EFFECT OF DIFFERENT GROOVE DESIGNS ON MARGINAL FIT AND FIT AT GROOVE REGION OF DIFFERENT CROWN MATERIALS: AN IN-VITRO STUDY

A Thesis

by

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Submitted to the Graduate and Professional School ofTexas
A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

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May 2022

Major Subject: Oral Biology

ABSTRACT

The purpose of this in vitro study was to evaluate the effect of different groove designs on the internal fit, marginal and fit at the groove region across crown materials using 3D-analysis. A total of 120 samples were used in this study. 3 different restorative materials were evaluated: milled zirconia, pressed emax and printed resin. There were 4 groove designs included in this study: no groove ‘control’, small groove, medium groove and large groove. There were a total of 12 groups and each group consisted of 10 samples.

All samples were designed on an ivorine master maxillary first molar tooth. Zirconia crowns were milled out of BruxZir 16 blocks. Emax crowns pressed using HT IPS emax press ingots. Resin crowns were printed using Dentca crown and bridge resin material using SprintRay 3D printer. All samples were scanned using Trios 3 intraoral scanner. Marginal fit and fit at groove region were evaluated in Geomajic Control Software (3D systems) using the triple scan technique.

Data were not normally distributed, therefore non-parametric independent sample tests (Kruskal-Wallis test) were used to check for significant differences between the groups. Significance value was set at $\alpha=0.05$, and adjusted with Bonferroni correction for multiple tests. Statistical significant differences were found among the zirconia, resin and emax groups when they were evaluated for marginal discrepancy. Fit at mesial region was statistically significantly different among resin and emax groups, however different groove designs had no effect on the fit discrepancy across the zirconia groups.

The results of this study suggests that the introduction of a groove design into a crown preparation can affect the fit discrepancy (marginal fit and fit at groove area) of the definitive restoration. CAD/CAM fabricated crowns had better fit across all groups than crowns fabricated using conventional techniques.

DEDICATION

To my parents, siblings and friends for their consistent love, support and encouragement.

To my professors in Creighton University – school of dentistry and Texas A&M – college of dentistry, who provided me with inspiration and shared their knowledge with me.

ACKNOWLEDGEMENTS

I would like to thank my thesis committee members: Dr. Cho, Dr. Kesterke and Dr. Chen. I thank each of you for your time and effort.

To Dr. Cho, thank you for making this research possible and pushing me throughout the process.

To Dr. Kesterke, your hard work and dedication is an inspiration for everyone who worked closely with you.

To Dr. Chen, thank you for being a great and motivational instructor.

To Mr. Brandon Chin, for assistance and guidance with Geomajic software.

A special thank you to all my co-residents past and presents.

CONTRIBUTORS AND FUNDING SOURCES

Contributors

This work was supervised by a thesis committee consisting of Drs Seok-Hwan Cho (Head committee) and Dr Ken Jenn-Hwan Chen of the department of restorative sciences and Dr. Matthew Kesterke of the department of orthodontics.

The data analysis was provided by Dr Matthew Kesterke.

Funding Sources

Graduate study was supported by a research grant from Texas A&M University

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1. INTRODUCTION AND LITERATURE REVIEW

Resistance form is defined as, "the features of a tooth preparation that enhance the stability of a restoration and resist dislodgement along an axis other than the path of placement".[1] Several parameters can affect the resistance of a tooth to forces applied on an axis other than the path of insertion. The parameters can be divided into those that are related to the tooth preparation design and those related to the crown fabrication and modification. Multiple parameters, such as height, width, and convergence angle, influence resistance form of a crown preparation, however it is the cumulative effect of all these factors that determine if a preparation has a resistance form.[1] Reisbick and Shillingburg were the first to investigate the features of a crown preparation that increased resistance form, reporting that the placement of interproximal grooves and boxes increased the resistance form of the tooth preparation. In addition, they reported that the placement of boxes was more effective than prepared grooves. Reisbick in his theory emphasized the importance of the location of the grooves, which Woolsey and Matich later confirmed it.[1] Grooves placed in an interproximal location can offer improved resistance over grooves placed in a buccolingual location provided that the primary forces are applied in a buccolingual direction.[1–3]

Molar crown preparations tend to have the greatest convergence angles compared to premolars and anterior teeth. Molars usually have shorter clinical crowns and wide diameter, diminishing the resistance form in molar preparations. Due to the aforementioned reasons, molar preparations tend to require auxiliary features to improve the resistance. Grooves and boxes can reduce the rotational radius which in turn increase the resistance of the crowns to dislodgment.[4]

Marginal fit of the crown is an important factor in the long-term success. Due to increased chances of plaque accumulation in restorations with marginal discrepancies, associated teeth will be more susceptible to caries, periodontal diseases and cement dissolution. Marginal fit of ceramic crowns has a broad range from 7.5 to 206.3 μm. Such variation is caused by multiple factors such as differences in measurement methods, fabrication techniques, sample sizes and number of measurements per specimen.[5]

Previous studies show conflicting results regarding the marginal and internal adaptation of restorations fabricated with various methods.[6] Hasanzade et al concluded that fabricating dental restorations with fully digital workflow could result in comparable or slightly better marginal and internal adaptation when compared with partially digital or fully conventional workflows.[7] Papadiochou and Pissiotis indicated that marginal fit of restorations fabricated with CAD/CAM milling technology, conventional casting, and direct metal laser sintering show similar adaptation.[8]

The evolution of CAD/CAM technology has significantly increased the use of new materials such as milled zirconia, 3D-printed metal and 3D-printed resin. With monolithic zirconia, high strength tooth- or implant- supported restorations can be fabricated with acceptable esthetic results in a reasonable time and at a reasonable cost. Even after mechanical and thermal aging, monolithic zirconia crowns can endure much higher fracture loads than the average maximal occlusal forces in the posterior section of the mouth.[7,9] In addition to improved physical properties, appropriate internal fit adaptation is fundamental for the long-term clinical success of CAM dental prostheses.[9] Previous studies evaluated the marginal fit of printed crowns show a wide range of discrepancies from 47 to 280 μm. Several factors can affect marginal fit such as the resin type and different printing build angles.[7] 3D printed crowns show high accuracy of internal fit, specially in the occlusal region. It is attributed to the fabrication process since 3D printers use additive pattern of applying materials layer by layer. This allows the accurate fabrication of objects with complex structures which positively affect the fit of restorations.[10] Studies show that the fit of zirconia restorations fall within the range of 120 μm, which most researchers consider it acceptable. Svanborg[11] showed that the marginal gaps ranged from 48 to 141 μm and the internal fit from 59 to 238 μm in a systematic review.

