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The Effect of Preparation Quality on Marginal Fitness of CAD/CAM Restorations

Hsuan Chen[1] and Ming-Lun Hsu[1*]

*[*1]School of Dentistry, National Yang Ming University, Taiwan*

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ABSTRACT

Marginal fit of the crown is a key assessment of the fixed partial denture quality. Numerous studies have been performed to evaluate the marginal fit of CAD/CAM all-ceramic crowns fabricated under ideal conditions, but very few studies have investigated the impact of real clinical factors, such as the quality of the abutment preparation. The purpose of this study is to evaluate the effect of preparation quality on the marginal fit of CAD/CAM crowns. Fifteen dental clinicians made three preparations of the upper left first molar on the typodont, and the quality of the preparation was objectively determined using preparation analyzer software. CAD/CAM crowns were fabricated using the standard digital workflow on the CEREC System. The marginal fit of the crown was measured using the Triple-Scan Protocol, and digitally analyzed and measured in 3D with computer software. Out of 45 prepared abutments, 19 were rated “poor” (PP) and 26 were rated “good” (GP). The average marginal gap in PP and GP were 82.13 (±9.41) µm and 62.12 (±10.11) µm, respectively. Statistical analysis with two-tailed t-test showed p-value < 0.01, indicating significant difference between the two groups. Within the limitations of this study, the quality of the margin preparation has significant effect on the marginal fitness of the CAD/CAM all-ceramic crown

Keywords: Preparation quality, CAD/CAM, Triple scan protocol, Over-mill, Marginal fitness

Abbreviations: GP: Good Preparation; PP: Poor Preparation; ME: Marginal Edge; MR: Marginal Ramp; TSP: Triple Scan Protocol

INTRODUCTION

Recent developments in dental CAD/CAM have vastly improved its technical maturity, producing restorations that are not only clinically acceptable and reliable, but cost-effective as well [1]. An abundance of literature exists that compare the quality and accuracy of restorations fabricated from conventional workflow versus those from digital procedures. In general, their conclusions can be split into two groups. Either the studies concluded that there was no significant difference in quality [2-4], or that digital workflows are more accurate [5-7].

Fitness of a restoration is a measure of accuracy, and it can be evaluated by measuring the space between the restoration and the underlying abutment. McLean et al conducted a 5-year clinical study evaluating marginal fit of crowns, and determined that marginal gaps up to 120 µm were acceptable [8]. Several authors also considered marginal gaps between 100 and 150 µm to be clinically acceptable [9-11]. The source of this large variance in accuracy is of considerable clinical interest, considering that the resolution of most dental milling machines is around 25 µm.

In an in-vitro study, the authors compared the marginal gaps of lithium disilicate crowns fabricated by using three different impressions techniques: one conventional and two digital. The typodont tooth was prepared extra-orally with a clear guide, and the marginal gaps of the final crowns were measured using a stereomicroscope. The overall marginal gaps for conventional and two digital methods were 112.3 µm, 89.8 µm, and 89.6 µm, respectively [3]. In another study extracted molars were prepared extra-orally to the recommended reduction guidelines, and the marginal fitness of their respective CAD/CAM crowns were compared. The study also concluded that marginal discrepancies in all cases

Corresponding author: Ming-Lun Hsu, School of Dentistry, National Yang Ming University, Taiwan. Email: mlhsu@ym.edu.tw

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met the clinically-acceptable standard [12,13]. Similar conclusions can be observed from other similar studies that compared marginal fitness of CAD/CAM crowns [14,15].

Most of these studies use ideal abutments either prepared extra-orally or replicated using metal casts. In real clinical situations, ideal preparations are impractical due to a multitude of environmental, human, and technical factors. One study that attempted to investigate the human factor examined the marginal fit of crowns fabricated with the E4Dsystem (PLANMECA, Finland) and its correlation to the quality of the abutment preparation [16]. The prepared abutments were categorized into "excellent", "fair", or "poor" quality based on visual inspection. In its discussion, the authors admitted to the possibility of bias and subjectivity with this method. Therefore, the purpose of this study is to use an objective assessment of preparation quality, and to investigate whether the preparation quality has a significant effect on the fitness of the final CAD/CAM crown.

