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Effect of Digital Blocking of Reversed Tapered Preparations in Comparison to Conventional Wax Blocking on Fracture Resistance of Monolithic Zirconia Crowns

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ABSTRACT

Background: Intra-oral digital scanning can correctly capture single abutment tooth preparations, and the CAD software's algorithms can manage to design restoration for reversed tapered abutment. ***Aim:*** The purpose of this in vitro study was to assess the fracture resistance of CAD/CAM zirconia crowns made on reverse-tapered preparations with two different blocking techniques. ***Materials and methods:*** Thirty dies were 3D printed using SolidWorks software. Blocking reverse taper preparation, was done with two different blocking techniques; conventional wax blocking and digital blocking. Group II (B) (-4 TOC) n=5 and group III (D) (-8 TOC) n=5 underwent conventional wax blocking, Group II (C) (-4 TOC) n=5 and group III (E) (-8 TOC) n=5 used the software's algorithms (Exocad) to block undercuts digitally, and Group I (A) (12 TOC) served as the control (n=10). Thirty dies were individually scanned, and separate design was made for each die (Generic type); scanning was done with Cerec Omnicam intraoral scanner. Thirty CAD/CAM monolithic translucent zirconia crowns were milled with 120µm of cement space. Cementation was done using self-adhesive resin cement (Thera-Cem). Fracture test was done using universal testing machine. SEM analysis was used to identify crack origins and propagation directions, and intra and intergroup analyses were performed of fractured parts. ***Results:*** Only the tapering angle had a significant effect on fracture resistance (p=0.012). ***Conclusion:*** There was no significant difference between digital or conventional blocking nor their effect on the fracture resistance test, 12◦ TOC control group showed the highest fracture resistance, and -8◦ TOC showed the least.

Keywords: Fracture resistance, Fractography, Monolithic zirconia, Reversed taper preparations, 3D printing technology.

INTRODUCTION

The degree of preparation taper will, of course, determine the thickness of the restoration. This will change based on the material selection and the restoration part

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(e.g., occlusal, axial, or margin). Balancing between preserving tooth tissue and creating enough room for a durable, biocompatible restoration is frequently challenging when performing tooth preparation, whether for adhesively bonded or traditionally cemented restoration.[1] Convergence angle is the angle formed between each of two opposing axial walls of a tooth prepared to receive a crown restoration. It determines the taper of the prepared tooth. Convergence(taper) angle affects the load tolerance of the restorations, avoiding its damage. Most commonly, a convergence angle of 5–6 degrees is chosen to provide the desired retention, while less than 5-6 degrees is considered reversed taper (undercut).[2] A study by Sadid-Zadeh et al.,[3] found that 67% of posterior teeth prepared for monolithic zirconia crowns lacked proper path of placement due to an undercut at the axial wall. Management of reversed tapered preparation can be done conventionally (by manual blocking) or digitally depending on the degree of taper. Furthermore, if an undercut is recorded during the first stage of a fully digital workflow, the clinician can either remove more dental structure (overprepare) to obtain a tapered preparation or, whenever possible, use the CAD software's algorithms to overcome (i.e., digitally blocking out undercuts or changing the path of insertion of the crown). Naturally, preserving dental structure without jeopardizing the integrity of the final restoration is desirable, provided that the design software can manage undercuts successfully.[4] Ceramics are the focus of research and development; they are basically classified according to composition: glass matrix, polycrystalline and hybrid ceramics. The available ceramics are Feldspathic (glass matrix), Lithium Disilicate (synthetic glass), Zirconia reinforced Lithium Silicate (synthetic glass), Zirconia (polycrystalline), and finally Hybrid ceramics.[5]Dental zirconia is composed of approximately 90% zirconium dioxide and 10% other oxides, such as yttrium oxide, aluminum oxide, and magnesium oxide. These other oxides are added to improve the mechanical properties of the material, such as its strength, toughness, and resistance to wear.[6] To get the desired shade, different powders are applied, like how tints are used to paint to generate color in a base tone.[5] Yttria-stabilized tetragonal zirconia (3Y-TZP) was brought to dentistry because of its remarkable strength and color that closely resembles teeth. The original purpose of using 3Y-TZP, however, was for frameworks for crowns and fixed dental prostheses (FDPs), but because it is opaque, they are veneered with feldspathic porcelains. The main technical issues that have been documented are veneer chipping and delamination, which are linked to residual heat pressures brought on by the production process, differences in the coefficient of thermal expansion (CTE) between the zirconia substructure and the veneering ceramic, improper framework design, rapid cooling rates and low fracture toughness and flexural strength of veneering ceramic compared to the zirconia core.[7] A possible solution that has been proposed is monolithic zirconia. Compared to natural teeth, a typical monolithic 3Y-TZP restoration would be highly opaque. Reduced light scattering by impurities and grain boundaries was achieved by raising the sintering temperature and using fewer Al2O3 sintering aids, among other measures, to increase translucency.[8] Compared to other dental ceramics, the 4Y-TZP zirconia has a flexural strength of over 1,000 MPa and a fracture toughness that helps prevent chipping and fractures during clinical use. In addition, its translucency and tooth-colored appearance allow it to fit in perfectly with natural teeth for restorations which appear magnificent. 4Y-TZP zirconia is a useful material for modern restorative dentistry because of its blend of mechanical strength and aesthetic characteristics, which allows for the creation of long-lasting and natural dental prostheses.[9,10]

