Evaluation of Influence of Finish line Design on Marginal Discrepancy of All-ceramics Lithium disilicate Crown restorations using μ-CT

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Abstract. Purpose of this study was to evaluate the influence of finish line design on marginal discrepancies of lithium disilicate crown restoration fabricated with CAD/CAM. 24 crown restorations (n=8 each group) were designed with three different finish lines: Shoulder finish line (SFLC), Round Shoulder finish line (RSFLC) and Deep Chamfer finish line. All dies were prepared with additive manufacturing whereas crowns were fabricated with CAD/CAM using these preparations. After fixation, restorations were scanned using SRµCT and obtained reconstructed 2D slices were used to measure marginal discrepancy (MD) and absolute marginal discrepancy (AMD) at four sites (buccal, lingual, mesial and distal) of each specimen with the help of Image J software. Finally, recorded data was analyzed by one way ANOVA and Tukey’s test. The mean marginal discrepancies (MD±SD) for three groups were as follow: SFLC (91.6 ±3.5), RSFLC (72.8 ±3.9) and DCFLC (65.9 ±5.2) whereas Mean absolute marginal discrepancies (AMD±SD) were as follow: SFLC (104.4 ±6.8), RSFLC (85.5 ±3.5) and DCFLC (78.7 ±5.3). According to results, marginal discrepancies and absolute marginal discrepancies of SFLC group were significantly higher than those of RSFLC and DCFLC groups. After all, MDs and AMDs of all three groups were below clinical acceptable value.

For all-ceramics restorations, marginal discrepancies of lithium disilicate crown restorations were below clinical acceptable range and restorations designed with RSFLC and DCFLC demonstrated superior results compared to preparations designed with SFLC.

1. Introduction
Among the various factors responsible for the longevity of a complete crown restoration, marginal discrepancy plays a vital role [1,2,3]. In general, marginal discrepancy is explained in terms of marginal discrepancy or gap, which can be defined as the vertical distance from the finish line of prepared tooth to the cervical margin of the restorations [4]. Poor marginal discrepancy creates high plaque accumulation and exposes the cemented region to oral environment, which increases micro-leakage and leads to periodontal diseases. Finally restoration losses its mechanical stability and failures occur [5,6].

The past studies acknowledged that cast restorations have shown better marginal discrepancy (even marginal gap below 10 μm have been reported in some studies for high-palladium-content alloys and gold-platinum-palladium alloys) than base metal, metal ceramic and all ceramic CAD/CAM fabricated restorations [7,8], however, in dentistry, applications of casting process is limited to few metals which are high in cost and do not satisfied the esthetic issues for patients. In other hand, due to advancement in dental CAD/CAM various biomaterials such as ceramics are in practice for dental restorations [9,10,11,12]. In case of dental ceramic materials, lithium disilicate glass ceramic has been used for fabrication of anterior or posterior crowns, inlays, onlays, veneers since it was first introduced in dentistry by Ivoclar Vivadent in 1990 [13,14,15]. Furthermore, pre-crystallized lithium disilicate blocks can be easily milled without excessive diamond bur wear or damage to the restoration and finally, restoration posses fine graine size, natural tooth shade and
superior mechanical properties [15]. As far as maximum marginal discrepancy, no pre established acceptable range of marginal discrepancy and researchers suggested it according to their convenience in initial studies. Recently, several studies recommended that marginal discrepancies up to 120 µm are considered clinically acceptable. As CAD/CAM process reduces the possibility of human error and the inaccuracy inherent in different restorative materials, 100 µm is the maximum acceptable marginal discrepancy for CAD/CAM restorations [16,17].

In past three decades, various studies investigated the factors those influence the marginal discrepancy of all-ceramics crown restoration. Many of these studies reported that factors such as finish line design, veneering firing cycles, angle of preparation, cement space, type of cementation, and material used reportedly influence the marginal discrepancy of complete crown restoration [18,19,20,21,22,23].