METHOD

Preparation

Fifteen dentists from a teaching hospital, with clinical experiences ranging from 2 to 18 years, were recruited as subjects of this study. All participants were given a mandatory 10-minute presentation that reviewed important preparation parameters. Each participant prepared the same tooth (#26) on the typodont (Kao Dental GmbH, Germany) three times. The first preparation was preceded by a 5-minute calibration period, during which the subjects were able to familiarize themselves with the hardware. All subjects were provided with identical sets of new burs (**Figure 1**). In the period between each preparation, the prepared abutment tooth was removed from the phantom-head and the typodont. The subjects were not allowed to see the removed teeth until all three preparations were finished. Once the preparation phase has completed for the subject, the three abutment teeth were collected, rinsed with tap water, labeled, and stored in separate containers.

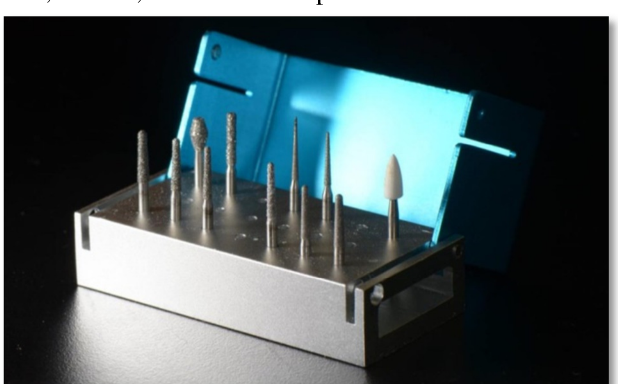

Figure 1. High-speed burs provided to each subject.

Crown Fabrication

The CEREC Omnicam (Dentsply-Sirona, Germany) was used to create the digital impression of the prepared abutments. Once the scan data has been acquired, it was analyzed using the Preparation Analyzer tool to assess the margin quality of the preparation, which was subsequently categorized into two groups. If the Preparation Analysis showed no warning, then the preparation is assigned into the "good preparation" (GP) group. If the software showed one or more warnings on the margin, then the preparation is designated as "poor preparation" (PG).

For digital restoration design, the original morphology of the unprepared tooth was used was used an index. The material selected for fabrication is the feldspathic porcelain Mark II 14-mm bloc (VITA, Germany), and all restoration parameters were set to manufacturer's recommended defaults. The restorations were milled in the In Lab MCXL (Dentsply-Sirona, Germany) using extra-fine settings with 12Sburs. The burs were replaced after having milled 10 crowns. Each crown was visually inspected for milling defects and re-milled in the off-chance that defects were detected. Then the sprues were removed and polished via a low-speed hand-piece, and the lumen surfaces steam-cleaned before trying-in on the abutment.

Analysis

The primary technique used for the data acquisition in 3D marginal fit analysis is the Triple Scan Protocol (TSP) [17]. In this study, the TRIOS intra-oral scanner (3Shape, Denmark) was used as the scanner in the protocol. The Triple-Scan Protocol consists of three scans. First, the crown is fixed in place with beading wax, with the lumen surface facing up and all external axial surfaces exposed (Scan #1). The TRIOS was then used to scan using high-resolution mode. The number of 3D image stacks was limited to under 300, irrespective of the scanning time. After scanning was completed and inspected in the software for holes, the file was converted and saved into ASCII STL file format. For the second scan of the protocol, the prepared abutment scanned in a similar method to the previous step, and the final model was converted into STL file format (Scan#2). Finally, the third scan of TSP consists of both the crown and the abutment in their seated positions (Figure 1). Before the scan, the porcelain crowns were seated onto the abutments with light-body silicone (3M). Maximum finger pressure was applied for 5 minutes until setting, and entire specimen was scanned using the same method as the previous steps (Scan #3).

3D Marginal Analysis

Geomagic Studio was used for to create 3D registration of the crown (Scan #1) and the abutment scan data (Scan #2), using the scan data (Scan #3) as reference. The margin of the prepared abutment was divided into two regions. The area from the edge of the margin to the highest curvature before the axial wall was designated as the marginal ramp (MR) (**Figure 2**). The outer band of MR consisting of all mesh triangles in contact with the edge boundary was designated as the marginal edge (ME). Once these two regions were specified on the abutment, their average distance to the lumen side of the corresponding crown model can be determined using standard software functions. For each region, the mean and maximum distances across all sampling points were calculated.

