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Original Article

ASSESSMENT OF MARGINAL ACCURACY AND FRACTURE RESISTANCE OF GLASS CERAMIC CROWNS AS PRODUCED BY TWO MILLING PROTOCOLS (4-AXIS VERSUS 5-AXIS)

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Abstract

Aim: Investigate the impact of two different milling protocols on the marginal accuracy and fracture resistance of advanced lithium disilicate glass-ceramic crowns.

Subjects and methods: A typodont model was prepared following all-ceramic crown preparation principles. Crowns were fabricated using CEREC Tessera and then divided into two groups, each consisting of nine crowns: Group A (4-axis CEREC MCXL) and Group B (5-axis MCX5). The marginal accuracy was assessed at 30× magnification using a stereomicroscope. The fracture resistance was evaluated using a universal testing machine after crown cementation.

Results: Group A (4-axis CEREC MCXL) exhibited significantly higher marginal accuracy (140.46 µm) compared to Group B (5 axis MCX5) (109.68 µm). Fracture resistance showed no significant differences between the groups.

Conclusion: : The number of CAD/CAM axes influences the marginal accuracy of advanced lithium disilicate glass-ceramic crowns, with the 4-axis milling machine demonstrating higher marginal accuracy compared to the 5-axis machine. However, there were no significant differences in fracture resistance between the two groups.

Keywords: Marginal accuracy; Fracture resistance; CAD/CAM system; Glass ceramics; CEREC Tessera.

Introduction

The marginal accuracy of the final restoration determines its success from both a biological and mechanical aspect. A large marginal gap can result in postoperative sensitivity, mechanical failure, secondary caries, margin discoloration, and an unpleasant aesthetic appearance. Marginal accuracy refers to the precision of a dental restoration along the margin of the prepared tooth, evaluating its adaptation to the tooth without discrepancies at the interface.[1]

Various factors influence the marginal accuracy of CAD/CAM restorations, including milling precision, scan and design parameters, manufacturing techniques, and firing which can impact ceramic materials' accuracy as exposure to high temperatures can induce dimensional changes in some ceramics. However, not all CAD/CAM materials undergo this process, so its influence varies depending on the material and fabrication method.[2]

Fracture resistance is a crucial parameter in assessing the durability and long-term success of dental restorations, reflecting their ability to withstand mechanical forces without fracturing. This parameter is significant in evaluating the durability, reliability and performance of dental materials and restorations.[3]

Lithium disilicate glass ceramic is preferred for both anterior and posterior restorations due to its outstanding mechanical and aesthetic properties. The recent introduction of advanced lithium disilicate glass-ceramic CEREC Tessera has achieved a flexural strength exceeding 700 MPa and enhanced aesthetics, attributed to its composition of virgilite crystals.[4]

It is still a debate if increasing the CAD/CAM milling axes will improve the marginal accuracy and mechanical properties of restorations or if it will only be useful in highly complex dental restorations. The current study aimed to assess the impact of two milling protocols Group A (4-axis CEREC MCXL) and Group B (5-axis MCX5) on the marginal accuracy and fracture resistance of advanced lithium disilicate glass-ceramic crowns. The first null hypothesis was that there would be no difference in marginal accuracy between advanced lithium disilicate glass-ceramic crowns milled with 4-axis versus 5-axis protocols. The second null hypothesis was that there would be no difference in fracture resistance between crowns milled with 4-axis versus 5-axis protocols.

Subjects and Methods

Sample size calculation

Based on previous work by (Manmohan, 2017)[5] a sample size of 9 in each group was determined to have 95% power to detect a mean difference of 4.47 with a significance level (alpha) of 0.05 (two-tailed). This ensures that in 95% of experiments, results with a p-value less than 0.05 (two-tailed) will be considered statistically significant, while in the remaining 5%, the difference will be deemed not statistically significant.