Interestingly, for conventional full crown restorations, effect of finish line design on marginal discrepancy denied by several investigators in their reports but studies on CAD/CAM fabricated metal-ceramic and all-ceramics crown restorations reported contradictory results. Some studies showed that no significant difference between two finish line design whether other studies recommended that finish line design influence the marginal discrepancy [18,20,24,25,26,27]. A study by Akbar Hussain et al [26] based on Cerec3 system compared two different finish line designs reported that no significant effect of finish line design on marginal discrepancy whereas in two different studies by same Raul Euan et al [16,27] finish line design significantly influences the marginal discrepancies. However, due to heterogeneity in experimental environment, direct comparison of these studies was impossible. Although, heavy or deep chamfer and round shoulder finish line designs have been recommended for all-ceramic crown restorations [4,18,28,29,30] but adequate literature is not available. So investigation of influence of finish line design on marginal discrepancy of all-ceramics restorations is needful.

However, in vivo studies, marginal discrepancy can be measured by various methods including stereomicroscope, scanning electron microscopy, optical microscopy, optical comparator screen, and computed tomography [31,32,33,34] whereas various techniques including silicon replica, resin replica, and marginal interval measurement by direct sectioning of a specimen can be used for in vitro studies. Among all, method for evaluation of marginal and internal discrepancy of restorations by µ-CT is noninvasive and non destructive [35]. However, high quality 2D and 3D images from any angle and position can be obtained, and very thin sections may also be imaged safely from close proximity[36,37], but formation of radiation artifacts caused by the differences of radiation absorption coefficients between different materials during cement space volume measurement is the major disadvantage of this method. [38]

The purpose of this study was to evaluate the marginal discrepancies of CAD/CAM fabricated all-ceramics lithium disilicate crown restorations having three different finish line designs (shoulder, round shoulder and deep chamfer) using µ-CT. All three groups were evaluated to test the following hypotheses: null hypothesis that no difference would be found among the marginal discrepancies measured in different locations for these finish line designs; and alternative hypothesis that finish line influences the marginal discrepancies of the all-ceramics crown restorations.

2. Materials and Methods
An extracted human lower left second premolar tooth with no carries or anatomical defect was used in this study. Tooth was obtained following the guidelines of local human research ethics committee and stored in 10% formaldehyde solution until it was used for study. The extracted tooth was scanned using 3D blue light scanner (Shining3D, DS100) and therefore obtained STL file was then sent and used for CAD modeling using Solid works CAD software where three CAD models were designed. These CAD models were classified by three different finish line configurations i.e. Shoulder Finish Line Configuration (SFLC), Round Shoulder Finish Line Configuration (RSFLC), and Deep Chamfer Finish Line Configuration (DCFLC).
However, different finish line configurations were used to designed CAD models to categorize the three groups of preparations but all other parameters were common and had following characteristics: approx. 12 degree convergence angle, 1.5 to 2 mm anatomic occlusal reduction, axial reduction of 1.0 to 1.2 mm, and a finish line located 0.5 mm above the cementoenamel base. For first group, shoulder finish line was designed whereas round shoulder finish line and chamfer finish line were designed for second group and third group respectively.

In this study eight specimens were included from each group and all 24 master dies (or preparations) of specimens were fabricated by Rapid Prototyping Technique (RPT) using clear resin material (SLA FOAM LAB). Then all fabricated master dies sprayed with white color and scanned with 3D blue light scanner (Shining3D, DS100). The obtained scanned files were then sent to crown designing unit where crowns were designed for each master die with EXOCAD dental CAD software. All the crowns were designed under following manufacturer’s instruction: 0.5 mm wall thickness, a 0.35 mm reinforcement of the restoration edge, and 40 micron cement space.

