control Group I	188.7	182.5	198	189.5	5.7	0.069	0.422
-4° Group II B "Digitally blocked"	155.6	63.1	226.8	147.4	62.3		
-8° Group III B "Digitally blocked"	322.4	167.5	458.9	315.4	112.4		
-4° Group II A "Conventionally wax blocked"	215.3	135.6	295.7	213.6	61.6		
-8° Group III A "Conventionally wax blocked"	250	114.6	318.6	232.6	78.7		

Significant level at P ≤ 0.05.

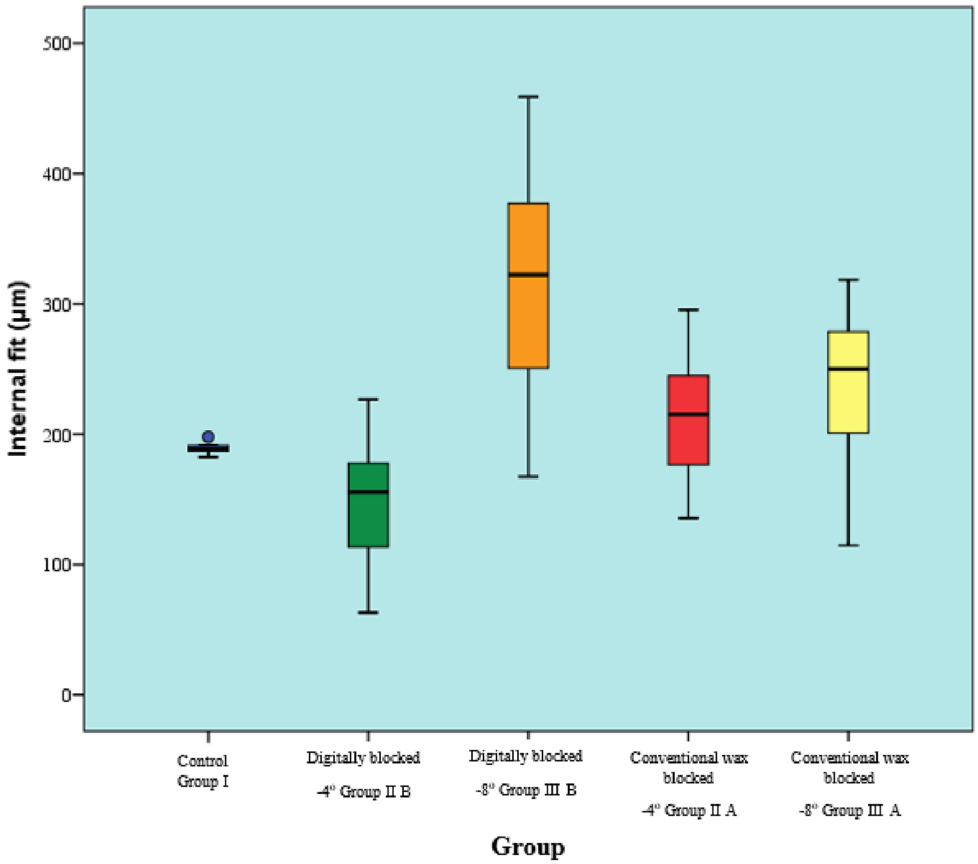


Figure (6): Box plot representing median and range values for gap distances in different groups (Circle represents outlier).

algorithm of the CAD program and the designing software is capable of identifying, analyzing, and, if necessary, correcting any existing undercuts.[18]

Table (3): Descriptive statistics and results of Mann-Whitney U test for comparison between gap distance (µm) measurements of unwaxed and waxed techniques regardless of taper degree.

Technique	Median	Min.	Max.	Mean	SD	*P*-value	Effect size *(d)*
Unwaxed (Digital)	202.3	63.1	458.9	231.4	123.3	0.940	0.034
Waxed (Conventional)	230.1	114.6	318.7	223.1	67.4		

Significant level at P ≤ 0.05.

