Published in final edited form as:

J Esthet Restor Dent. 2015 ; 27(4): 194–202. doi:10.1111/jerd.12148.

Evaluation of the Marginal Fit of CAD/CAM Crowns Fabricated Using Two Different Chairside CAD/CAM Systems on Preparations of Varying Quality

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Abstract

Purpose: This study evaluated the marginal gap of crowns fabricated using two new chairside computer-aided design/computer-aided manufacturing systems on preparations completed by clinicians with varying levels of expertise to identify whether common preparation errors affect marginal fit. The null hypothesis is that there is no difference in the mean marginal gaps of restorations of varying qualities and no difference in the mean marginal gap size between restorations fabricated using the PlanScan (D4D, Richardson, TX, USA) and the CEREC Omnicam (Sirona, Bensheim, Germany).

Material and Methods: The fit of 80 lithium disilicate crowns fabricated with the E4D PlanScan or CEREC Omnicam systems on preparations of varying quality were examined for marginal fit by using the replica technique. These same preparations were then visually examined against common criteria for anterior all-ceramic restorations and placed in one of four categories: excellent, good, fair, and poor. Linear mixed modeling was used to evaluate associations between marginal gap, tooth preparation rating, and fabrication machine.

Results: The fit was not significantly different between both systems across all qualities of preparation. The average fit was 104 μ m for poor-quality preparations, 87.6 μ m for fair preparations, 67.2 μ m for good preparations, and 36.6 μ m for excellent preparations.

Conclusion: The null hypothesis is rejected. It can be concluded that preparation quality has a significant impact on marginal gap regardless of which system is used. However, no significant difference was found when comparing the systems to each other.

INTRODUCTION

Recently dentistry has been significantly influenced by digital technology. The emergence of newer and more user-friendly intraoral scanning devices has made the use of computer-aided design/computer-aided manufacturing (CAD/CAM) dentistry more mainstream. Recently, two new CAD/CAM systems have been introduced: CEREC Omnicam (Sirona, Bensheim, Germany) and E4D PlanScan (D4D, Richardson, TX, USA). Both systems are utilized by clinicians to fabricate restorations in a single visit by providing the capability for digital scanning of intraoral preparations and in-office fabrication of the final restoration via an on-site milling unit. It has been researched and concluded with the previous generation of chairside CAD/CAM systems that preparation quality has an impact of marginal fit of milled restorations and milled restorations may not be as forgiving of a manufacturing process compared with the lost wax technique.^{1,2} As chairside CAD/CAM technology improves and newer systems are released, it remains unclear if preparation quality still impacts marginal adaptation of the milled restoration. The purpose of this study is to evaluate the marginal gap of restorations fabricated using these two new CAD/CAM systems to determine if preparation quality has an impact on marginal adaptation of the milled restoration and if the marginal adaptation will vary between systems.

In order to investigate the marginal fit of CAD/CAM generated restorations, the marginal fit of conventionally fabricated restorations must first be reviewed as it is presented in the literature. Fortunately, many studies have been conducted evaluating the marginal fit of conventionally fabricated restorations and several general conclusions can be extrapolated from the literature.^{3–14} Restorations fabricated using conventional techniques generally have acceptable marginal fit, but the stratification in the literature range from 0 μm to 313 μm with a mean marginal opening of 155 μm .^{3,4} Interestingly, this average contrasts the often suggested acceptable marginal gap of 25 to 40 μm .^{5,6} In a landmark in vivo study, McLean and Fraunhofer determined that 120 μm is clinically acceptable for conventionally cemented restorations. This is in agreement with many other studies where 120 μm is considered in the range of clinical acceptability with regard to longevity.^{5,7–13}