Preparation of Typodont tooth

Following the principles of all-ceramic crown preparation, a full coverage posterior crown was prepared on a maxillary right first molar of a typodont model (NISSIN, Kyoto, Japan).[6] Preparation was performed by one investigator with a 2 mm occlusal reduction and a 1.0 mm circumferential rounded heavy chamfer finish line following the manufacturer's recommendation. **(Figure 1)** All the preparation had a 0.5-mm supra-gingival margin. The uniformity and the amount of reduction were assessed using both the putty index, which was made before preparation, and the CEREC intraoral scanner.

Figure (1): The typodont tooth all -ceramic crown preparation

Duplication of Typodont tooth to obtain epoxy resin dies

REPLISIL Silicone Rubber 22 N (Dentona, Hünfeld, Germany) was used to create a silicon index. Equal parts of its two components were mixed and poured into a glass container, embedding the prepared tooth to form the mold. After mold setting, the tooth was removed, and KEMAPOXY epoxy resin (CMB Group, Cairo, Egypt) was poured into the silicon mold. Upon setting, the resin was removed from the mold. This process was repeated to produce 18 epoxy resin duplicates of the typodont. **Figure (2**)

Figure (2): The duplicated epoxy resin die

Scanning and designing

The data entry was configured in the CEREC Primescan acquisition unit (Sirona, Pennsylvania, USA) in the administration phase. Using the Primescan intraoral scanner (Sirona, Pennsylvania, USA), a single scan of the master typodont prepared tooth was performed to generate a color 3D model. Subsequently, the Connect SW 5 acquisition software (Sirona, Pennsylvania, USA) produced a virtual 3D model, while the In-Lab CAD 22.0.0 software (Sirona, Pennsylvania, USA) facilitated crown design. The process was started by defining the insertion axis of the restoration, followed by outlining the preparation margin. Design parameters were standardized for all 18 crowns across both groups, with an 80µm radial spacer. After parameter adjustment, a virtual 3D model of the proposed conventional crown design was displayed, and the crown data was exported to the In-Lab cam software (Sirona, Pennsylvania, USA) to initiate milling.

Milling

Group A (4-axis CEREC MCXL): Grinding of the crowns from CEREC Tessera MT A3 C14 blocks (Sirona, Pennsylvania, USA) using step bur 12S (tip diameter: 1.35 mm) and cylinder pointed bur 12S (tip diameter: 1.75 mm) for wet grinding. Step bur was employed for inner surface grinding, while cylinder-pointed bur was used for the outer surface, taking approximately 14 minutes.

Group B (5-axis MCX5): Grinding was fully automated using three successive burs (Diamond 2.2 mm, 1.4 mm, and 1.2 mm) with copious water coolant. The process lasted around 60 minutes, during which the MCX5 constructed 7 crowns before requiring a change of the 1.4 mm grinding bur.

Glazing

Following manufacturer's instructions, thin and even coat of Universal Overglaze paste (Sirona, Pennsylvania, USA) was applied to all sides of the crowns then were air-dried for 10 seconds before insertion into Multimat NTXpress furnace (Sirona, Pennsylvania, USA) at the recommended program.

Marginal accuracy measurement

The seated CEREC Tessera crowns and their corresponding dies were aligned perpendicular to the stereomicroscope's field of view (Nikon MA 100, Whitman, Melville) with 30× magnification. [6] Three measurements were taken for each surface at three predetermined reference lines at equal distance with the help of a micrometer ruler and were separately analyzed. **Figure (3)** to ensure precise alignment and stabilization during the testing procedure, a custom-made holder with a special pin to lock the crowns in place on their corresponding epoxy resin die was used. [7] A total of 12 measurements were taken for each specimen. The marginal gap was assessed using Omnimet analysis software (Buehler, Illinois, USA)

After measuring marginal accuracy, surface treatment of crowns was done by etching the fitting surface of the crowns using Bisco Porcelain Etch 9.5% hydrofluoric acid (BISCO, Schaumburg, USA) for 30 seconds, according to the manufacturer, then water rinsed and air - dried. The intaglio surface of the crowns was silanized with Bisco silane primer for 60 seconds and air-dried. Finally, VOCO Bifix, a dual-cured, self-adhesive resin cement (VOCO, Cuxhaven, Germany), was used to cement the crowns to the epoxy resin dies.