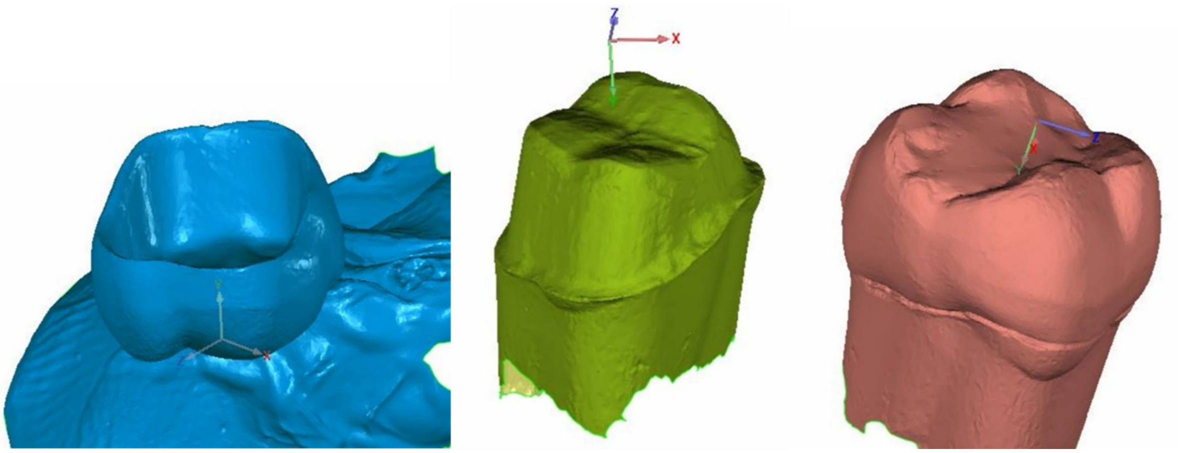

Figure 2. Digital impressions of the restoration's lumen and external axial surfaces (left), the prepared abutment (middle), and the restoration bonded to the abutment (right).

RESULTS

The numbers of samples in PP and PG groups were 19 and 26, respectively. The mean gap measurements using data acquired from TSP were as followed; For ME, the mean gap size for PP was 82.13 µm (±9.41), while the mean gap size for GP was 62.12 µm (±10.11). For MR, the mean gap size for PP was 99.15 µm(±13.46), while the mean gap size for GP was 86.25 µm (±14.23) (**Figure 3**). No samples were rejected during inspection.

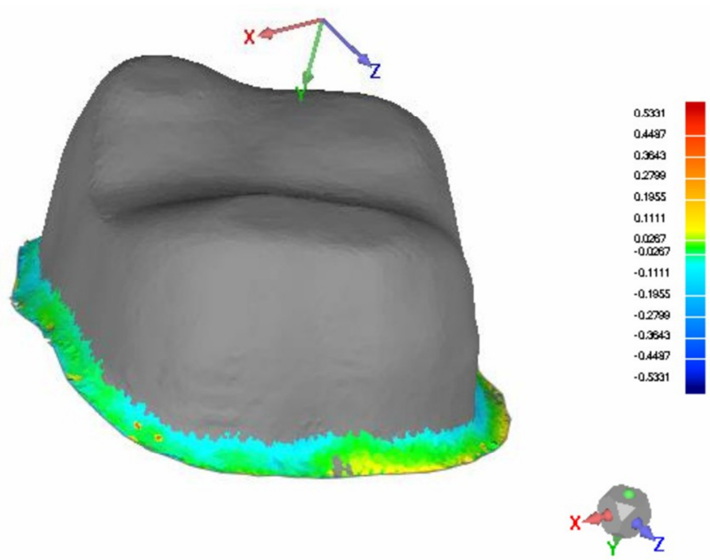

Figure 3. Visualization of the marginal gap distances in three dimensions. The colored band indicate the region defined as the marginal ramp.

STATISTICAL ANALYSIS

The results for data from ME and MR indicated statistical significance ($p < 0.01$) between PP and GP values. For ME results, the t-score was 6.82 with 43 degrees of freedom. For MR results, the t-score was 2.87 with 43 degrees of freedom.

DISCUSSION

For CAD/CAM restorations, marginal fitness is often of primary concern because it directly correlates to the long-term health of the dentition and the surrounding tissue [13,18,19]. Marginal fitness, or discrepancy, is defined as the "vertical dimension from the finish line of the preparation to the margin of the restoration" [20]. Poor marginal adaptation of the restoration can increase micro leakage and plaque accumulation, leading to cement dissolution, secondary caries, and periodontal disease [21]. There is, however, no clear guideline for clinically acceptable marginal fit. Christensen [22] considered 39 µm to be the acceptable marginal discrepancy according to the linear regression prediction formula. Several authors also considered marginal discrepancies between 100 and 150 µm to be clinically acceptable [8-11].