The fit of CAD/CAM fabricated restorations can be affected by several factors such as scanning, designing and milling. Diamond coated burs are commonly used for milling ceramic restorations. The mechanical properties of those burs can affect the surface roughness, surface microcracks, marginal and internal adaptation of the CAD/CAM restorations.[12] The desirable properties of the diamond burs include high hardness, good wear resistance and increased life expectancy. Bur deterioration gradually builds up with repeated use and their life expectancy can widely vary depending on the size and the material of the fabricated restoration.[13] Payaminia et al[12], evaluated the effect of repeated usage of diamond burs on marginal and internal adaptation of CAD/CAM fabricated ceramic restorations. They concluded that marginal and internal fit was significantly affected when the diamond burs were repeatedly used up to 10 times. Therefore, repeated use of diamond burs can affect the long term success of the CAD/CAM fabricated restorations.

There are multiple techniques that have been used to evaluate the fit of full coverage restoration. Those techniques can be classified into two groups: 1. Invasive or destructive methods (eg. Cross sectioning) 2. Non invasive or non destructive methods (eg. Direct viewing, replica techniques, prolifometry, qualitative techniques, micro-CT scans). According to Sorenson, methods to measure restorations' misfit can be classified into 4 groups: 1. Direct view 2. Cross sectional 3. Impression technique 4. Visual examination.[14] Literature showing that the direct view technique is the most often used method to evaluate misfit (47.5%), the cross-sectioning method (23.5%), and impression technique (20.2%).[15] Due to its inaccuracy in evaluating vertical misfit and subgingival margins, visual examination with an explorer is not commonly used method.[14]

However, there has been no publication studying the effect of different grooves of milled and 3D-printed single crowns on the marginal fit and fit at groove region. Therefore, the purpose of this in-vitro study is to investigate the effect of different groove dimensions of milled and 3D printed single crowns on the marginal fit and fit at groove region in comparison with e.max pressed crowns thru 3D Analysis. The null hypothesis is that there is no significant difference of marginal fit and fit at groove region among the different groove designs and among the different fabrication methods. This study will provide the scientific guideline for groove preparation for milled and 3D printed dental prostheses to improve the resistance of dental single crowns

2. MATERIALS AND METHODS

Total of 120 samples were used in this study. Samples were divided in 12 groups, and each group had 10 samples. Groups were divided based on restorative material (zirconia, Emax or printed resin) and the groove design (no groove "control", small, medium, large). All samples were designed on one master tooth preparation. Marginal fit and fit at groove region were evaluated in Geomagic Control Software (3D systems) using the triple scan technique.

2.1 Master Tooth Preparation

An ivorine maxillary first molar #3 (Dentoform Columbia Soft Gingival Model, SM-PVR-860) was selected for the master tooth preparation. Tooth was mounted vertically in ISO Type 3 mounting stone (Whipmix). Round glass beads were included on the model around the tooth to maximize the accuracy of the alignment (Figure1). Before tooth preparation, an impression of the model was made using Vinyl Polysiloxane putty material (3M ESPE) to be used as a matrix for the wax pattern for Emax crowns fabrication (Figure 2). Tooth was prepared using high-speed hand piece and a round diamond bur (Brasseler, USA). The occlusal surface was uniformly reduced by 1.5 mm. All margins received a uniform deep chamfer reduction with 1 mm width. The prepared tooth resulted in a 4 mm axial height with a total convergence angle of 20° (Figure 3). This tooth preparation served as the control since there was no groove included. The cast was scanned using an intraoral scanner (TRIOS; 3Shape). The digital scan was post processed and exported as a standard tessellation language file (STL).

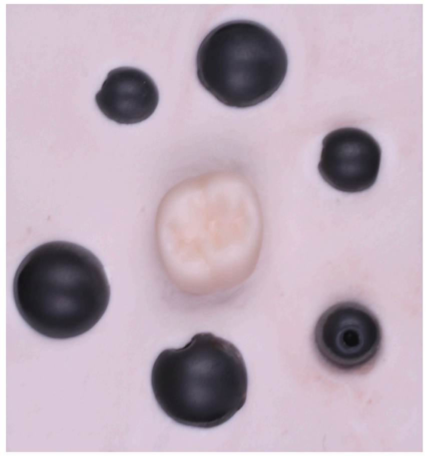


Figure 1: Master Tooth Mounted with Round Glass Beads

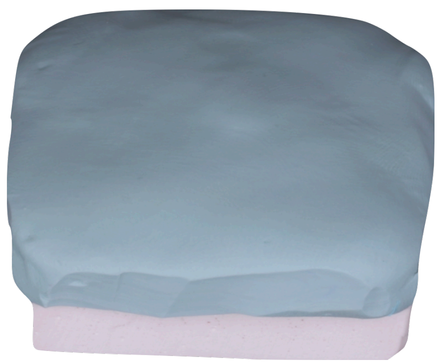


Figure 2: Silicon Matrix

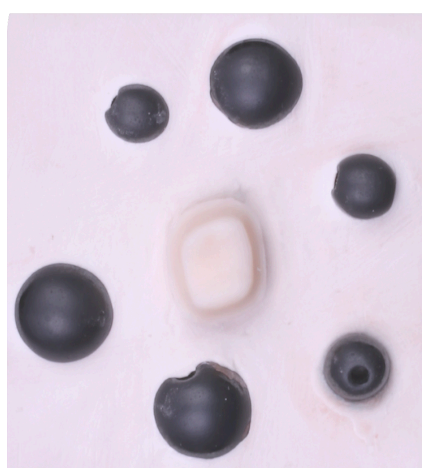


Figure 3: Master Tooth preparation (No Groove)

2.2 CAD/CAM Crown Design

The digital scan was imported into a CAD/CAM software (Exocad). A single crown design was created for both resin and zirconia with system default parameters (50 µm cement space). The crown design was exported as STL file. The STL file was sent to a 5-axis milling unit (Roland DWX, Haus Milling center, USA). Zirconia crowns were milled out of BruxZir 16 using 1-mm cutting edge diamond coated burs (Sierra dental tools, USA). Milling burs were replaced every 85 hours after first use per manufacturer's recommendations. Crowns were sintered for 2 hours at 1,530 Celsius degrees. The same STL file was imported in SprintRay printing application. Support was added on the occlusal surfaces of the samples, and they were oriented to be printed with a 45° angle. Print order was uploaded to a DLP 3D-printer (Pro55 S;, SprintRay). Resin crowns were printed using DENTCA crown & bridge resin. Printed sample were washed using Isopropyl alcohol 91% following manufacturer's recommendations for 12 min (Pro Wash/Dry;, SprintRay). After samples were dried, they were post-cured for 60 min using ProCure 2 system (SprintRay).