As a result of these developments, the restoration's general prognosis was enhanced, and the surrounding periodontium was better supported.[39]

The use of zirconia for crown construction in this study is justified by the fact that, among all ceramic crown materials, zirconia shrinks greatly following the sintering process. These volumetric changes may affect the fit of zirconia crowns, especially when constructed over reverse-tapered preparation.[9]

Die printing was accomplished by the Halot 3D Sky printer. The printer has a resolution accuracy of 0.034mm and XY axis accuracy of 0.05mm, making it capable of providing high quality dies with high precision.[40] The material of choice for dental dies is Proshape model resin. It is a 3D resin with a ceramic basis which is characterized by its exceptional dimensional stability and distinctive texture.

Undercut blocking methods were divided into digital and conventional. Digital undercut blocking was carried out by using Exocad software, a highly versatile designing software providing faster workflows and improved proficiency.[43] Whereas conventional undercut blocking was carried out using 1-arm dental parallelometer Surveyor II. It provides easy movement of fixing vise and 360° rotation Along with its superior precision milling, drilling, establishing attached models, and tapping equipment.[44]

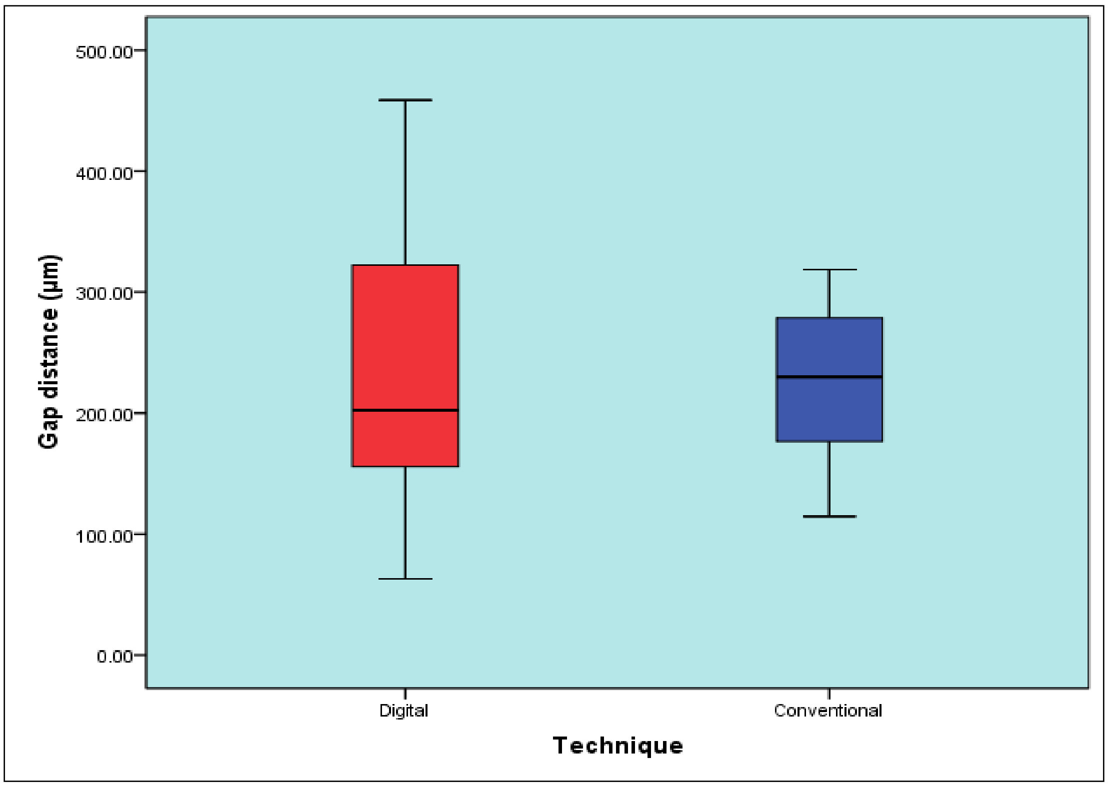


Figure (7): Box plot representing median and range values for gap distances of digital and conventional techniques.

