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Factors Affecting the Marginal Fit of CAD-CAM Restorations and Concepts to Improve Outcomes

Alan Atlas[1,2,3] · Wael Isleem[4] · Michael Bergler[5] · Howard P. Fraiman[2,4] · Ricardo Walter[6] · Nathaniel D. Lawson[7]

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Abstract

Purpose of Review With the advent of CAD-CAM technology, it is essential to examine factors that affect outcomes of restorations fabricated by the new methodologies.

Recent Findings This report assesses and compares ceramic crown fabrication systems to determine what factors affect marginal fit and provide solutions for better outcomes.

Summary The review revealed key scientific evidence about what factors influence the marginal fit of CAD-CAM ceramic restorations. Solutions were recommended to help the clinician achieve greater long-term success when providing this treatment to their patients. The dental microscope enables the dental practitioner to achieve improved clinical outcomes in all phases of restorative dentistry, especially CAD-CAM restorations.

Keywords CAD-CAM · Marginal fit · Marginal Gap · Ceramic restoration · Dental Microscope

Introduction

CAD-CAM technology for crown and bridge fabrication has rapidly expanded in the dental market during recent years primarily due to the belief that it can mill different restorative materials more accurately than conventional techniques [1•]. These conventional fabrication techniques include conventional casting, heat pressed manufacturing, slip casting, direct metal laser sintering, and copy-milling manufacturing processes [2•].

CAD-CAM systems differ in their scanning methods, software parameter settings, number of milling axes, and milling settings (i.e., wet or dry) [3]. Additionally, CAD/CAM systems are capable of milling several different classes of materials, which each possess various levels of machinability [4••]. The biggest questions that remains is how all these variables, either collectively or individually, affect the marginal fit and subsequently the short- and long-term clinical outcomes.

Marginal Gap, Marginal Discrepancy, and Marginal Adaptation

Marginal fit, discrepancy, and adaptation, regardless of the type of restoration, are critically important for longevity of dental restorations [5].

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✉ Alan Atlas
amatlas@upenn.edu

[1] Department of Endodontics, University of Pennsylvania School of Dental Medicine, Philadelphia, PA, USA

[2] Department of Preventive and Restorative Sciences, University of Pennsylvania School of Dental Medicine, Philadelphia, PA, USA

[3] Philadelphia, PA, USA

[4] Periodontal Prosthesis Program, Department of Periodontics, Philadelphia, PA, USA

[5] CAD-CAM Ceramic Center, University of Pennsylvania School of Dental Medicine, Philadelphia, PA, USA

[6] Department of Comprehensive Oral Health, University of North Carolina Adams School of Dentistry, Chapel Hill, NC, USA

[7] Department of Clinical and Community Sciences, School of Dentistry, University of Alabama at Birmingham, Birmingham, AL, USA

Holmes et al. [6•] stated the perpendicular measurement from the internal surface of the margin of the crown to the outermost edge of the finish line of the tooth margin is termed the marginal gap. Furthermore, absolute marginal discrepancy, according to Holmes, is the extension (over or under) of the crown margins in relation to the margins of the tooth substrate leading to misfit, plaque accumulation, and compromised periodontal status.

Crown misfit and marginal irregularities causing gaps at the tooth-restoration interface may lead to excessive cement at the margins with exposure to oral fluid triggering dissolution, microleakage, secondary caries, endodontic inflammation, and periodontal disease [7, 8].

The literature reveals several in vivo and in vitro quantitative evaluation fit methods for assessment of CAD/CAM prostheses [1•]. These include micro-CT, scanning electronic microscopy, triple scan protocol with virtual 3D analysis, and the silicon weight and density methods.

There is lack of agreement in the research regarding a clinically acceptable marginal gap with a recent systematic review of marginal adaptation of ceramic crowns indicating the widest marginal gap measured 174 microns, and the smallest measured 3.7 microns [5]. In 1971, McLean and von Fraunhoffer [9] completed an in vivo study of more than 1000 crowns and concluded that restorations with a gap and luting space of less than 120 microns is clinically acceptable. This landmark study is still considered today to be the standard reference for acceptable marginal gap even though the method of evaluation lacked scientific sophistication that exists currently. Recent studies on CAD-CAM-fabricated crowns reported marginal gaps between 50 and 100 microns [10–13].