2.3 Emax Crowns Fabrication

10 cone shaped custom trays were fabricated using light cure material (DENTALNY) (Figure 4). PVS tray adhesive (3M ESPE) was applied. Impressions were made of the master tooth preparation with light body VPS material (Aquasil Ultra). All impressions were poured with type IV die stone (Resin rock, Whip mix). Die hardener was applied on the dies (Stone Die & Plaster Hardener – Taub). Dies were coated with thin layer of die spacer 1 mm away from the margins (Tru-fit; Taub) (Figure 5). Full-contour wax patterns were made by using the previously PVS matrix on the master model.

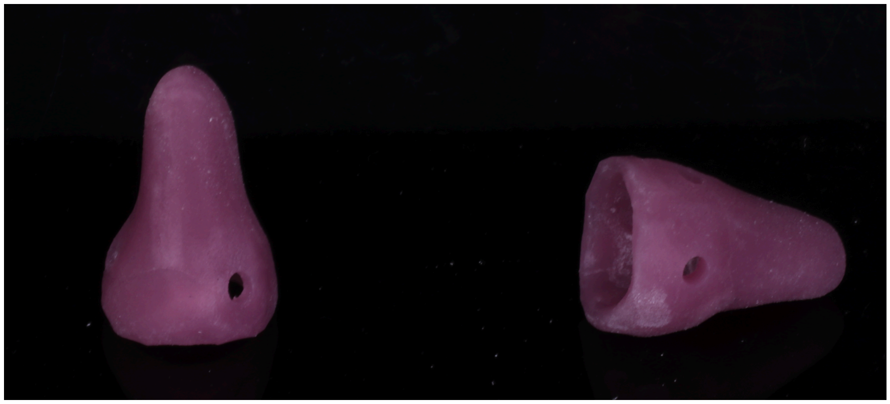


Figure 4: Cone Shaped Custom Trays

Figure 5: Die Coated Die Spacer and Hardener

Wax patterns were then transferred to the dies finalize and close the margins. Each wax pattern was sprued with an individual 4-mm long, 10 gauge wax sprue at mesial marginal ridge. A 100-gram investment ring (IPS silicone Ring) was using to invest wax patterns. 2 crowns were invested at a time. Sprues were attached at a 45° to the base of the investment ring. Wax patterns were invested with a phosphate-bonded investment (IPS PressVEST, Ivoclar Vivadent) (Figure 6). After a 60-min of setting time, the investments were removed and placed in a preheated furnace

(Apollo II Whip Mix) at 1562˚F for an additional 60 minutes. After completion of the burnout process, a HT IPS Emax Press ingot was attached to a disposable plunger (Zobler USA Inc.) and inserted into each investment. The loaded investment was immediately placed in the center of the hot press furnace (Vario Press 300; Zubler USA Inc.) and the recommended press program was selected. After the completion of the pressing, investments were cooled down for 60 min at room temperature. Crowns were divested using polishing beads at 60 psifor gross removal of investment material and 25 psi for fine removal of investment material directed 20 mm from the crowns.

Figure 6: Wax Pattern Invested with Phosphate-Bonded Investment

Crowns were immersed in 0.5% hydrofluoric acid (Invex Liquid;, Ivoclar Vivadent) to remove the reaction layer and cleaned in an ultrasonic machine for 20 min. Sprues were removed with an aluminum- oxide separating disc (Keystone Industries) with irrigation. Each crown was fitted to its respective die. Complete seating of the restoration into the master die was confirmed visually with 2.5x magnification and with an explorer tip (Brasseler USA). The crowns were blasted with Al_2O_3 at15 psi pressure. Surface was thoroughly cleaned with a steam jet and subsequently dried.

2.4 Cementation & Scanning

Prior to cementation, all samples were scanned individually using intraoral scanner (TRIOS; 3Shape). A 1-inch wooden stick was attached to the mesial marginal ridge of each sample using sticky wax (Figure 7). A hemostat was used to carry the crown to standardize the scanning process. After each sample was scanned, it was cemented to the master cast using light body VPS material (Aquasil Ultra) with a firm finger pressure for 5 min. The cemented crown on the master cast was scanned again. All scans were post processed thru the software (3Shape) and exported as STL files.

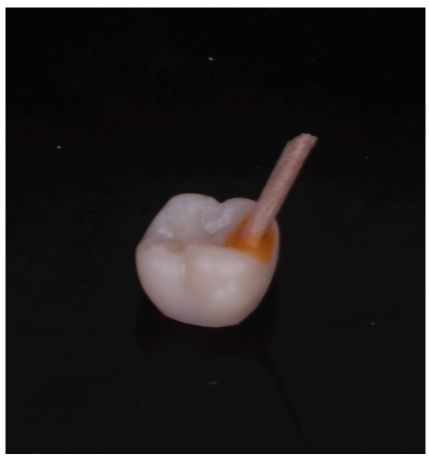


Figure 7: Sample Ready to Be Scanned

2.5 Groove Design

Following the completion of scanning process of the control group, auxiliary features were included in the preparation. There were 3 groove designs included in this study small, medium and large. For the small groove design, the ivorine tooth used for the control group was modified by preparing 1 interproximal groove centered on the mesial wall. The groove was prepared using straight carbide bur. The groove was extended from the occlusal surface of the preparation to the level of the margin. The faciolingual and mesiodistal dimensions of the small groove design was 1 mm (Figure 8). Once the groove created, the master cast has been scanned using the intraoral scanner

(TRIOS; 3Shape). Steps that were previously mentioned in sections 2.2-2.4 were repeated. Following the completion of scanning process of the small groove group, the groove design was modified on the master ivorine tooth. The faciolingual dimension was further extended to have a total width of 2 mm (Figure 9). Mesiodistal dimension remained the same, and the master cast has been scanned again. Steps 2.2-2.4 were repeated. Subsequently, the groove design was modified once again on the master ivorine tooth. The faciolingual dimension was further extended to have a total width of 3 mm with no changes to the mesiodistal dimension (Figure 10). The master cast was scanned, and steps 2.2-2.4 were repeated to complete all data collection.