The most frequent problems with zirconia crowns are fractures and loss of retention. Monolithic zirconia crowns have been developed, which has lessened the issues with chipping and delamination and preservation of more tooth structure. The optimum scenario from a biological standpoint is to remove as little tooth material as feasible.[11] 1 mm thickness of zirconia crown has strength comparable to that of conventional metal-ceramic crowns. Crack initiation and propagation of zirconia are influenced by the restoration's design, the size and distribution of material defects, residual stress, low thermal degradation, ceramic-cement interfacial characteristics, wall thickness, elastic moduli of the material, and forces applied.[11] Numerous studies show that fractures starting in the crown margins are the leading cause of failure for all ceramic crowns. Therefore, it is likely that margin or axial wall thickness matters more influencing fracture resistance than occlusal thickness.[11] Different aspects of the preparation can affect the stress distribution of the restoration and hence its fracture resistance. Among these aspects the taper of the preparation, amount of occlusal reduction, and finish line configuration are the most significant. Data concerning the effect of blocking undercuts is important to learn. Therefore, this study was designed to reflect blocking effects on the mechanical behavior of milled monolithic translucent zirconia crowns.[4,11–13]

(Null hypothesis):

1- Techniques of blocking reverse taper using conventional wax blocking or digital blocking will show no difference in fracture resistance of monolithic translucent zirconia crowns.

2- There will be no difference in fracture resistance of monolithic translucent zirconia crowns between different preparation angles.

MATERIALS AND METHODS

Thirty 3D printed dies taper 12, -4, -8 were engineered utilizing SolidWorks. SolidWorks is developed to create 3D CAD software. The addition of the required design characteristics (taper: 12, -4, -8, finish line design: 0.8mm chamfer, internal surface design: 1.5mm occlusal and 1mm axially and height: 6mm) were fed into the software to produce the STL file, then printed with the aid of SLA 3D printer Halot sky **(Figure 1).**

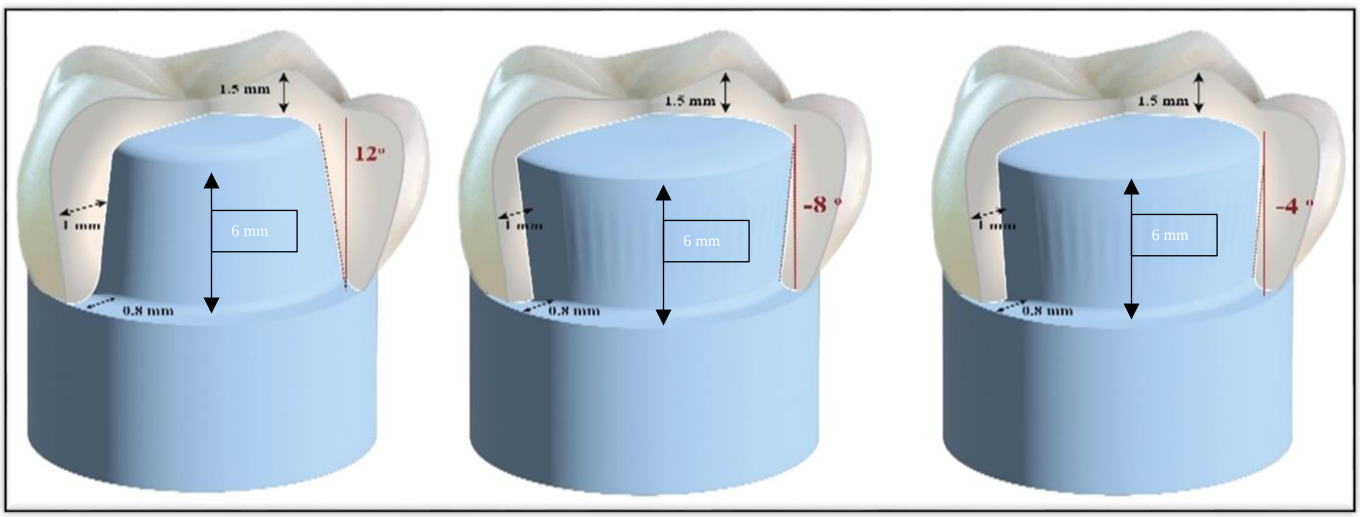

Figure (1): Different tapering angle of samples.