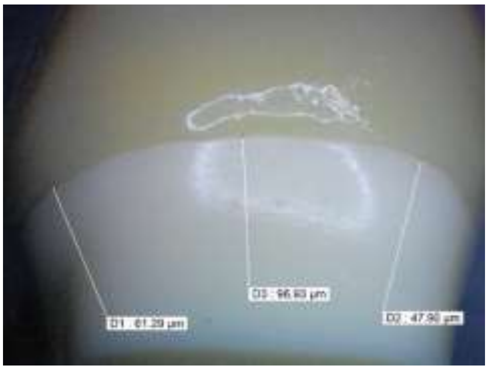

Figure (3): Three equidistant landmarks along crown surface

Fracture resistance measurement

The specimens cemented to epoxy resin dies were individually fractured under static compressive axial load using a universal testing machine (model 3345) (Instron, Massachusetts, USA) with a load cell of 5000 N at a crosshead speed of 0.5 mm/min. The specimens were loaded with a hemispherical steel indenter (Ø = 4mm) applied over the occlusal surface of the sample. A tin foil sheet of 0.5 mm thickness was placed between the loaded applicator and the sample to confirm even stress distribution.[8] **Figure (4)** Failure was confirmed by a sharp drop in the load-deflection curve recorded using Instron Bluehill Software.

Figure (4): Sample after fracture

Statistical Analysis

Data were analyzed using SPSS 20® and GraphPad Prism®. Quantitative data were first assessed for normality using the Shapiro-Wilk and Kolmogorov normality tests. One-way ANOVA was utilized to compare different surfaces, followed by Tukey's post hoc test for multiple comparisons. Independent T-tests were performed to compare both groups. Descriptive statistics, including minimum, maximum, means, and standard deviation (SD) values, were calculated for all data. The level of significance was set at $p < 0.05$.

Results

Normality test: Both the Shapiro-Wilk and the Kolmogorov-Smirnov tests for normality were conducted on the data. The resulting p-values were found to be greater than 0.05, indicating a non-significant deviation from normality. This suggests that the data originated from a normal distribution, resembling a normal Bell curve in both groups. As a result, parametric statistical tests, such as the one-way ANOVA and independent T-tests, were appropriate for use. The normal distribution of the data ensured the validity of the statistical analyses and the reliability of the study results.

Marginal accuracy: In **group A (4-axis CEREC MCXL):** comparison between different surfaces was conducted using the one-way ANOVA test, which revealed a significant difference (p < 0.0001). Subsequent Tukey's post hoc test for multiple comparisons showed that the distal surface exhibited the highest marginal discrepancy (186.73µm), while no significant difference was observed among the other surfaces.

group B (5-axis MCX5): comparison between different surfaces was performed using a one-way ANOVA test, which revealed an insignificant difference between different surfaces. (p = 0.06). A comparison between the two groups as shown in **table (1) & figure (5)** using an independent T-test revealed that:

- There was an insignificant difference between groups on buccal, lingual, and mesial surfaces (p > 0.05).
- There was a significant difference between groups in distal surface, as **Group A (4-axis CEREC MCXL)** (186.73 µm) was significantly higher than **Group B (5-axis MCX5)** (103.6 µm) with an (83.13) mean difference of p = 0.0001*.
- There was a significant difference between groups overall, as **Group A (4-axis CEREC MCXL)** (140.46 µm) was significantly higher than **Group B (5-axis MCX5)** (109.68 µm) with a (30.77) mean difference (p = 0.0001). *