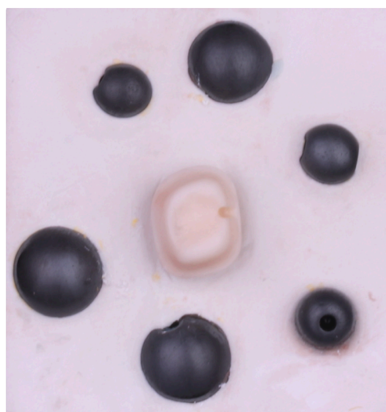


Figure 8: Master Tooth preparation (Small Groove)

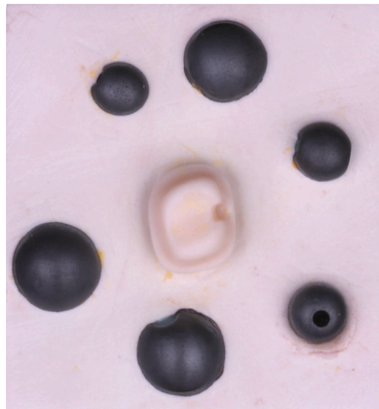


Figure 9: Master Tooth preparation (Medium Groove)

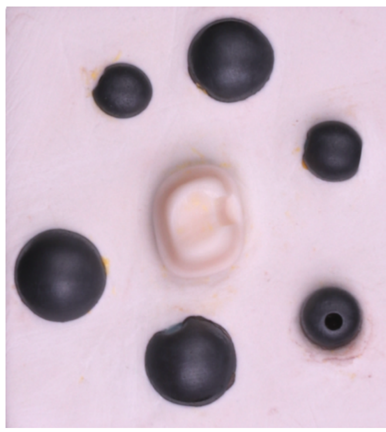


Figure 10: Master Tooth preparation (Large Groove)

2.6 Fit Measurement

Geomagic Control X software (3D Systems) was used to evaluate marginal fit and fit at the mesial wall. The entire mesial wall was selected to serve as a control when measuring the fit at the groove region. All STL files were imported into the software. The master cast was set as the reference for the data measurement. Regions of interest to measure were highlighted on the reference: marginal area and mesial wall. The cemented STL file of each sample (intermediary scan) was aligned to the reference with initial fit alignment, followed by best fit alignment utilizing the glass beads that are incorporated on the cast to maximize accuracy of alignment. Then, individual crowns scans were aligned to the cemented crowns STL. Once, the individual crowns were aligned with the master cast, the intermediary scans were deleted from the software in order not to be included in the measurement. Therefore, 3D analysis was conducted to obtain the results of fitness between the individual crowns and the master cast at the regions of interest.

The results that were obtained from the 3D analysis included some negative values. Since it was unrealistic that marginal openings would have values of less than 0, all individual crowns were raised in the y-axis my 0.2 mm in order to minimize negative values. The final results would be clinically applicable if 0.2 mm is subtracted from all the data collected. The RMS values generated for each sample were used for the statistical analysis.

2.7 Statistical Analysis

Data were analyzed using a statistical software (SPSS 27.0; SPSS Inc.,).

Data were not normally distributed, therefore non-parametric independent sample tests (Kruskal-Wallis test) were used to check for significant differences between the groups. Significance value was set at $\alpha=0.05$, and adjusted with Bonferroni correction for multiple tests. Correlations were used to evaluate how the size of the groove affected the fit of each restorative material.

3. RESULTS

For each sample material (Zirconia, Emax, and Resin), a total of 80 measurements were collected from Geomagic control X software. The root mean square (RMS) measurements were used for statistical analyses. The mean, median, and standard deviation of the fit discrepancy of zirconia material across the different groove designs are shown in table 1.

Table 1. Mean and Std of Zirconia Groups (n=10 for all groups)

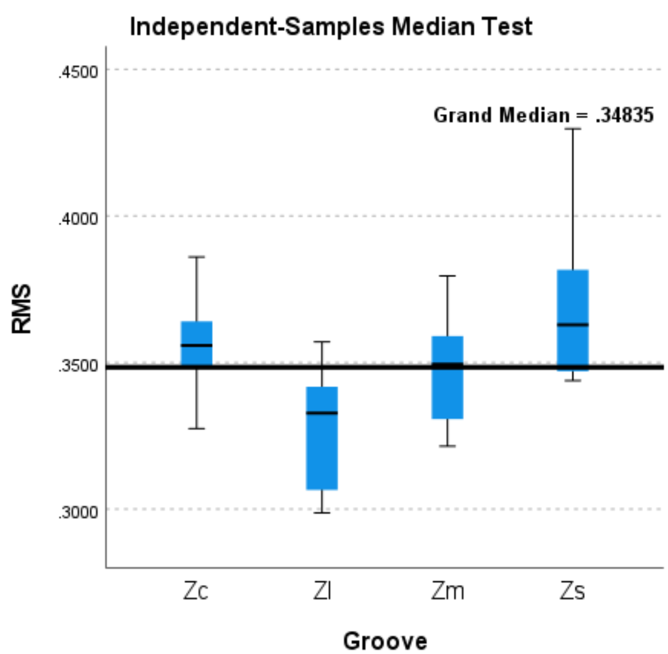
Groove Size	Region	Mean	Median	Std. Deviation	N
Control	Marginal	0.355	0.356	0.017	10
Control	Mesial	0.145	0.140	0.051	10
Small	Marginal	0.371	0.363	0.029	10
Small	Mesial	0.151	0.147	0.035	10
Medium	Marginal	0.345	0.349	0.017	10
Medium	Mesial	0.121	0.117	0.012	10
Large	Marginal	0.328	0.333	0.019	10
Large	Mesial	0.145	0.151	0.020	10

The total median of the marginal fit of the zirconia groups is 0.348 mm. The difference of the medians of marginal fit across different zirconia groove designs is statistically significant (p=.022). Table 2 shows the results of pairwise comparisons among the grooves. The NG group, which had a median marginal fit of 0.356 mm with an IQR ±0.015, was not statistically different from the SG group (p=1.000), which had a median of 0.363 mm with an IQR ±0.033, and was not statistically different from the MG group (p=1.000), which had a median of 0.349 mm with an IQR ±0.024. The NG group was statistically different from the LG group (p=.044), which had a median of 0.333 with an IQR ±0.028. The SG group was not statistically different from the MG group (p=1.000), however there was statistically significant difference between SG and LG groups (p=.002). There was no statistical difference between MG and LG groups (p=.442) (Figure 11).