3D printed dies, then divided into three groups (n=10) according to the degree of total occlusal convergence angle (TOC) as seen in **Figure (2)**.

- Group I (control group) (n =10): 12 º total occlusal convergence.

- Group II (n =10): - 4 º reverse taper TOC.

- Group III (n =10): - 8 º reverse taper TOC.

Group II and group III were further sub-divided into 2 sub-groups (n=5) according to the method of reverse taper blocking.

- Group II B & Group III D conventional wax blocking technique
- Group II C & Group III E digital blocking technique.

Dies were divided into groups for different blocking techniques. Group **B** (n=5) and **D** (n=5) underwent conventional wax blocking using a dental surveyor. The preparations were assessed on the surveyor using the paralleling arm as shown in **Figure (3)**.

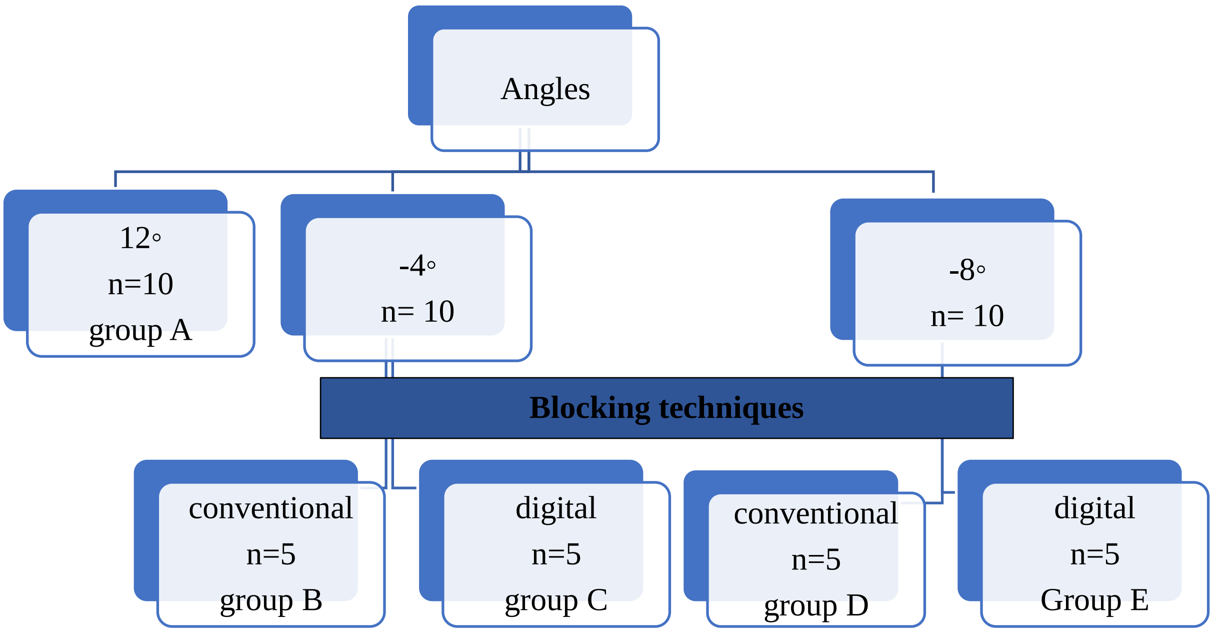

Figure (2): Sample Grouping.

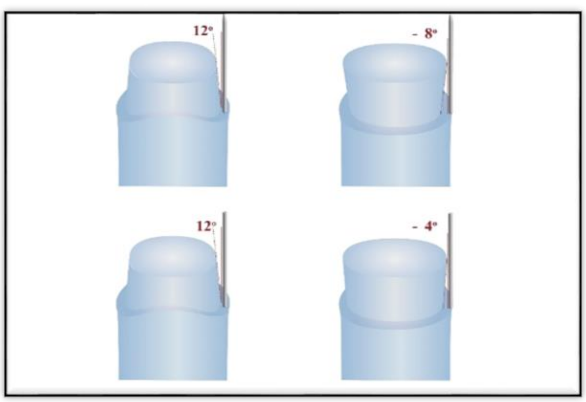

Figure (3): Negative tapers were first surveyed.