Table 1: values for mean, standard deviation and p-value in relation to marginal accuracy between Group A and Group (Independent T test analysis)

	Group A		**Group B**		**Independent T test**				
					p value	**MD**	**SED**	**95% CI**	
	Mean	**SD**	**Mean**	**SD**				**Lower**	**Upper**
Buccal	122.86	25.79	123.14	29.98	0.98 ns	-0.28	13.18	-28.22	27.66
Lingual	119.30	27.82	91.45	29.74	0.06 ns	27.84	13.57	-0.93	56.62
Mesial	132.93	14.62	120.54	15.85	0.10 ns	12.39	7.19	-2.85	27.63
Distal	186.73	19.83	103.60	24.51	0.0001*	83.13	10.51	60.85	105.41
overall	140.46	16.07	109.68	16.91	0.0001*	30.77	7.78	14.29	47.26

***SD**: standard deviation **MD**: mean difference **SED**: standard error difference **Ns**: non -significant difference as p>0.05*

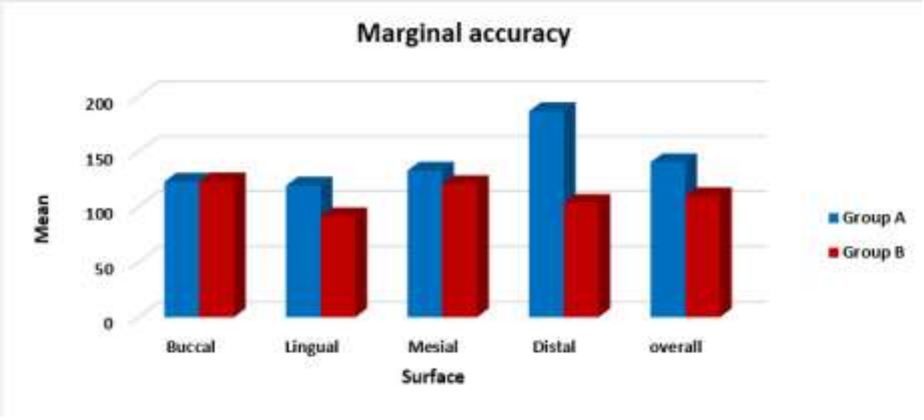

Figure (5): Bar chart showing marginal accuracy regarding group A&B

Fracture resistance

A comparison between both groups was performed using an independent T-test, which revealed that there was an insignificant difference between groups as **Group A (4-axis CEREC MCXL)** (1458.92 N) and **Group B (5-axis MCX5)** (1783.22 N) (p = 0.06). as shown in **table (2)**

Table2: values of mean and standard deviation of fracture resistance between group A and group B:(independent T-test analysis)

Fracture resistance					**Independent T test**				
					P value	**MD**	**SED**	**95% CI**	
	Min	**Max**	**Mean**	**SD**				**Lower**	**Upper**
Group A	1120.33	1790.58	1458.92	207.92	0.06	-324.30	158.62	-660.57	11.97
Group B	1379.93	2648.78	1783.22	428.05					

DISCUSSION

The first null hypothesis was rejected, a significant difference in marginal accuracy between (Group A) 4-axis CEREC MCXL and (Group B) 5-axis MCX5 milling machines was found. Conversely, the second null hypothesis was accepted, as the statistical analysis showed no significant difference in fracture resistance between the two groups.

Advanced lithium disilicate (ALD) CEREC Tessera glass -ceramic was selected to be assessed in this study as it has been recently launched as a unique material and one of the newest materials in glass -matrix ceramics. According to the manufacturer, its biaxial strength is greater than 700 MPa.[9] Tessera provides enhanced mechanical properties, contributing to its durability and longevity compared to conventional ceramics. Additionally, its excellent aesthetic properties allow for its use in various types of dental restorations.