Table 2. Pairwise comparisons among the grooves (Zirconia marginal)

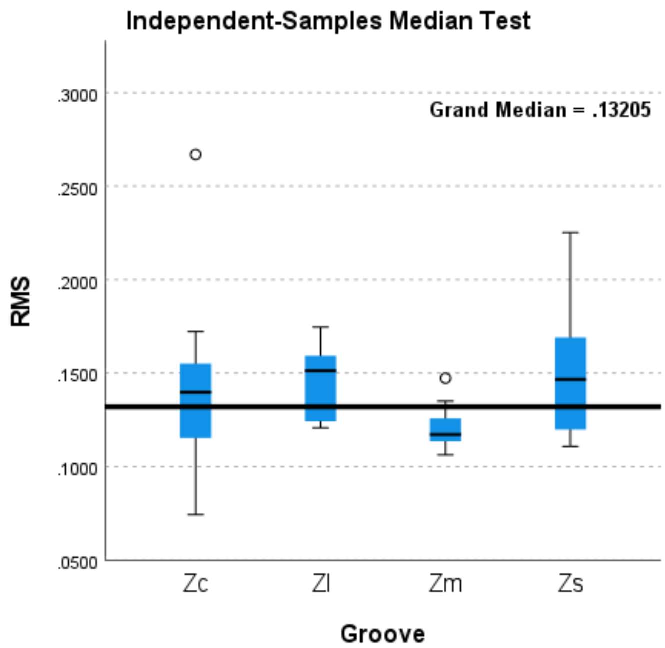
Samples	Significance * (P≤0.05)
LG-MG	.442
LG-NG	.044
LG-SG	.002
MG-NG	1.000
MG-SG	1.000
NG-SG	1.000

Figure 11. Marginal Fit of Zirconia Groups



The total median of the fit at the mesial wall of the zirconia groups is 0.132 mm. The difference of the medians of mesial fit across different zirconia groove designs was not statistically significant (p=.133). The NG group had a median of 0.140 mm with an IQR ±0.035, while the SG group had a median of 0.147 mm with an IQR ±0.041. The MG group had a median of 0.117 mm with an IQR ±0.012, while the LG group had a median of 0.151 mm with an IQR ±0.034 (Figure 12).

Figure 12. Mesial Fit of Zirconia Groups



The mean and standard deviation of the fit discrepancy of Emax material across the different groove designs are shown in table 3.

Table 3. Mean and Std of Emax Groups

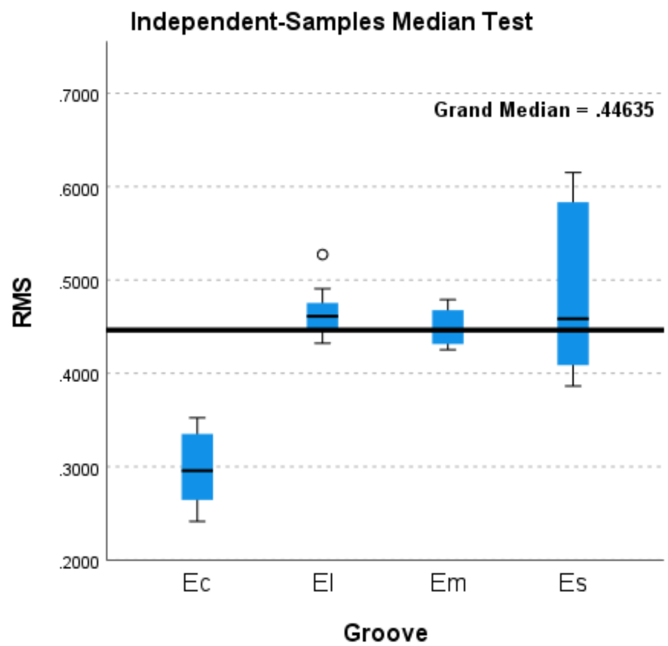
Groove Size	Region	Mean	Median	Std. Deviation	N
Control	Marginal	0.298	0.296	0.038	10
Control	Mesial	0.179	0.158	0.080	10
Small	Marginal	0.482	0.454	0.087	10
Small	Mesial	0.278	0.278	0.092	10
Medium	Marginal	0.448	0.446	0.019	10
Medium	Mesial	0.232	0.231	0.061	10
Large	Marginal	0.466	0.461	0.027	10
Large	Mesial	0.281	0.275	0.041	10

The total median of the marginal fit of the Emax groups is 0.446 mm. The difference of the medians of marginal fit across different Emax groove designs was statistically significant (p<.001). Table 4 shows the results of pairwise comparisons among the grooves. The NG group, which had a median of 0.296 mm with an IQR ±0.059, was statistically different from the SG group (p<.001), which had a median of 0.454 mm with an IQR ±0.141, and statistically different from the MG group (p=<0.001), which had a median of 0.446 mm with an IQR ±0.033. The NG group was also statistically different from the LG group (p<.001), which a median of 0.461 mm with an IQR ±0.025. There was no statistically significant difference between the SG and MG groups, and SG and LG groups, both p-values were 1.000. There was also no statistical difference between the MG and LG groups (p=.442) (Figure 13).