Wax was added in the detected areas of the reverse taper, and the wax trimmer tool of the surveyor was held parallel to the long axis of the die to remove the excess wax, and hence, the undercut was blocked.

Groups **C** (n=5) and **E** (n=5) were scanned using Cerec omnicam Intraoral scanner. The generated STL files were then managed using the software's algorithms (Exocad) to block the existing undercut digitally, allowing for complete blocking of the undercut. Group **A** (n=10) served as the control. Group B & D conventionally blocked dies were digitalized (scanned) after blocking into STL files using (CEREC OMNICAM)[1] intraoral scanner, while Group C & E were scanned without blocking and were digitally blocked by software; all were done by the same opera-

[1] Dentsply Sirona. Germany

tor.

Afterwards, thirty CAD/CAM monolithic translucent zirconia crowns were designed (Generic type) using dental CAD software (Exocad; Exocad GmbH, Darmstadt, Germany)[2] with **120µm** of cement space and milled using utilizing Roland DWX-51D[3] Dental Milling Machine. After milling of crowns, specimens were cleaned by steaming to remove residues and sintering at high temperatures for 3.5 hours. Try in of each crown for proper seating on their corresponding die, then polished by NexxZr shine polishing paste and kit, and glazed by NexxZr glaze spray according to manufacturer recommendations. Then Sandblasting was carried out using Al2O3 particles size 50 µm for 15 seconds at a pressure of 2.5 bar perpendicular to the bonding surface at a 10 mm working distance by using an air abrasion unit[4] according to the manufacturer's recommendation.[14]

All zirconia crowns were ultrasonically cleaned in 99% isopropanol for 3 minutes. Afterwards, Self-Adhesive Resin Cement (TheraCem) was applied to the internal surface with its application tip at an angle of 45 to avoid voids. A cementing device was used to hold each specimen and maintain a constant seating pressure parallel to the longitudinal axis of each tooth sample during the cementation procedure. Each cemented crown was vertically loaded with a 4 kg static load, then the surfaces of each sample were photo-polymerized for 3 seconds (tack curing), and the excess cement was removed; after that, every surface was photo-polymerized for 20 seconds following the manufacturer's recommendations. Then, each cemented crown was kept under the load for 5 minutes.[15,16] All steps were standardized and performed by the same operator. Each sample was placed independently on a computer-controlled materials testing machine (Model 3345; Instron Industrial Products, Norwood, MA, USA). Samples were mounted on the universal testing machine and fixed to its lower compartment. A metallic rod with a round tip (5.8mm in diameter) was attached to the upper compartment of the testing machine to apply occlusal load at the central fossa using a compressive mode at a cross head speed of 1 mm/min and a 1 mm thick tin foil was placed between the indenter and the specimen.[17]

Loading was carried out till an audible crack manifested and a dramatic decline of load deflection was noticed, both of which were recorded using computer software

[2] Exocad, Darmstadt, Germany.
[3] Roland DG Corporation, Japan.
[4] Basic Classic, Renfert, Germany.

(Bluehill Lite Software Instron® Instruments)[5] indicated the load at failure. The necessary force that caused the fracture was recorded in Newtons.

Fractured specimens were analyzed using SEM to identify crack origins and propagation directions, with various distinguishing features such as hackles, compression curls, and arrest lines being identified.

RESULTS

In the present study, only the tapering angle had a significant effect on fracture resistance (p=0.012), while the effect of the blocking technique and its interaction with the tapering angle was not statistically significant (p>0.05). The results are summarized in **Table (1) and Figure (1).**

Numerical data were presented as mean and standard deviation (SD) values. They were explored for normality by checking the data distribution and using Shapiro-Wilk test. The data showed parametric distribution and were analyzed using two-way ANOVA followed by Tukey's post hoc test. A comparison of main and simple effects was done utilizing one-way ANOVA followed by Tukey's post hoc test and the pooled error term of the two-way model. P-values were adjusted for multiple comparisons utilizing Bonferroni correction. The significance level was set at p < 0.05. Statistical analysis was performed with R statistical analysis software version 4.3.0 for Windows. **Conventional:** There was no statistically significant difference between all groups, although there was a difference in the values, as shown in **Figure (4) and Table (1)**.

Table (1): Intergroup comparisons, mean and standard deviation values of fracture resistance (N) for different tapering angles within each blocking technique.

Blocking technique	Fracture resistance (N) (mean±SD)			p-value
	-4°	-8°	12°	
Conventional	1018.28 ± 105.94^A	979.91 ± 35.09^A	1185.39 ± 236.61^A	0.094ns
Digital	987.88 ± 202.02^A	917.28 ± 271.80^A	1185.39 ± 236.61^A	0.111ns

Means with different superscript letters within the same horizontal row are significantly different.
***; significant (p ≤ 0.05).** ***ns**; non-significant (p>0.05).*

SEM images of all samples showed that the occlusal surface was the source of the fracture. In **Figures (5), (6), and (7)**, the

[5]© Illinois Tool Works Inc. 825 University Ave Norwood, MA, US.