The literature demonstrates conflicting evidence regarding the marginal fit of CAD/CAM restorations. Tamac and colleagues compared the marginal gap and internal fit of metal ceramic restorations fabricated using CAD/CAM milling and conventional casting techniques and found no statistically significant difference in fit.¹⁴ This study concluded that the marginal gaps of the cast group averaged 75.92 μm and the milled group averaged 86.64 μm .¹⁴ Contrastingly, in a different publication, hot isostatic pressed ceramics were demonstrated to have better fit compared to milled ceramics.¹ Despite these inconsistencies in the literature regarding chairside milled restorations, it has repeatedly been shown that marginal adaptation of laboratory milled restorations meets or exceeds those of conventional laboratory methods.^{15–22} For example, CAD/CAM fabricated implant frameworks and fixed partial dentures have been compared with those fabricated using conventional lost wax

technique, and the CAD/CAM fabrication method produced consistently better fits.^{17,22,23} In another study, four-unit fixed partial dentures fabricated using the Lava COS system (3M, St. Paul, MN, USA) were found to have better fit than restorations fabricated on the same cases using conventional impression techniques.²⁴ In a recent study, Brawek and colleagues compared the fit of restorations made from intraoral scans with both the Lava COS and CEREC AC Bluecam and concluded that at the mean marginal gap of the Lava COS crowns was 51 μm ($\pm 38 \mu\text{m}$) whereas the CEREC AC had a mean gap of 83 μm ($\pm 51 \mu\text{m}$), placing both in the range of clinical acceptability.²⁵ It has been repeatedly reported that the previous generation CEREC system yielded internal and marginal fit within the range of acceptability; however, often fit is evaluated using perfect preparations that may be impossible to achieve clinically.^{15,18,19,22,26} One study of ceramic onlay restorations compared CEREC Bluecam restorations to laboratory-pressed restorations and found that the CEREC-produced restorations had better marginal fit.¹⁵ Restorations fabricated with the most recent generation E4D system has also been researched and found to have excellent fit. One study showed that the E4D system had a mean marginal gap of 79.32 on the buccal and 50.39 on the lingual.²⁷ In a recent publication similar to the present study, e.max restorations fabricated using the previous generation E4D system on preparations of varying quality were evaluated. It was found that the mean marginal gap of crowns fabricated on ideal preparations was 38.5 μm . Those preparations considered fair had a mean marginal gap of 58.3 μm , whereas those categorized as poor averaged 90.1 μm .² This seems to indicate that preparation quality does have an impact on marginal adaptation in these older CAD/CAM systems.²

As new systems arrive on the market, it is essential to systematically and objectively evaluate the marginal fit of the restorations they produce. Studies indicate that a better marginal fit of the restoration leads to less microleakage, periodontal disease and recurrent caries.^{28,29} Although authors agree that marginal openings of less than 120 μm are in the range of clinical acceptability with regard to longevity, it can be concluded that the smaller the marginal gap the better the restoration will fare in the oral environment.^{5,12,13}

In this study, the replica technique was used to measure marginal gap.^{2,30–32} This technique has been validated as an accurate method of determining marginal misfit.^{33,34} This technique is a nondestructive evaluation method where light body silicone is used in place of resin cements for crown cementation and is accurate because the film thickness of the light body silicone most closely mimics that of resin cement.³⁵ It has been previously researched and determined that marginal gaps obtained with resin cement are not statistically different than those obtained with light body vinyl polysiloxane (VPS) impression material, and therefore the replica technique is very accurate.³⁵ Marginal gaps increase after cementation because of the cement impacting the fit; therefore, fit can be considered better when evaluated without a viscous medium such as cement and any gap value measured postcementation is artificially high.^{4,22–40}

In the present study, marginal discrepancies were measured after simulating cementation with a light body VPS material, possibly increasing the value of the true marginal gap but giving a value similar to that found in a clinical situation.^{4,22–40}

It is clear that milled restorations can have excellent fit on perfect preparations; however, many practitioners may not have been taught the ideal all ceramic CAD/CAM preparation in dental school. Because of the subtractive process of manufacturing fluctuations and variations in finish line, smoothness and design may have a profound impact on final restoration fit. Although practitioners may understand that certain guidelines for tooth reduction must be followed, some fine details such as finish line design and smoothness may be overlooked. This may be because until now many dental labs have utilized the more forgiving lost wax technique to fabricate restorations. CAD/CAM systems produce milled restorations. For restorations fabricated in this manner, it may be particularly important to follow preparation guidelines. Currently, milling systems use fairly large diameter rotary diamonds that machine every surface of the restoration. The size of these diamonds may limit the ability of the mill to accurately replicate certain preparation errors.