Table 4. Pairwise comparisons among the grooves (Emax marginal)

Samples	**Significance * (P≤0.05)**
NG-MG	<.001
NG-SG	<.001
NG-LG	<.001
MG-SG	1.000
MG-LG	.442
SG-LG	1.000

Figure 13. Marginal Fit of Emax Groups

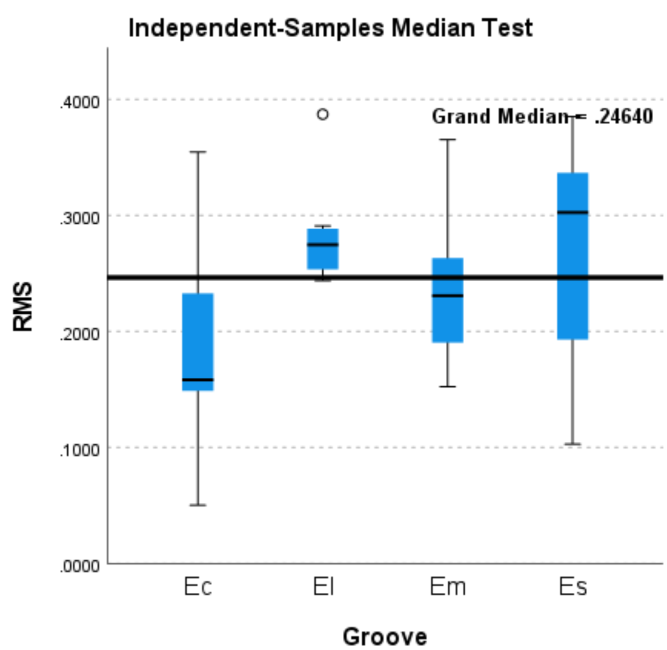


The total median of the fit at the mesial wall of the Emax groups is 0.246 mm. The difference of the medians of mesial fit across different Emax groove designs was significant (p=.007). Table 5 shows the results of pairwise comparisons among the grooves. The NG group, which had a median of 0.158 mm with an IQR ±0.067, was not statistically different from the SG group (p=.442), which had a median of 0.278 mm with an IQR ±0.123, and was not statistically different from the MG group (p=.442), which had a median of 0.231 mm with an IQR ±0.066. The NG group was statistically different from the LG group (p=.010), with a median of 0.275 mm with an IQR ±0.029. There was no statistically significant difference between the SG and MG groups (p=.442), and SG and LG groups (p=1.000). There was also no statistical difference between the MG and LG groups (p=.442) (Figure 14).

Table 5. Pairwise comparisons among the grooves (Emax mesial)

Samples	Significance * (P≤0.05)
NG-MG	.442
NG-SG	.442
NG-LG	.010
MG-SG	.442
MG-LG	.442
SG-LG	1.000

Figure 14. Mesial Fit of Emax Groups



The mean and standard deviation of the fit discrepancy of Resin material across the different groove designs are shown in table 6.

Table 6. Mean and Std of Resin Groups

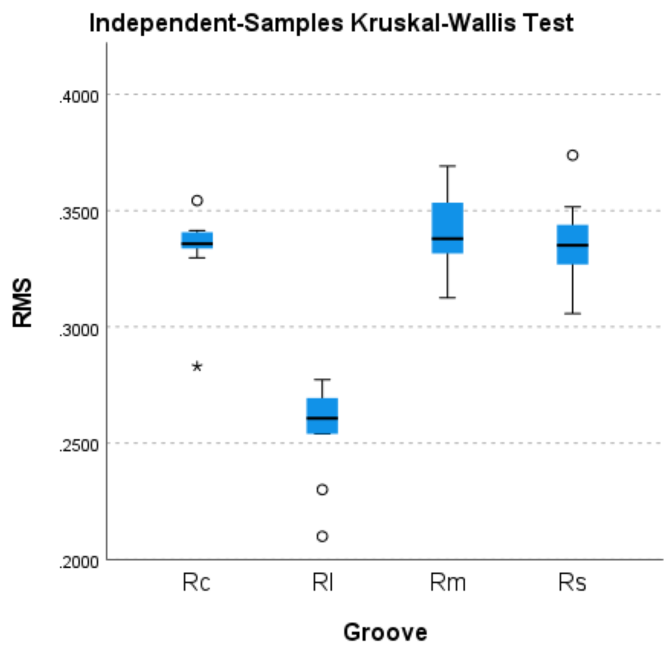
Groove Size	Region	Mean	Median	Std. Deviation	N
Control	Marginal	0.333	0.336	0.019	10
Control	Mesial	0.070	0.064	0.020	10
Small	Marginal	0.407	0.403	0.017	10
Small	Mesial	0.158	0.152	0.019	10
Medium	Marginal	0.351	0.346	0.015	10
Medium	Mesial	0.099	0.102	0.020	10
Large	Marginal	0.256	0.261	0.021	10
Large	Mesial	0.124	0.116	0.020	10

The total median of the marginal fit of the Resin groups was 0.341 mm. The difference of the medians of marginal fit across different Resin groove designs was statistically significant (p=<.001). Table 7 shows the results of pairwise comparisons among the grooves. The NG group, which had a median of 0.336 mm with an IQR ±0.007, was not statistically different from the SG group (p=1.000), which had a median of 0.403 mm with an IQR ±0.018, and from the MG group (p=1.000), which had a median of 0.346 mm with an IQR ±0.017. The NG group was statistically different from the LG group (p=.001), which a median of 0.261 mm with an IQR ±0.014. There was no statistically significant difference between the SG and MG groups (p=1.000), however there was statistical difference between the SG and LG (p=.001), MG and LG groups (p=.001). (Figure 15).

Table 7. Pairwise comparisons among the grooves (Resin marginal)

Samples	Significance * (P≤0.05)
NG-MG	1.000
MG-SG	1.000
MG-LG	<.001
NG-SG	1.000
NG-LG	.001
SG-LG	.001

Graph 15. Marginal Fit of Resin Groups



The total median of the fit at the mesial wall of the Resin groups was 0.114 mm. The difference of the medians of mesial fit across different Resin groove designs was statistically significant (p=<.001). Table 8 shows the results of pairwise comparisons among the grooves. The NG group, which had a median of 0.064 mm with an IQR ±0.009, was not statistically different from the SG group (p=.137), which had a median of 0.152 mm with an IQR ±0.022, and was not statistically different from the MG group (p=1.000), which had a median of 0.102 mm with an IQR

±0.033. The NG group was statistically different from the LG group (p=.000), which a median of 0.116 mm with an IQR ±0.018. There was statistically significant difference between the SG and MG groups (p=.028), and MG and LG groups (p<.001). There was no statistical difference between the SG and LG groups (p=.490). (Graph 16).