Marginal accuracy was assessed using gold standard direct visualization, measuring the vertical gap distance between the crown margin and the typodont finish line with a stereomicroscope. This non-invasive, time-efficient method is widely used for reliable results.[6]

Universal testing machine was used in this study because it allows for the precise application of controlled compressive force to test the fracture resistance. samples were fractured individually with a 5000 N load cell, at a crosshead speed of 0.5 mm/min. This method aligns with a study by (Elbasty and Taymour, 2022)**,** where they tested e.max CAD crowns using a universal testing machine with a 5000 N load cell until fracture.[10]

CAD/CAM grinding can result in varying degrees of mechanical removal, leading to micro-cracking and chipping. These defects not only affect the fit of the restoration but can also diminish its mechanical strength.[11] According to (Luthardt *et al.*, 2004), severe grinding may induce deep surface cracks. If these cracks exceed the depth of the compressive layer, they can evolve into strength-determining cracks. [12] Although our study did not examine this phenomenon in Tessera, we included this information to highlight the impact of CAD/CAM grinding on ceramics overall.

In our study, a typodont was selected for crown preparation to maintain consistency and standardization in the preparation process due to its standardized anatomy, ensuring uniform testing conditions. Additionally, it helps overcome any variations in natural teeth size, form, or wear that may cause difficulties in standardizing preparation and impact the design and thickness of the restoration. Furthermore, it allows for precise scanning of the entire NISSIN dental model to create a comprehensive digital image.

A single scan was performed to ensure consistency and minimize the variability introduced by multiple scanning sessions. As our focus was on comparing the performance of samples milled using two different milling protocols under controlled conditions, Additionally, recent intraoral scanners, such as the Primescan used in our study, provide accurate and detailed 3D imaging in a single scan.

Epoxy resin dies were selected for their elastic properties, which mimic those of natural dentin, providing a suitable substrate for testing dental restorations, as well as for their dimensional accuracy and resistance to deformation and degradation, ensuring standardization.

Wet milling was chosen as the recommended method for producing high-quality glass ceramic restorations, such as advanced lithium disilicate glass-ceramic which minimizes material wastage and ensures a superior surface finish, contributing to the overall quality of the restorations.

Because the marginal gap would greatly increase after cementation, an assessment of the marginal accuracy was performed without cementation. [13] This increase could be attributed to several factors, including the hydraulic pressure increase of the resin luting, variations in cement thickness, and excessive or uneven distribution of the cement layer, which may introduce discrepancies at the margin, while polymerization shrinkage can contribute to gap formation by reducing the volume of the cement layer. Additionally, uneven seating pressure may lead to gaps at the margin.

The long-term success of a fixed dental restoration relies on the marginal accuracy of the restoration. According to (Makky *et al*, 2020), the clinically acceptable range for dental restoration's long-term success is between 100 and 200 µm. [14] In our study, we utilized this reported range as our benchmark for acceptable marginal accuracy.

In terms of marginal accuracy, Group A (4-axis CEREC MCXL) exhibited a significantly higher mean value (140.46 µm) compared to Group B (5-axis MCX5). This finding aligns with the research of (Hamza *et al.*, 2013) who noted that the number of axes on a milling machine can significantly affect the marginal fit of dental restorations. [15] Additionally, they suggested that the 5-axis milling machine can enhance both productivity and accuracy. However, it contradicted (Roperto *et al.*, 2016) who stated that no significant difference and similar marginal accuracy values were detected for different milling generations (Cerec3 / MCXL Premium). [16] Differences in software versions might cause this variation**,** they used the Cerec 4.3 software version; however, in our study, we used InLab CAM SW 22. Thus, marginal accuracy values may change according to the different software.