Because of the newness of these two CAD/CAM systems, little research is available about the relationship between preparation design and the marginal fit of the milled restorations that they produce. The null hypothesis is that there is no difference in the mean marginal gaps between the crowns fabricated on poor preparations and those on ideal preparations with the E4D PlanScan and the CEREC Omnicam, and that no difference exists in marginal gaps of restorations fabricated on the same preparations by both systems.

MATERIAL AND METHODS

Preparation of Specimens

For this study the definition of marginal gap is defined as reported by Holmes and colleagues⁴¹ as the perpendicular measurement from the internal surface of the crown to the preparation closest to the finish line. Forty clinicians with varying degrees of clinical experience ranging from 3 to 38 years were calibrated to ideal preparation parameters through a 1-hour lecture based on the most current texts of Rosenstiel and colleagues and Shillingburg and colleagues.^{42,43} They then prepared a ceramic preparation on Typodont tooth #8 (Kilgore, Coldwater, MI, USA), as shown in Figure 1, and each die was inserted into a 200 series Typodont (Model D85SDP-200, Nissin, Japan) to simulate intraoral scanning. Dies were scanned into the E4D PlanScan system and the CEREC Omnicam system. The crowns were fabricated from e.max CAD C14 A2 blocks (Ivoclar Vivadent, Mississauga, ON, Canada) on the E4D PlanMill (D4D) on standard mill setting and the CEREC MCXL Mill (Sirona) on normal mill setting. The mills and cameras for both systems were calibrated prior to the study. For the PlanMill, new Two Striper diamonds (Premier Dental, Plymouth Meeting, PA, USA) were inserted before the study and were replaced when worn or broken as indicated by the mill. Likewise, for the CEREC new 12S stepbur and 12S cylinder pointed burs (Sirona) were used and replaced when worn or broken. Default cement space and margin settings were used on each system. Preparations were visually evaluated by the researchers and categorized as excellent, good, fair, and poor according to the number and level of severity of deviations from the ideal. Excellent preparations had no noticeable errors in preparation design. Good preparations had one to two common errors present, fair preparations had three to four, whereas poor preparations

had five or more visible errors. The most common errors included beveled, lipped or J-shaped margins, sharp cervicoaxial line angles, and spiked margins with serrated finish lines.

Milling

The E4D PlanMill and CEREC MCXL were used to fabricate 40 crowns. Each crown on the PlanMill was made on standard mill mode, which uses the Two Striper ellipsoidal diamond rotary cutting instrument to mill the intaglio surface and the tapered Two Striper diamond rotary cutting instrument to mill the external surface. The PlanScan software was used to control the cement gap and marginal ramp in order to standardize each restoration. The default parameters used included a 100- μ m cement gap and a 250- μ m marginal ramp. The marginal ramp setting is the area of the margin on the crown that should be in contact with the tooth before the cement spacer starts. Therefore, a marginal ramp setting of 250 μ m indicates that the outer 250 μ m of the margin of the crown should be in contact with the preparation and then the cement spacer starts. Likewise the CEREC MCXL mill used size 12S step bur and 12S cylinder pointer burs to mill 40 restorations on the same preparations as above. The CEREC Omnicam software version 4.2.4 default mill settings were used to control the cement space and margin to settings of 110 μ m for spacer and 500 μ m for margin ramp. Also margin thickness for the crown was increased to 80 μ m to prevent chipping during the milling process for restorations underprepared at the finish line.

Replica Technique and Measurement

A green light body VPS rubber impression material (Genie, Sultan Healthcare, Englewood, NJ, USA) was used help visualize the marginal gap. A single operator, blind to the specimen groups, injected the crowns with light-bodied VPS material and placed them on the corresponding die with maximum finger pressure. After the 5 minutes manufacture recommended set time, the excess VPS material was trimmed and the crowns were gently removed from the dies. A film of green light body VPS remained attached to the typodont tooth preparation, representing the misfit of the restoration. This fragile film was carefully supported with a reflective blue VPS bite registration material (Flexitime Bite, Heraeus, South Bend, IN, USA). This material was injected into a custom fabricated tray and placed on the typodont die that had the light body VPS attached to it. Once set, the reflective bite VPS bonded to the light body VPS, creating a stable replica of the misfit that can then be handled without deforming the green layer (Figure 2).