To imitate a real clinical or lab situation for which an STL file is generated to build the crown, each die model used in this study was once scanned by an experienced user utilizing an intraoral scanner.[41] Omnicam IO scanner was used for its remarkable 12.5 ±3.7 µm precision and 13.8 ±1.4 µm trueness.[42]

In the present study, the silicone replica approach was used to assess the internal fit of zirconia crowns. This method, which has been applied in both in vitro and in vivo settings, is non-destructive, exact, repeatable, and reliable method.[18,45–50] Furthermore, due to the fact that zirconia is a hard and highly radiopaque material, destructive methods or micro-CT-based techniques Expensed a lot of money, took a lot of time, or was even impossible. 5 points of measurement were taken unilaterally for evaluation since almost both sides were equal.

In accordance with the findings of the present study, there was no statistically significant difference between the two blocking techniques regarding the internal gap values of zirconia crowns constructed over blocked reverse tapered preparations. Also, no statistically significant difference in the internal gap values of zirconia crowns constructed over blocked reverse tapered preparation and zirconia crowns constructed over 12º TOC preparation. So, the first and the second hypotheses are accepted.

By reviewing the literature, currently there is no consensus on the clinically acceptable internal gap value. Several authors [51–53] reported that 50–100 µm is acceptable, with respect to the physical and clinical properties of resin-based luting agents. Meanwhile, in vitro studies of CAD/CAM ceramic crowns reported that the average internal gap values ranged from 30 to 204 µm is acceptable.[54–56] Other in vitro studies presented clinically acceptable restorations with internal discrepancies between 200 and 300 µm.[52,57] Thus, The mean internal fit values of the tested groups of the present study were within the clinically acceptable range (100-300 µm) except group IIIB (-8º TOC, digitally blocked preparation) which had internal fit values >300 µm.[52,54–57]

The virtual space created at the CAD stage may be behind the non-significant differences between the tested groups. According to **Grajower and Lewinstein.**[58] the cement spacing chosen at the CAD stage has a considerable influence on the crown internal fit. The cement gap of a restoration is advised be set to at least 50 µm, of which 30 µm would be occupied with cement and the remaining 20 µm would permit crown seating in the event to subside any probable manufacturing errors.[15] However, **Boitelle et al.**[59] reported in a meta-analysis that There is no "optimal" cement spacing value that would provide the optimum crown fit regardless of the CAD/CAM system employed; nevertheless, 50 to 60 µm was more frequently reported.

The results of this study disagreed with an investigation performed by Carbajal **Mej́ıa et al**.[18] They discovered statistically significant differences in internal fit values of zirconia crowns with negative and positive TOC. The variation in the results were a result to the difference in the research methodology, the authors used default parameters (50 µm cement space) on abutments with positive TOC angles, whereas 100 µm on abutments with negative TOC angles. While, in the current investigation, 120 µm cement space was used on abutments with positive and negative TOC angles plus a digital block-out of the undercuts following the CEREC manual (Software version 4.6.x) recommendations.[31]

The current study has a number of shortcomings. The present study does not mimic the oral environment and was limited to single intraoral scanner, single designing software and single prosthetic material. Therefore, more studies should be done using the diverse oral environmental and clinical parameters that may significantly affect the final outcome. Furthermore, multiple IO Scanners and other design software should be integrated into future studies. Moreover, investigations are required to evaluate the accuracy of digital undercut-blocking software's algorithm with different ceramic brands, including hybrid ceramics, and lithium disilicates can be assessed with reverse tapered geometry. Additionally, supplementary research should be done about the reverse tapered geometry's impact on fracture resistance, retention, and after-cementation fit.

CONCLUSIONS

The following findings were drawn within the limitations of this in vitro study:

1. The internal fit of the zirconia crowns fabricated on reverse tapered preparations was within clinically acceptable limits. (300µ) except for -8^{o} digitally blocked specimen (315.6µ).

2. Regardless of taper, traditional wax blocking offered superior efficacy to digital blocking in terms of precision.

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CONFLICTS OF INTEREST: The authors say they have no competing interests.

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