Table 8. Pairwise comparisons among the grooves (Resin mesial)

Samples	Significance * (P≤0.05)
NG-MG	1.000
MG-SG	.028
MG-LG	.000
NG-SG	.137
NG-LG	<.001
SG-LG	.490

Graph 16. Mesial Fit of Resin Groups

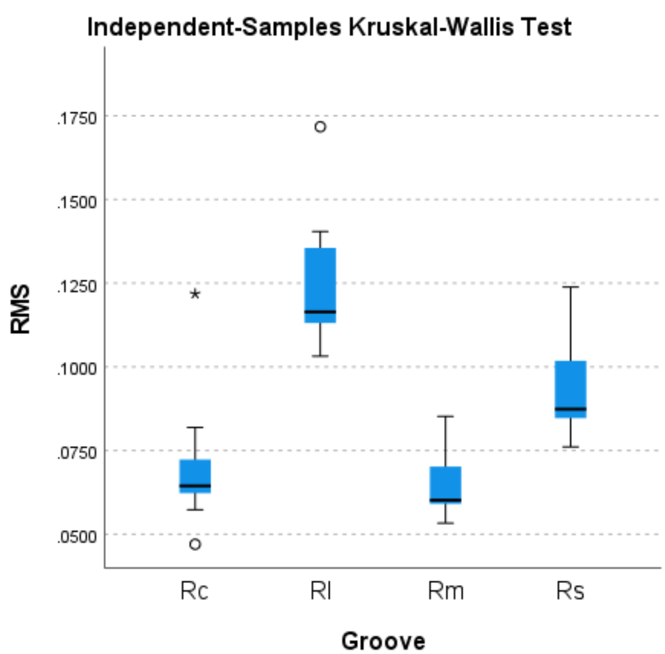


Figure 17 shows the correlation between the groove size and marginal fit across the different restorative materials. The figures shows that Emax (gray) had the best marginal fit with no groove, however the fit discrepancy had significantly increased once a groove was included. The marginal discrepancy of emax had exceeded resin and zirconia groups with a groove included despite the groove size. The figure also shows that zirconia group had a relatively steady line across the different groups, which means that marginal discrepancy was not affected by the groove size. However, However, emax marginal discrepancy had increased as the groove size increased and resin marginal discrepancy decreased as the groove size increased.

Figure 17. Correlation between groove size and marginal fit across materials

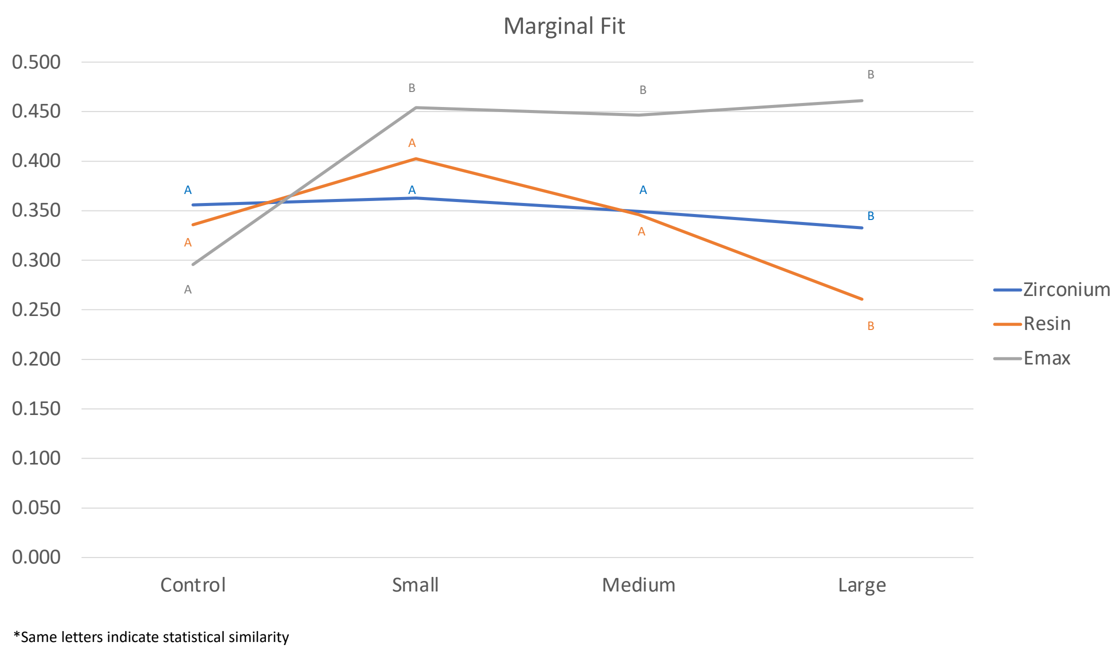
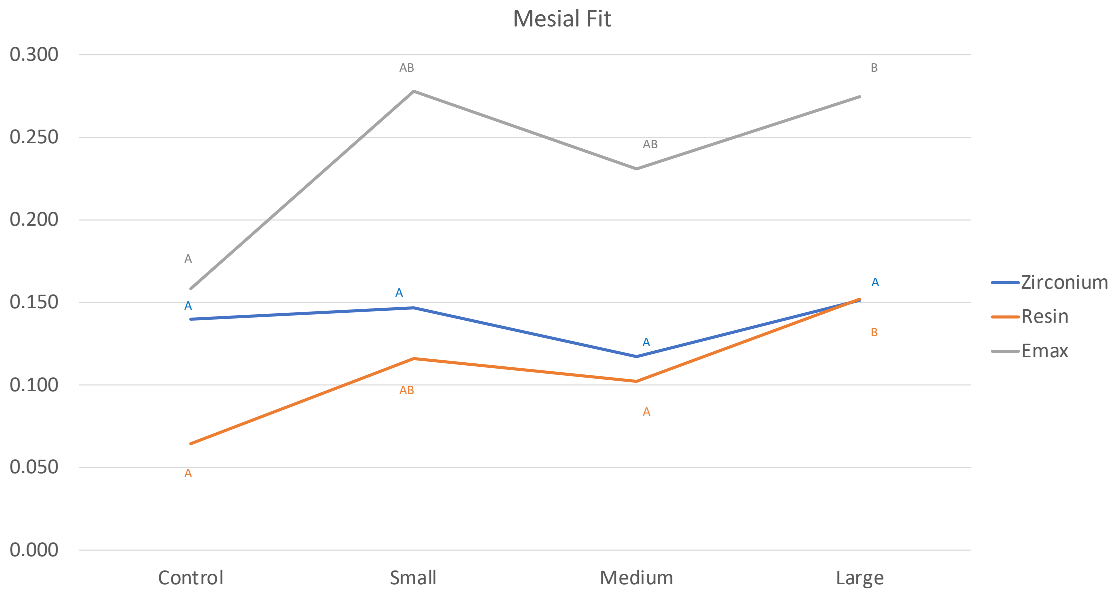


Figure 18 shows the correlation between the groove size and the fit at the mesial across the different restorative materials. The figures shows that Emax (gray) and resin (orange) had a better fit at mesial wall with no groove, however the fit discrepancy had increased once a groove was included. The figure also shows that zirconia group had a relatively steady line across the different groups.