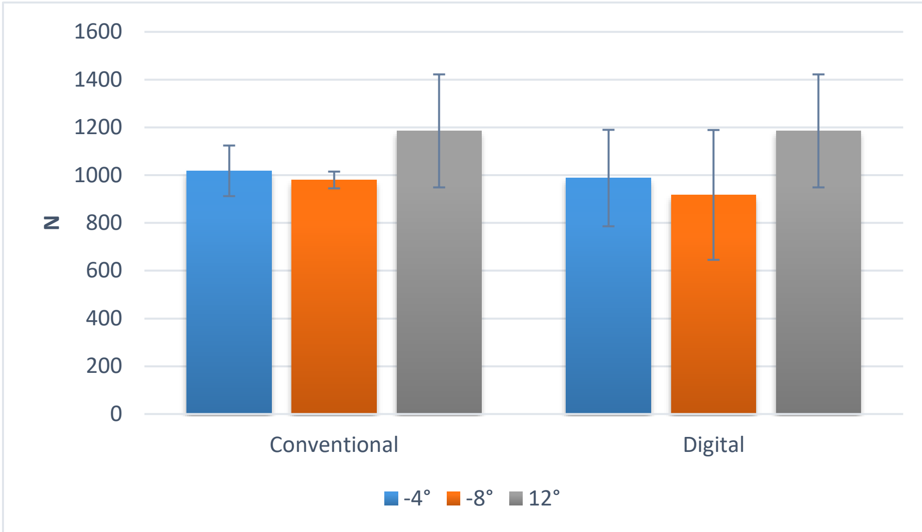

Figure (4): Bar chart showing average fracture resistance (N) for different tapering angles within each blocking technique.

crack origin has been indicated by mirror regions where the hackle lines that appear help in identifying the crack propagation.

DISCUSSION

Few studies evaluated the effect of the undercut blocking algorithm of the CAD software on the fracture resistance of dental crowns fabricated over conventional and reverse-tapered preparations. Digital fabrication techniques are very well recognized and are effectively replacing traditional methods. These approaches enable the manufacture of restorations using virtual models and dies using CAD software without the necessity for a working model, followed by digital manufacturing (CAM) processes that are either subtractive (milling) or additive (3D printing).[18]

Accordingly, the preparation taper of different groups was done by software and 3D printing to accomplish standardizations of samples within the same group. The die material used was Proshape 3D printed material with modulus of elasticity 2.5 GPa, which is the closest to dentin in all other printing resins. Using natural teeth instead of dies was impractical due to their varying ages, storage conditions, forms, and sizes. In our study, Proshape 3D printing material was used for the following reasons: 3D printing offers precision and customisation. Time-saving operations and reliable results are achievable by the technology's capacity to handle complicated geometries, consistency, and reproducibility. By using additive manufacturing, 3D printing reduces material waste and offers a sustainable substitute for subtractive techniques.[21] Cerec omnicam intraoral scanner was used in order to mimic