In milling unit, two different size burs (2.5 mm & 1 mm) were used to manufacture each of the all 24 crowns from lithium disilicate block (IPS e.max CAD). All the manufactured crowns were operated under 850 porcelain firing cycles for 20 min in a single shift and no additional finishing or polishing was carried. Therefore, complete specimens were prepared by fixing of each crown on its respective master die with ionomiser cement solution under a constant load of 20 N for 20 min.

Synchrotron Radiation (SR) x-ray microtomography (SRµ-CT) was used to obtain high quality images of all the assembled specimens which were analyzed to evaluate the marginal discrepancies. Therefore, each specimen was fixed on experimental table and positioned perpendicular to the x-ray beam for scanning process. In this scanning process, the SR-Micro CT was operated at 25KV energy and between 100 to 165mA x-ray beam line current. Total 901 images were acquired for every specimen whereas each image capturing time was 6 to 10 seconds.

All acquired projections were reconstructed and translated into cross-section slices with the help of image processing software and after that image analysis software (ImageJ, 1.51p22) was used to analyze the reconstructed cross-sectional images. For all 24 specimens, marginal discrepancies were measured in both buccolingual and mesiodistal directions hence in this course five slices for buccolingual direction (slice no. 1,5,10, 890 & 895 of each specimen) and five slices for mesiodistal direction (Slice no. 215,220, 225, 230 & 235 of each specimen) were selected and evaluated for each specimen. For each selected slice two regions (buccal and lingual areas on buccolingual slices whereas mesial and distal areas on mesiodistal slices) were marked and evaluated for two measurements: MD, AMD [fig] thus each specimen had total 40 measurements. Finally, one way ANOVA technique was implemented using the statistical software (IBM

Figure 1: Preparations CAD models with (a) Shoulder finish line, (b) Round Shoulder finish line and (c) Deep Chamfer finish line.
SPSS Statistics 20) to perform statistical analyses. Tukey’s (HSD) test was used for homogeneous variance groups whereas for non-homogeneous groups Tamhane T2 test was performed. (α =0.05)

3. Results
For each of three SFLC, RSFLC and DCFLC groups including 8 crowns/group and 4 sites/crown, total 80 images were analyzed. Descriptive analyses of the AMDs and MDs statistics is given in Table 2 and Table 3 respectively. Mesial site of SFLC group attains highest AMD (122.43µm) that was significantly higher than minimum AMD (65.23µm) was found at buccal site of DCFLC group (p<0.01). On average, AMDs of SFLC group were significantly higher than those for RSFLC and DCFLC groups (p<0.01). In case of MDs, the highest MD (104.02µm) which measured at mesial site of SFLC group was significantly higher than minimum MD recorded in DCFLC group for buccal site (p<0.01). Overall, MDs of SFLC group were seen significantly higher than those of the RSFLC and DCFLC groups (p<0.01).

For the SFLC group, highest AMD (122.43µm) was seen at mesial site that was also significantly higher than lowest AMD (90.43µm) recorded at lingual site (p<0.01). However, rather than AMDs significantly higher than those of lingual site (p<0.05) there was no significant difference between AMDs of all other sites. Maximum value of MD (104.02µm) was seen at mesial site that was also significantly higher than minimum MD value (82.73µm) at buccal site. In average, MDs at mesial site were significantly higher than those of buccal and distal sites (p<0.01) as well as of lingual site (P<0.05).

Table 1: Mean and standard deviation values of MD (µm)

| Group/Site | Buccal Mean ±SD (a) | Lingual Mean ±SD (b) | Mesial Mean ±SD (c) | Distal Mean ±SD (d) | Mean ±SD * | P * |
|------------|---------------------|---------------------|---------------------|---------------------|------------|-----|
| S FLC (A)  | 86.0 ±3.2           | 91.5 ±4.2           | 99.1 ±3.5           | 89.9 ±3.7           | 91.6 ±3.5  | <0.01|
| RS FLC (B) | 66.3 ±2.4           | 70.3 ±8.4           | 72.4 ±3.8           | 72.2 ±2.5           | 72.8 ±3.9  | <0.01|
| DC FLC (C) | 70.8 ±4.9           | 65.1 ±4.6           | 71.1 ±7.2           | 67.3 ±4.6           | 65.9 ±5.2  | <0.01|