After the supporting material had set, each silicone replica was removed from the die and sectioned with a razor blade in four locations. Sections were placed on the ViewMet Inverted Laboratory Metallograph Microscope (Buehler, Lake Bluff, IL, USA) and viewed at $\times 100$ magnification. A green filter was used to further create more contrast between the green VPS and the blue Bite registration material. The digital images were captured with a digital camera (Ueye, Obersulm, Germany) connected to the microscope. Measurements were made of the marginal gap with the digital software Omnimet 8.81(Buehler) (Figure 2). The software was calibrated before the start of the project and checked at several intervals to ensure accuracy. A total of eight measurements were made for each crown: two buccal, two lingual, two mesial, and two distal.

Statistical Analysis

The primary outcome of interest was the marginal gap at the eight locations. The null hypothesis is that there is no difference in the mean marginal gaps of restorations on excellent, good, fair, and poor preparations, and there is no difference in marginal gaps between restorations fabricated using the E4D PlanScan and the CEREC Omnicam. Linear mixed modeling was used to evaluate associations between marginal gap and tooth preparation rating and fabrication machine. The models included random tooth effect to account for the correlation between measures taken on the same tooth. Different covariance structures were considered including compound symmetry and unstructured, selecting the most appropriate structure by comparing AIC. All analyses were conducted in SAS v. 9.3 (SAS Institute, Cary, NC).

RESULTS

Crown preparations were ranked on a scale from poor to excellent prior to evaluating the marginal gap of each fabricated crown. Thirty percent of the preparations were ranked as poor, 35% were ranked as fair, 22.5% were ranked as good, and 12.5% were ranked as excellent. In the linear mixed model, quality of the preparation was significantly associated with marginal gap with marginal misfit decreasing as quality of the preparation improved ($p < 0.001$). There was not a significant difference in marginal gap between crowns prepared by the E4D PlanScan and CEREC Omnicam systems after controlling for quality of the preparation ($p = .761$). Mean marginal gap for the different levels of quality and by fabrication methods are shown in Table 1. Figure 3 is a boxplot showing the distribution of marginal gap by quality of the crown preparation across both machines.

DISCUSSION

The null hypothesis was partially rejected as a statistically significant difference was found among all groups; therefore, preparation errors had a direct effect on the mean marginal gaps of restorations. However, no statistical difference was found in the marginal gap of restorations fabricated using the CEREC Omnicam and the E4D PlanScan system. Within the limitations of this study, it was shown that certain preparation design flaws had an adverse effect on the marginal fit of the restorations fabricated by the latest CAD/CAM systems. It seems that meticulous attention to dental must be followed particularly as it relates to the preparation finish line. The most common flaws were sharp cervicoaxial line angles, lipped margins, and beveled and/or spiked finish lines. In general, the preparations that yielded the poorest fitting restorations could be predicted based on the presence and severity of these errors.

While preparing the teeth for ceramic crowns, the operators were asked to create a modified shoulder finish line. The modified shoulder is created with an 847KR018 (Brasseler, Savannah, GA, USA) diamond rotary cutting instrument. It is an ideal bur for ceramic finish line preparation. The tip of this bur creates a 1-mm rounded shoulder, as shown in Figure 1. A lipped finish line is created when greater than the entire diameter of a shoulder diamond bur is used. The lipped area may cause chipping in the mill, or a binding spot at the margin preventing other areas of the restoration from seating correctly.