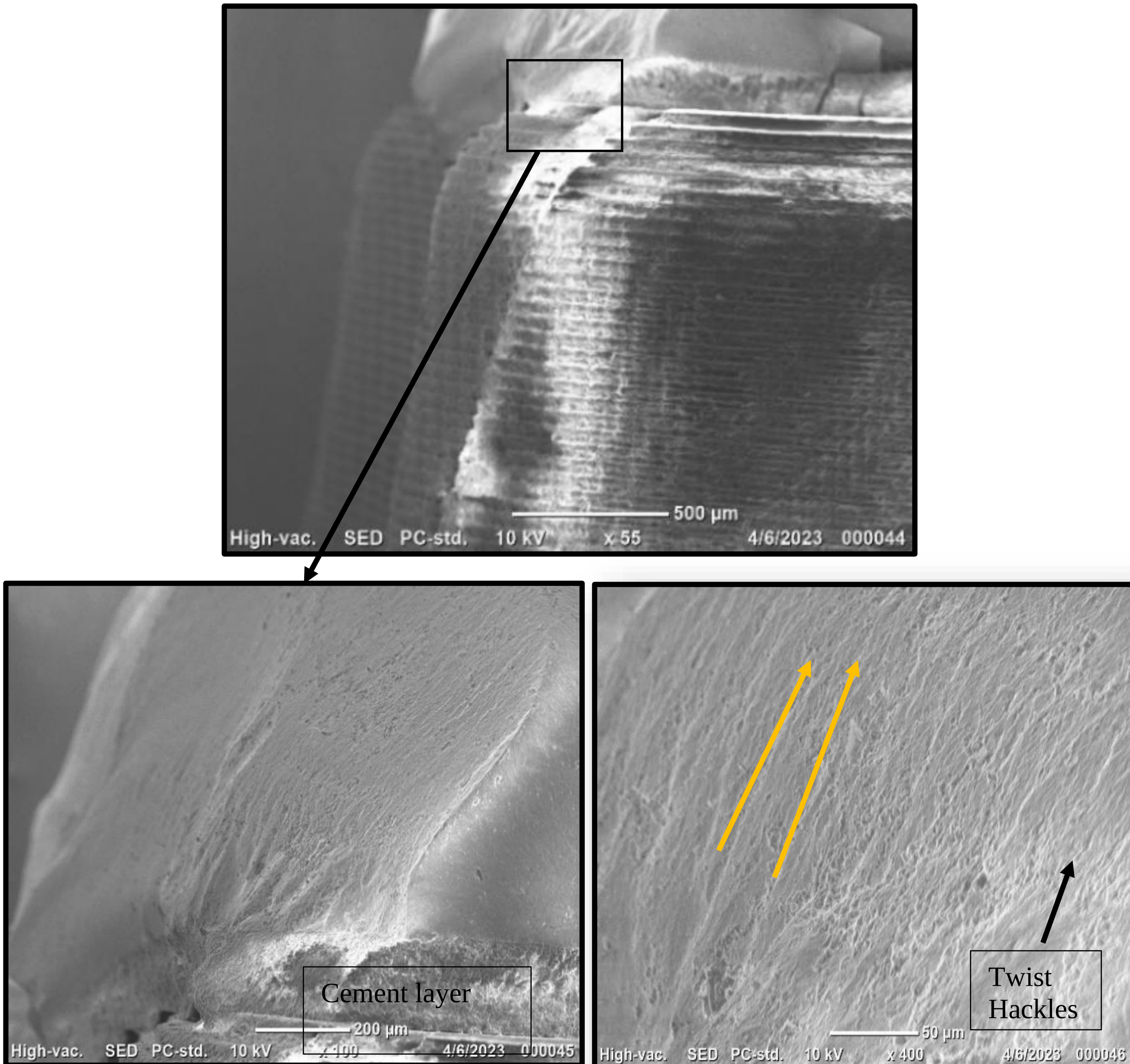

Figure (5): SEM images of group A with 12 angle TOC, showing arrest lines semi-circular line segments resulting from crack arresting episodes. The concave side of arrest lines is turned to the crack initiation location, which also helps to determine crack origins. Twist Hackles are lines originating from local changes in the axis of principal tension and can be triggered by geometrical variations and local stress gradients. In smooth fracture surfaces twist and wake hackles indicate the direction of crack propagation, thus helping to track the location of crack initiation. Yellow arrows indicating Direction of Crack propagation.
This fracture origin is classified as Radial Crack (internal surface).

the clinical situation of the digital workflow in terms of marginal reduction, marginal design, finish line homogeneity, and undercuts.[22] Clinically, a restoration with a cement gap of 120 µm has been prefered to allow for satistfactory designing of the crow-