P <0.01 <0.01 <0.01 <0.01 <0.01

MD, Marginal Discrepancy; SD, Standard Deviation; S, Shoulder; RS, Round Shoulder; DC, Deep Chamfer; FLC, Finish Line Configuration; Mean values followed by different lowercase letters in same row show statistical differences (p <0.05). Mean values followed by different uppercase letters in same column show statistical differences (p <0.05). * Average value (Mean ±SD) of buccal,lingual, mesial and distal. * Repeated measures analysis of variance. ~ One way ANOVA

Table 2: Mean and standard deviation values of AMD (µm)

| Group/Site | Buccal Mean ±SD (a) | Lingual Mean ±SD (b) | Mesial Mean ±SD (c) | Distal Mean ±SD (d) | Mean ±SD * | P * |
|------------|---------------------|---------------------|---------------------|---------------------|------------|-----|
| S FLC (A)  | 96.9 ±6.3           | 104.2 ±8.8          | 114.7 ±5.2          | 104.4 ±6.8          | 104.4 ±6.8 | <0.01|
| RS FLC (B) | 75.2 ±3.6           | 83.2 ±3.1           | 98.4 ±5.5           | 85.0 ±3.9           | 85.5 ±3.5  | <0.01|
| DC FLC (C) | 70.0 ±3.2           | 76.0 ±6.0           | 86.0 ±6.2           | 82.8 ±5.3           | 78.7 ±5.3  | <0.01|

P <0.01 <0.01 <0.01 <0.01 <0.01
AMD, Marginal Discrepancy; SD, Standard Deviation; S, Shoulder; RS, Round Shoulder; DC, Deep Chamfer; FLC, Finish Line Configuration; Mean values followed by different lowercase letters in same row show statistical differences ($p<0.05$). Mean values followed by different uppercase letters in same column show statistical differences ($p<0.05$). * Average value (Mean ±SD) of buccal, lingual, mesial and distal. + Repeated measures analysis of variance. ~ One way ANOVA.

For RSFLC group, highest AMD (106.54µm) was found at mesial site and noticeably that was significantly higher than lowest AMD (71.47µm) located at buccal site ($p<0.01$). AMDs of mesial site were significantly higher than those of buccal, lingual and distal sites ($p<0.01$). Top most MD value (87.49µm) was also found for mesial site whereas with significant difference ($p<0.01$), lower most MD value (56.04µm) was seen at buccal site. MDs of mesial site were significantly greater than MDs of buccal, lingual and distal sites ($p<0.01$).

For DCFLC group, In AMD values highest (94.77µm) were seen for mesial and distal sites that were significantly higher than lowest value recorded for buccal site ($p<0.01$). Overall, AMDs seen in mesial site were significantly higher than AMDs of buccal site ($p<0.05$). In case of MDs, highest (77.62µm) and lowest (52.11µm) values had significant difference and were located at mesial site and buccal site respectively ($p<0.01$). In comparison, mesial site’s MDs were significantly higher than that of buccal site ($p<0.01$).

4. Discussion

Aim of this study was to evaluate influence of the different finish line configurations of preparation on the marginal discrepancy of all-ceramics crown restoration using Micro CT. The null hypothesis that stated there was no significant difference in tested group should be rejected on the basis of present study.