A major limitation of current CAD/CAM mills is their inability to replicate the features caused by these preparation errors. This is due to the large diameter of the rotary cutting instruments used for the milling process. For example, one common preparation error is a spike at the cavosurface margin. The instrument that is used to mill in standard mode is unable to accurately reproduce this sharp spike in the ceramic. This is illustrated in Figure 4. The standard bur for milling the margin on both systems is around 1.3 to 1.5 mm in diameter and thus is not able to precisely mill very rough, spiked, or lipped finish lines when the defect is less than the diameter of the bur. The two errors that result are either overmilling where the mill will over grind the spike area creating a marginal gap or undermilling where the mill will ignore the spike causing a premature binding spot preventing full seating of the restoration. It is worth noting that both systems offer smaller burs for milling restorations requiring more detail such as inlays and veneers; however, standard settings were used to mimic typical clinical situations.

An increasing number of laboratories are using CAD/CAM technology to fabricate restorations and may also have similar problems with poorly finished preparations. Formerly, the lost wax technique was used to create fixed prosthesis with metal copings. This technique was far more forgiving than modern milling techniques. It is important for clinicians to realize that the quality of the preparation will affect the marginal fit of the restoration regardless of whether they are fabricated in-office or by a dental laboratory.

Some potential problems with the design of this study may include variability within the mill itself, such as diamond rotary cutting instrument wear and water quality. These factors may affect the quality of the milled restoration. Likewise, errors in visual inspection and characterization of the preparations may have been a factor. Although careful examination with $\times 2.5$ magnification loupes was conducted, it is possible that errors were overlooked or were too minute to detect under this level of magnification. Additionally, scanning preparations on a typodont and in the absence of oral fluids such as saliva and heme is not indicative of how challenging it can be to scan intraorally.

It is worth noting that all restorations were deemed clinically acceptable by experienced clinicians. However, it is the hope of the authors that practitioners will be able to recognize and correct these common preparation errors in order to improve the overall fit of their restorations.

CONCLUSION

Within the limitations of this in vitro study, it can be concluded that preparation quality has a significant effect on marginal gap of the restoration when the clinician uses either CEREC Omnicam or E4D Planscan. The null hypothesis was rejected. It was found that common errors in preparation design have a profoundly negative impact on the mean marginal gap. It was concluded that these errors can be detected with routine examination of the finish line and therefore could be avoided by further smoothing. Common finish line errors if left on the preparation are difficult for the milling system to replicate adequately because of the size and shape of the diamond rotary cutting instrument; therefore, extra care should be taken regarding the smoothness and quality of all-ceramic chairside CAD/CAM preparations.

DISCLOSURE AND ACKNOWLEDGEMENTS

I (Walter Renne) and Dr. Mennito have done a few Continuing Education lectures for E4D. We are not paid consultants. Dr. Kessler is a CEREC trainer and lecturer for Sirona Dental.

The authors would like to acknowledge Ivoclar Vivodent for providing all the e.max blocks used in this study. Dr. Renne has spoken on behalf of both Patterson and E4D/Henry Schein at continuing education and training events and Dr. Mennito has spoken on behalf of E4D at continuing education and training events. Both have received honorariums for speaking. Dr. Kessler is a consultant and certified CEREC trainer for Patterson.

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CLINICAL SIGNIFICANCE

Within the limitations of this in vitro study, it can be concluded that crown preparation quality has a significant effect on marginal gap of the restoration when the clinician uses either CEREC Omnicam or E4D Planscan.

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FIGURE 1.
Description of an ideal ceramic anterior crown preparation.

FIGURE 2.

A segment of sectioned vinyl polysiloxane (VPS) material showing the contrast between the two impression materials as it looks to the human eye as well as blown up on the microscope.

FIGURE 3.
A boxplot showing the distribution of marginal gap by quality of the crown preparation across both machines.

FIGURE 4.
Visualization of why milling burs are not able to accurately mill to marginal errors.

TABLE 1.

Mean marginal gap by quality of the crown preparation and by crown fabrication machine

Quality	Marginal gap	95% CI
Poor	104.0	92.5, 115.4
Fair	87.6	77.0, 98.2
Good	67.2	54.0, 80.4
Excellent	36.6	18.9, 54.4
System		
E4D PlanScan	81.0	71.2, 90.8
CEREC Omnicam	82.1	72.4, 91.9

CI = confidence interval.