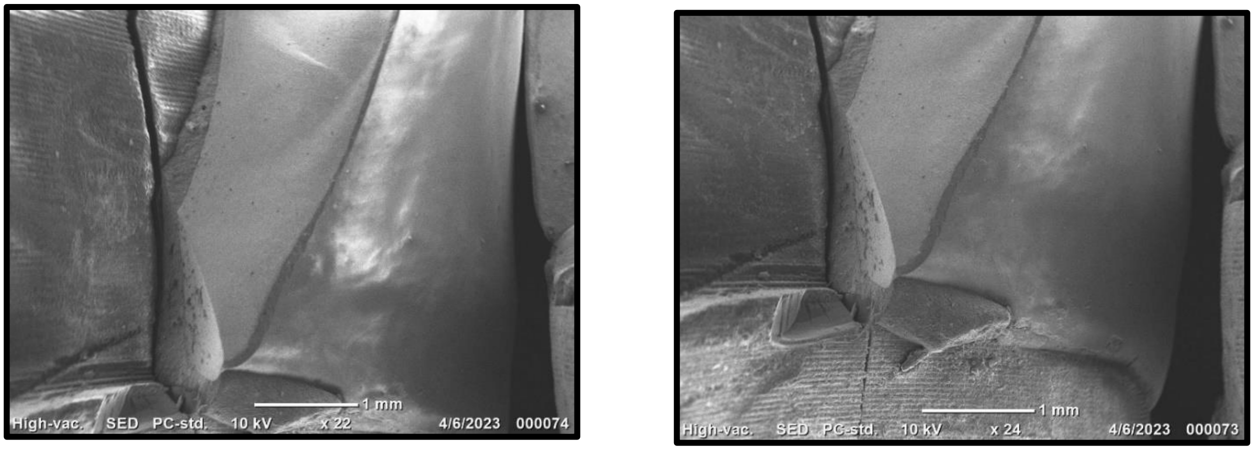

Figure (6): SEM images of group C (-8 W) Right Cervical area showing separation of die that completes till the cervical area with no other sign of cracks of restoration. (catastrophic fracture).

ns on the CAD software.[23]

The current study employed airborne particle abrasion with alumina particles (sandblasting) to raise the zirconia crown's surface energy, wettability, and roughness. Furthermore, it was noted that hydroxyl groups are produced on the surface of zirconia by airborne particle abrasion with alumina particles, which will facilitate bonding with self-adhesive resin cements. A durable resin-zirconia bond was achieved by using airborne particle abrasion in combination with resin cement based on phosphate monomer.[24]

In the present study, self-adhesive resin cement (TheraCem) was selected because it contains MDP, an adhesion-promoting monomer that enhances the bond strength to zirconia without the use of an additional dental adhesive or primer. It also offers a high degree of conversion for increased strength.[25,26,24]

The results found in the present study proved that reversed taper preparations influence the integrity of the overlying crowns. This may be due to the forces applied at the center of the occlusal surface that are transferred to the internal angle of mesial and distal sides (as found in the SEM pictures) which caused cracks and fractures in some. This can be illustrated that a compressive stress (applied stress) at the center was converted to tensile stresses to the sides because zirconia crowns at this point had less thickness than the control group (12 angle) which was not supported enough to withstand these stresses even if they were blocked out digitally or conventionally. Choosing (4Y-TZP) monolithic zirconia was done because of its fracture strength that exceeds 3000 Newton and its optimum translucency, allowing for its use as a monolithic posterior restoration.[7,27,28, 29] have reported that increasing the TOC angle to a limit can improve the fracture resistance