![Figure 2: Comparison of AMD mean of three groups at buccal, lingual, mesial and distal locations.](image-url)
Minimal marginal discrepancy remains essential factor for clinical success of all-ceramics crown restorations. However, marginal discrepancy influences by various manufacturing process parameters but finish line configuration of preparation is one of the primary stage design parameter. In addition, method used for measurement of marginal discrepancy is another whole process influencing factor. In the literature, in order to evaluate marginal discrepancy, various destructive and nondestructive, and quantitative and qualitative measurement methods have been applied. Micro CT, a non destructive evaluation method has capability of 2D and 3D investigations of the marginal and internal fit at multiple sites and directions within a few micrometers [39,40,41]. Major disadvantages of this technique are the low power of distinction in inadequate radiographic contrast cases and radiographic artifacts [42]. In the present study, lithium disilicate crown restorations are introduced for investigation of influence of different finish line configurations on marginal discrepancy of all-ceramics crown restorations. To apart the disadvantages of Micro CT measurement approach, Synchrotron X-Ray Micro CT was used. In this study, Image J software implemented to investigate the marginal discrepancy at 2D reconstructed slices.
However, many researchers have criticized the marginal and internal discrepancies of CAD/CAM fabricated crown restorations [42,43]. Deoggu et al [44] investigated restoration prepared with shoulder finish line. The mean marginal discrepancies seen in this study were between 200.2 to 253.3µm. But recent studies reported better marginal discrepancy results for crown restoration fabricated with CAD/CAM. Euan et al [27] found marginal discrepancies between 17.2 to 72.8µm for group of crown restorations with chamfer finish line whereas those for round shoulder finish line crown restoration group were between 13.9 to 63.1µm. The differences could be explained by restoration fabrication process and discrepancy measurement method used in these studies. Moreover, no clinical guidelines of acceptable marginal discrepancy value for all-ceramics crown restorations fabricated with CAD/CAM in the literature but the maximum clinical acceptable marginal discrepancy value 165µm suggested by some authors [45,46]. In later studies below 150µm considered acceptable value [47,48]. A clinical study by Maclean and Fraunhofer over 5 years included 1000 restorations, recommended 120µm as upmost marginal discrepancy value [17].

Although, various studies investigated the marginal discrepancy of lithium disilicate crown restorations. In a research by Kim et al [35] three groups of mandibular first molar classified by different impression techniques and manufactured with CAD/CAM were investigated with Micro CT and found that the marginal discrepancies MDs of three lithium disilicate crown restoration groups were between 129µm and 207µm whereas the maximum mean absolute marginal discrepancy AMD seen in this study was 155.5µm which were significantly higher than those of reported in another study by Mously et al [42] In addition, Reich et al [11] reported marginal discrepancy about 101µm whereas Yildrim et al [38] found it 129µm in their respective studies for IPS crown restorations. In the present vitro study including all three groups, results for maximum mean marginal discrepancy MD (99.6µm) and absolute marginal discrepancy AMD (104.4µm) were below clinical acceptable value (120µm). However, marginal discrepancies of both DCFLC group and RSFLC group had no significant differences but these were significantly lower than those of SFLC group. The reasons of this difference may be (a) Preparations with shoulder finish line had more depth than those of preparation with chamfer finish line and round shoulder finish line. (b) Due round angle between gingival and axial surfaces, the preparations with chamfer finish line provided more accurate seat for the crown whereas preparations with shoulder finish line had slight round angle that lead to partial seat of crown and enlarged the vertical gap. The other existing causes may be limited [49,50,51].

Nevertheless, other than finish line design, various other design parameters i.e. convergence angle, cement space; fabrication process parameters i.e. impression technique, scanner, milling process, porcelain firing; as well as discrepancy measurement technique influence the marginal and internal discrepancies of all-ceramics crown restoration. In this study, to provide the homogeneity in complete fabrication process and experimental conditions, all the preparations and crowns were designed using common parameters while fabricated with same manufacturing setup. However, during scanning process the beam current of Micro CT was not constant but tube power was sufficient to achieve necessary image resolution.

5. Conclusion

For all-ceramics restorations, marginal discrepancies of lithium disilicate crown restorations were below clinical acceptable range and restorations designed with RSFLC and DCFLC demonstrated superior results compared to preparations designed with SFLC.

6. References
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