The limited degree of motion of the milling machine, restricting the milling process, is due to the MCXL block's vertical rotation capability, coupled with the coordinated movement of two motor spindles in three dimensions. Consequently, certain surfaces of the restoration may exhibit milling defects. Moreover, the geometry of the milling tool, specifically its diameter and length, can significantly influence the accuracy of the

CAM strategy, thereby impacting the precision of CAD/CAM restorations. (Zimmermann *et al.*, 2018) concluded that the two-step milling mode demonstrated superior performance compared to normal milling with step bur 12 and normal milling with step bur 12S.[17]

Also, degradation of the diamond bur and loss of diamond granules can produce chipped margins affecting glass-ceramic crown accuracy. Moreover, these results could be justified by the fact that the 5-axis milling machine controls X, Y, and Z linear axes, plus rotational axes (A) horizontal plane and (B) vertical plan, offering enhanced precision and smoother edges.[18]

Additionally, the time required for the milling process can also play a role in the restoration's accuracy. (Bosch, et al., 2014) stated that the faster milling process results in a less accurate restoration and more marginal chipping.[19] In our study, milling with the MCXL group lasted approximately 14 minutes, while with the MCX5 machine, it took about 60 minutes. Tessera's composition requires longer milling, possibly compromising accuracy. According to (Yamamoto *et al.*, 2022) Tessera crowns exhibited the worst accuracy and the longest milling time (19.5 min).[20] In the researcher's opinion, different CAD/CAM shaping and diamond bur finishing technologies didn't develop to the same level as material development. The current protocol that uses diamond grit burs for grinding Tessera might have caused subsurface microcrack, compromising its marginal accuracy.

Our study's fracture resistance values showed that crowns were stronger than the highest chewing forces documented in previous research (ranging from 597 N to 847 N) in the posterior region, regardless of the milling protocol. [21]

This contribution suggests that the number of axes didn't impact the mechanical behavior of CEREC Tessera. This could be attributed tessera's microstructure, encompassing 0.5 µm lithium disilicate embedded in a glassy matrix and 0.2–0.3 µm virgilite, which provided a biaxial flexural strength of over 700 MPa.[22] Crack tip shielding, resulting from the thermal expansion mismatch between virgilite and lithium disilicate crystals, enhances material density and toughness. [23]

Our findings align with those with (Nouh, Rafla and Ebeid, 2023) who reported a mean fracture resistance value of 1112N for Tessera.[24] Another study by (Phark and Duarte Jr, 2022) observed numerous cracks of varying depths on the surface of Tessera before heat treatment, which gradually disappeared post-firing as the glass matrix fused, providing the material's strong biaxial flexural strength.[22] However, (Albakry, et al., 2004) demonstrated that ceramic materials produced through wet grinding exhibited lower strength values, attributing this to the intense grinding procedures.[25]

We did not use aging protocol before testing as our primary objective was to investigate the immediate effects of different milling protocols on the marginal accuracy and fracture resistance of advanced lithium disilicate glass-ceramic crowns, with a particular focus on the novel material (CEREC Tessera) we aimed to assess its properties without introducing additional variables that might complicate result interpretation. Moreover, aging protocol would have extended the duration of the study.

This study had limitations. Vertical, static fracture force was applied to the restoration, which does not mimic clinical loading. Resin dies were used for standardization instead of natural teeth.

CONCLUSIONS

Within the limitations of this study, we concluded:

1. Both milling protocols showed fracture resistance and marginal accuracy within the clinically acceptable range.
2. The number of CAD/CAM axes showed an influence on the marginal accuracy of glass-ceramic crowns.
3. The number of milling axes in both different milling protocols didn't significantly impact the fracture resistance of glass-ceramic material.

RECOMMENDATIONS

Further studies are required to:

- Examine the impact of different milling protocols on the marginal accuracy of other glass and hybrid machinable ceramics.
- Investigate the CEREC Tessera marginal accuracy and if it’s related to grinding bur wear.

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Ethics: This study protocol was approved by the ethical committee of the Faculty of Dentistry Cairo University on: 25/5/2021, approval number (2521)

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