Figure 18. Correlation between groove size and mesial fit across materials



*Same letters indicate statistical similarity

4. DISCUSSION

The purpose of this study was to compare the marginal fit and fit at the mesial region after the introduction of different groove designs to master tooth preparation across 3 different restorative materials (Zirconia, Printed Resin and Emax) thru 3D analysis. The null hypothesis was rejected, and it was concluded that the introduction of different groove designs can affect fit discrepancy except for the fit at the mesial region for the zirconia group. The fit discrepancy at the mesial region was not affected by different groove designs when crowns were milled from zirconia. As shown in figures 7 and 8, zirconia group (milled) was the least affected group by the introduction of different groove designs to the preparation. However, Resin (printed) and Emax (pressed) fit discrepancy were more affected than zirconia when different grooves were included in the preparation. It was also found out in this study that generally a medium size groove (2 mm width) would have a better fit adaptation across all the different restorative materials.

To the best of the author's knowledge, there has been no studies evaluating the effect of different groove designs on the fit discrepancy of different crown materials. However, Aktas[16] studied the effect of the digitizing techniques on the fit of implant-retained crowns with different anti-rotational features. Aktas et al, evaluated the marginal and axial fit of milled oxide ceramic crowns and milled alumina silicate ceramic designed on resin-retained abutments with different anti-rotational features. They found out that marginal fit of implant-retained crowns were significantly affected when anti-rotational features were included in the design. However, they did not find a significant discrepancy on the axial fit when anti-rotational features are introduced. This comes in partial agreement with the findings of this study, as the marginal and mesial fit discrepancy were generally affected once the grooves are included in the tooth preparation.

Another study, Lin et al[3], evaluated the marginal and internal adaptation of Procera copings using different tooth preparations. The variations in their study comprised different finish line forms, different occlusal forms, different occlusocervical undulation forms to the proximal finish line and different proximal auxiliary retention forms. They evaluated 3 different proximal auxiliary retention forms: 1.) 1.5 mm buccolingual dimension, 0.3 mm mesiodistal dimension, 2.) 1.5 mm buccolingual dimension, 0.5 mesiodistal dimension, 3.) 3.0 mm buccolingual dimension, 0.5 mm mesiodistal dimension. In contrary to the finding of the present study, Lin et al did not find any significant differences on the marginal fit among the different 3 auxiliary features forms. However, they found out that the wider the buccolingual dimension of the proximal auxiliary feature form, the more accurately it is reproduced. It was concluded that when anti-rotational features are included, it is recommended that they should be wider than 2.5 mm with rounded internal angles in order to maximize the accuracy and reproducibility.

Park et al[17], studies the effects of 3D printing parameters on the marginal fit and internal fit of 3D printed dental prosthesis. It was concluded that the fit of 3D printed restorations varied depending on the build orientation and layer thickness. The recommended build angles are 45° and 60°. In the present study, there were 4 different resin groups (control, small, medium and large groove), and each group was printed individually. Therefore, it was impossible to standardize the build orientation among the groups. According to Park[17], the area where the support structures are connected to the printed material would vary depending on the build orientation. Errors may be generated due to unsupported area, which changes depending on the printing orientation. Another factor that may attributed to the variations among the printed resin groups is the polymerization shrinkage. Due to the different printed crown designs, different shrinkage patterns may played a factor on the fit discrepancy among the samples.

There are several limitations in this study. The present study is an in-vitro study which does not replicate the intra-oral conditions. Moreover, all samples were scanned with an intraoral scanner which can introduce some margins of error due to different scanning patterns. Finally, with the 3D analysis, the digital alignment generated multiple negative values, which is unrealistic for the fit discrepancy to be less than 0.

In the last few decades, the CAD/CAM technology had significantly evolved and gained tremendous popularity in the dental industry. Since the CAD/CAM technology got integrated in the dental field, an increasing number of restorations are designed and manufactures. Some of the advantages of CAD/CAM technology that it has reduced production time and it is reproducible. Also, it is claimed that digitally fabricated restorations have comparable marginal fit to traditional techniques. As a result, it is prudent for future studies to compare the how different groove designs can affect the marginal and internal fit of the same material if its produced thru different techniques (eg. Conventional ‘lost-wax technique’ metal crown vs milled metal crown).

In the present study, zirconia group “milled” was the most consistent group regardless of the different groove designs. The marginal fit and the fit at the mesial wall of the zirconia groups were the least affected when a groove was included in the design in comparison to resin ‘printed’ and Emax ‘pressed’. In contrary, the Emax group was the most affected ‘fit discrepancy increased’ when a groove design was included in the preparation design.

5. CONCLUSIONS

Within the limitation of this in vitro study, the following conclusions can be drawn:

1. The introduction of a groove design into a crown preparation can affect the fit discrepancy ‘marginal fit and fit at groove area’ of the definitive restoration.
2. CAD/CAM fabricated crowns had better fit ‘marginal fit and fit at groove area’ across all the groups ‘once a groove is introduced’ than heat pressed crowns ‘emax’, which can be attributed to multiple steps of the heat-pressing technique
3. Zirconia group ‘milled’ was the least affected group compared to resin ‘printed’ and emax ‘pressed’ fit discrepancy when different grooves were included in the preparation
4. Variations among printed resin groups can be attributed to polymerization shrinkage, build orientation and layer thickness
5. Medium size groove ‘2 mm width’ had a better fit adaptation across all the different restorative materials

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