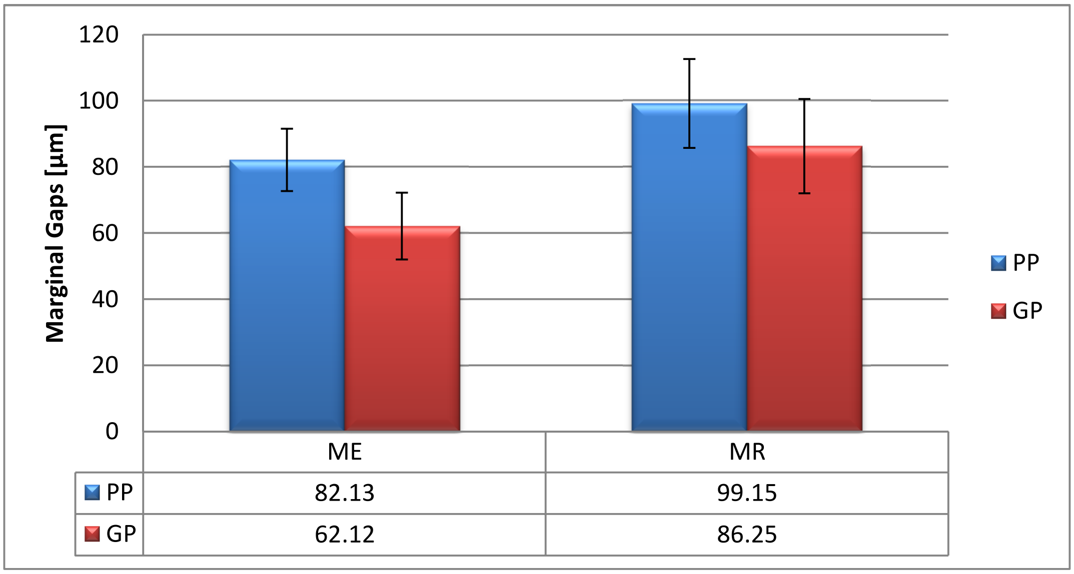

Figure 4. Mean marginal gaps at two different measuring sites. ME: marginal edge; MR: marginal ramp.

While digital workflows have shown to produce clinically acceptable margins [3,12,13], these kinds of studies mostly utilize abutments that were optimally prepared in-vitro. Ucar et al. [23] used machined steel dies to evaluate the internal fitness of laser-sintered crowns. Seker et al. [1] and Baig et al. [15] prepared extracted premolars with a uniform 1 mm rounded shoulder margin to evaluate marginal fit of CAD/CAM restorations. These studies failed to capture the inevitable variance caused by human error. In a real clinical setting, factors such as poor viewing angles, inadequate lighting, mouth opening limitations, and the skills of the dentist can potentially cause teeth preparations to become suboptimal. Therefore, the results from these previous studies represent the best-case scenarios that are very unlikely to occur.

Since in practice, dentists are able to detect gaps at only the margins with a dental probe [22], the criteria for preparation quality in this study is limited to the marginal area. In this study, the average gaps at ME for the PP and PG groups were 82.13 µm and 62.12 µm, respectively. The ME marks the band of area directly adjacent to the edge of the finish line, and the gap values in this study were all within the clinically acceptable value of 120 µm [8]. Furthermore, they are also in agreement with other similar studies that used intra-oral scanners to fabricate single crown restorations [13,15,24-26]. According to a systemic review [27], which performed a meta-analysis on the evaluation of marginal fit of single-unit full coverage ceramic restorations, the mean value of the marginal fit for in-vitro restorations fabricated after digital impressions was 63.3 µm(95% CI: 50.5–76.0 µm). Considering that these studies used optimally prepared abutments under controlled settings, the marginal fitness obtained for the GP group in this study (62.12 µm) is very close to the value obtained in the systemic review. This seems to suggest that if the marginal preparation is of sufficiently quality, then near-optimal marginal fitness can be achieved. On the other hand, if there are areas of roughness or acute angles that can be detected by the analysis software, then these imperfections are transferred to the fitness of the final crown.