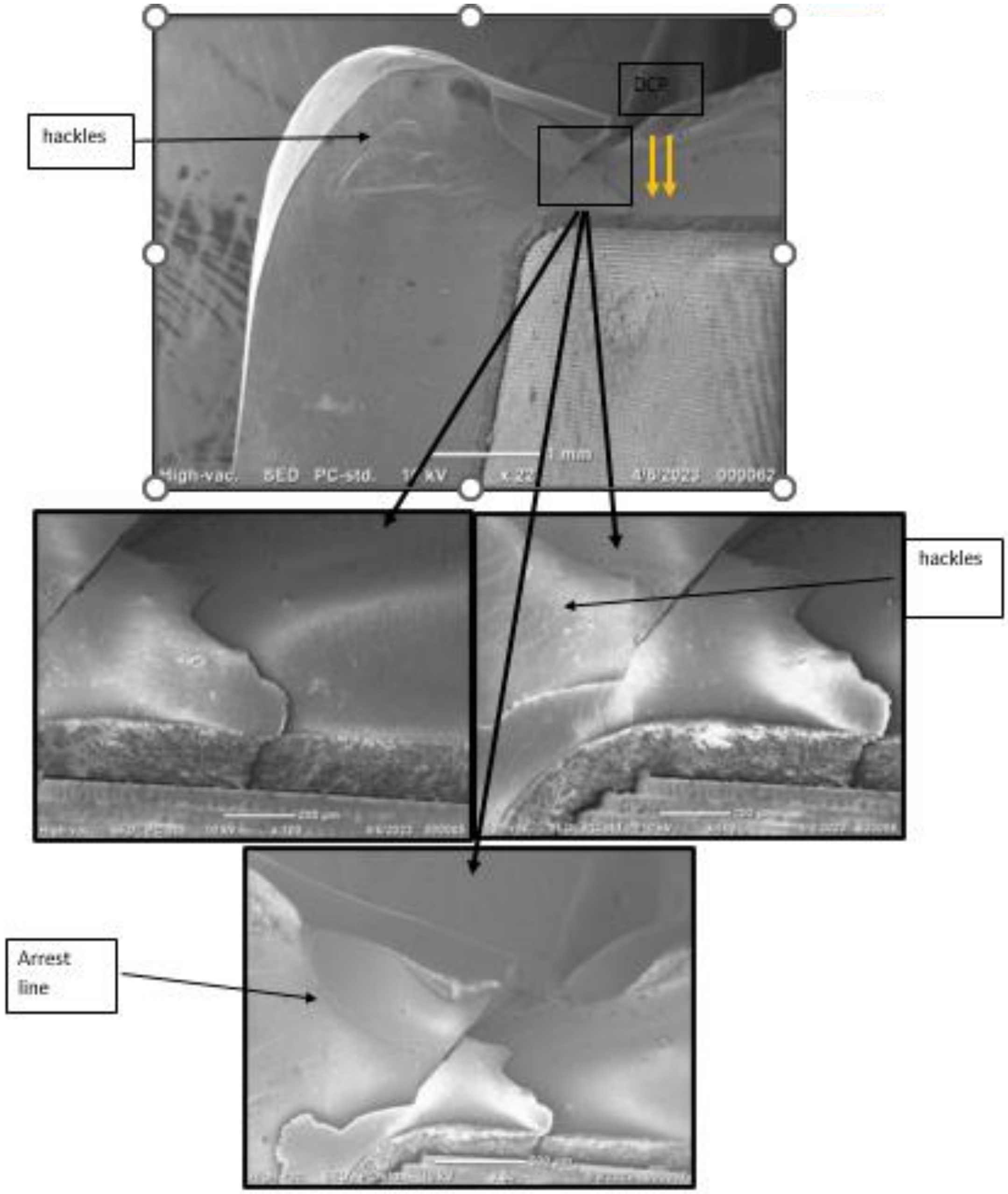

Figure (7): SEM of -8 Digitally blocked showing multiple cracks at the upper left angle of the restoration.

of zirconia crowns. In- contrast, a lower TOC angle can lead to increased stresses and reduced fracture resistance.[30] A study by Schriwer et al.,[11] evaluated the effect of TOC on

The relationship between total occlusal convergence (TOC) and the fracture resistance of zirconia crowns has been extensively studied in literature. Several studies the fracture resistance of zirconia crowns. The authors found that increasing the TOC angle to 30 degrees significantly improved the fracture resistance of the crowns. The authors attributed this improvement to a more favorable stress distribution pattern with a higher TOC angle. However, the reverse taper has a negative influence on the fracture resistance of the crown.

On the other side, Mejia et al.,[2] in his study demonstrated that the axial discrepancy (axial fit) in the -8 reversed taper preparations was increased up to 298µm which is higher than the control group TOC 12 (74.8µm) and TOC -4 (130.8µm). Therefore, this result could be attributed as the rationale behind the decrease in the fracture resistance of this group in the current study.

Universal Testing Machine was used to determine the material's ability to withstand forces and prevent failure. 1 mm thick tin foil was placed between the indenter and the specimen to evenly distribute stress. Different tooth preparation tapers affect fracture resistance of crowns, with taper 12 having the highest value, followed by -4 and the lowest value of -8. Fractography analysis identifies fracture sites, which can be caused by material deficiency, design deficiency, or in situ stress-induced conditions. Fracture origins can be classified into occlusal surface, internal surface, and crown margin cracks.[14,17,31–33] In this study, analysis of fractography revealed that -8 samples, both digitally and conventionally blocked, were both free of cracks internally and externally at the margin cervically, but they were affected internally at the top angle right and left. This may be due to stresses induced by the applied forces of the universal testing machine that lead to the escaping of stresses to the upper angles of the restoration internally, causing cracks. (-8) samples showed more aggressive crack propagations and fractures than from -4 and 12 angles, possibly due to the reversed preparation difference.

The lack of arrest lines other than those below the contact suggests that a large amount of energy was released during crack propagation, resulting in a high crack velocity.[34] Schriwer Ch, et al.,[11] concluded that, the load at fracture of monolithic zirconia crowns was lowered by a considerable preparation taper. A bigger pre-defined cement area improved seating but had no effect on fracture load.

According to the results of this study, the first Null Hypothesis was accepted, while the second Null Hypothesis was rejected.

Limitation of this study: Future studies are necessary to assess the effect of thermo-mechanical loading, and test several variables associated with the main objective of the research. Different softwares and intraoral scanners should be assessed for digital blocking of the undercuts.

CONCLUSION

Within the limitation of this study, the following could be concluded:

There was no difference between digital blocking of the undercut technique and conventional blocking. Digital or conventional blocking of the undercut did not affect the fracture resistance of the monolithic translucent zirconia crown. The tapering angle of the preparation did affect the fracture resistance of monolithic translucent zirconia crowns. Where 12◦ TOC control group showed the highest fracture resistance and -8◦ TOC showed the least.

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CONFLICTS OF INTEREST: The authors declare no conflict of interest.

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