The software used for preparation quality assessment, Preparation Analysis, is a simplified version of prep Check (Dentsply-Sirona). It checks the curvature process of the preparation margin, and if the margin exceeds a determined section length of a predefined curvature, the region is highlighted as a warning. The predefined curvature can be indentations or protrusions, and it is correlated to the milling process. The marginal fit of the CAD/CAM crown is dependent on how accurately the milling device can reproduce the contours of the preparation. Since milling is performed with burs, the radius of the bur poses a physical limitation on how fine a detail can be milled. Therefore, small features or contours smaller (i.e. rough surfaces, sharp angles) cannot be perfectly reproduced. When this problem is encountered during the milling pathway analysis, there are two options for the software algorithm. First, to ensure complete seating of the crown, the software will generate a milling path that guarantees milling of all surface features.

This is called over-milling [28], and it necessitates the creation of extra cement space around the problem region as a compromise. The alternative method is to simply ignore the geometries that cannot be milled, and instead favor the preservation of crown integrity. This is called under-milling, and it can potentially cause an inability for the crown to completely seat. For the marginal regions with severe enough roughness, either milling strategy will result in increased marginal gaps.

In a study, researchers fabricated 75 crowns based on abutments of varied preparation quality determined by visual inspection [16]. The study concluded that preparation quality has a significant effect on marginal gap when using chair side CAD/CAM systems and that common error in preparation design had a negative impact on the mean marginal gap. While our results concur, the determination of quality by visual inspection was subject to potential bias. In fact, several other studies have evaluated the intra-rater variability for the assessment of dental preparation quality, and found the intra-rater agreement to be between 0.53 and 0.68 [29,30], representing up to 22% variance in binary pass/fail decisions [31]. In contrast, our study uses the built-in preparation analysis tool (Dentsply-Sirona, Germany) to objectively evaluate the quality of the preparation.

The methods of evaluating the crown fitness have been well established in literature. For marginal fit, studies have used the optical microscope [1,13,15,32-35], scanning electron microscope [1,33,34] or silicone replica [4,13,14], [16,21,25,32,36]. According a systemic review by Nawafleh et al. [37], the direct-viewing technique (i.e. microscopes) is the most common method of studying marginal fitness, accounting for 47.5% of the 183 papers reviewed in the study. The study concluded that the there was a substantial lack of consensus relating to marginal adaptation of various crowns, because of the large variance 0in the results obtained. The silicone replica method, or any embed-then-section methods [24], for measuring marginal and internal fitness suffers from one major flaw: using a 2D method to analyze 3D metrics. A recent study by Kuhn et al. [38] compares analog and digital quantitative and qualitative analysis for the fit of dental copings, and concluded that the analog 2D replica technique revealed a loss of information due to the cutting process. In order to maximize the retention of data, our study employed TSP and digital software analysis for true 3D measurement.

Recently the Triple-Scan Protocol (TSP) was described and validated for the fitting accuracy assessment of cast metallic frameworks, titanium copings, and lithium disilicate partial crowns [17]. This protocol allows for the virtual registration of two scanned models (abutment and crown) in relation to the third reference model (crown bonded to abutment). The TSP is non-destructive and eliminates a great number of shortcomings of 2D fitting accuracy assessment techniques that have been applied routinely in other studies.

In a study by Boitelle that used the TSP methodology to evaluate 3D fitting accuracy of CAD/CAM copings, the marginal and internal fitness of the restoration was divided into three regions [39]. Using the height of the abutment as the reference, the abutment was separated into the marginal (bottom 15%), the occlusal (top 15%), and the axial (middle 70%) zones. While this strategy provided a quick method to differentiate various aspects of the abutment, it would only be useful if the prepared abutment was both axially and radially symmetrical. Since the teeth were prepared by real clinicians in our study, the height and width of the margin were highly variable. Therefore, our study used the morphology of the abutment to delineate different regions. The mean gap sizes of the marginal area in Boitelle's study ranged between 54.32 – 66.56 µm, depending on the digital system used, while in our study the corresponding fitness of the marginal ramp was 86.02 µm.

While the data seems to suggest that even poor-quality preparations can produce, on average, clinically viable results, these results are only average values. The presence of variance means that a percentage the margins can potentially be larger than the acceptable value. The inability for milling machines to compromise means that there is higher sensitivity to preparation errors.

CONCLUSIONS

Within the limitations of this study, the following conclusions can be made:

1. There is a significant difference in the marginal fitness of crowns fabricated from good quality preparations when compared with those fabricated from poor quality preparations. Therefore, the null hypothesis is rejected.
2. Regardless of preparation quality, the marginal gaps of CAD/CAM crowns were all within the clinically acceptable range.

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