The Evidence Demonstrating Marginal Gap Size and Restoration Failure Due to Bacteria Colonization, Demineralization, and Caries Development

The evidence thus far has shown that no matter what the fabrication method, a marginal gap of varying dimensions will exist. The major concern that remains is the threshold for marginal gap size where bacterial colonization can develop leading to demineralization and caries at the tooth-restoration interface. Recent in vitro studies [14–16] demonstrated that *S. mutans* possesses levels of esterase activity that degrade composite resin and adhesives. The authors concluded that caries can develop at the substrate-restoration interface caused by oral bacteria. Montagner et al. [17] showed that composite–dentin interfaces failed after aging demonstrating greater demineralization from interfaces with greater gaps ranging from 50 to 300 microns. Kuper et al. [18] concluded that patients with high caries risk are more susceptible to secondary caries development at a minimum marginal gap size of 68 microns. In a more recent study, Maske et al. [19•] concluded that very small marginal gaps of 30 microns develop secondary caries independent of the caries activity level of the patient. The evidence is suggesting that margin flaws and resulting gaps at the restoration –tooth substrate interface as low as 30 microns can lead to increased bacterial colonization, caries, and premature failure of the restoration.

Factors That May Influence Marginal Fit of CAD-CAM Crowns

Machining of CAD/CAM blocks results in marginal defects, cracks, chipping, subsurface damage, and residual stresses [4••, 20, 21]. After machining, CAD-CAM glass ceramic restorations undergo a heat treatment to ensure final crystallization and improve flexural strength. Recent studies by Fraga et al. [21] and Romanyk et al. [22] demonstrated that the damage induced by milling lithium disilicate and lithium silicate glass ceramics was not eliminated by the crystallization heat process. Additionally, in Fraga's study [21], surface roughness and defects after milling zirconia were less than what was observed with lithium disilicate.

Gold et al. [23] determined that a significant increase in the marginal gap for lithium disilicate crowns resulted from shrinkage of the ceramic at the margin during the crystallization firing process. Azarbal et al. [24] concluded in an in vitro study that the marginal gap for lithium disilicate CAD-CAM crowns was not clinically acceptable (less than 120 microns) after crystallization heat. The study also demonstrated that a hybrid ceramic material that did not require crystallization firing after milling showed superior marginal adaptation compared to the lithium disilicate material. Furtado de Mendonca et al. [25] concluded that although crowns fabricated from hybrid materials like high performance polymers (HHP) and polymer-infiltrated ceramic network (PICN) materials had less fracture and flexural strength than lithium disilicate and lithium silicate ceramics, they showed less chipping and catastrophic failure patterns.

In a critical review of the literature [26], studies evaluated compared the marginal fit of lithium disilicate crowns fabricated by the hot-press technique with the fit of those fabricated by the CAD-CAM technique. The conclusions found press ceramic restorations produced smaller marginal gaps compared with CAD-CAM restorations. Crowns fabricated by the hot-press technique require a complete contour wax pattern and pressing of ceramic ingots into the investment cast. Errors in preparation of the margin may be better managed when the lost wax technique is used in fabrication of the lithium disilicate crowns [27].

The effect of using different CAD-CAM systems on the marginal fit of the restoration has been evaluated. It was concluded by Shim et al. [28] that the fit of CAD-CAM restorations may be created by differences in software parameter settings and different design programs.

Hamza et al. in two separate studies [3, 29] concluded that the type and sophistication of the milling machine utilized for fabrication can affect the marginal fit of CAD-CAM crowns. A 5-axis milling machine produced a better marginal fit and more accurate restorations than 4-axis milling. Additionally, dry milling over wet milling of monolithic zirconia produced better restorations. Kirsch et al. [30] also concluded that 5-axis milling yields more accuracy; however, the 4-axis CEREC MCXL extra-fine mode showed chairside milling results comparable to those of 5-axis milling units with less milling time.

Contrepois et al. [5] in a systematic review on marginal fit of ceramic crowns concluded that four factors may influence marginal fit: value of the cementing space, veneering process, cementation, and finish line configuration.

Studies [13, 31, 32] examining marginal fit before and after cementation have found that marginal fit is inferior after cementation while the type of cement especially those that were more viscous and thicker had a significant negative effect on fit [33].

The Effect of Tooth Preparation on the Marginal Fit of CAD-CAM Crowns

Perhaps the most significant component affecting success or failure of CAD-CAM crowns may be the finish line configuration [34••]. Skjold et al. [35] studied zirconia crowns with two different preparations and found the chamfer preparation provided higher fracture loads compared to the slice preparation. The authors concluded that a thicker cervical collar provided greater fracture load. Lehmensiek et al. [36] concluded in an in vitro study that interfacial gaps of 100 microns and not the material (gold or lithium disilicate) or cementation strategy (glass ionomer or resin) determined the development of secondary caries under indirect restorations. The authors concluded that high interfacial integrity is required to prevent the formation of gaps and restoration compromise.

Winkelmeyer et al. [37] performed a retrospective study evaluating tooth preparations for zirconia crowns and fixed partial dentures done by general dentists in Germany to find out if the preparation or type of restoration affected outcomes the most. They found only 13 out of 305 abutment teeth met the clinical requirements for adequate preparations for zirconia restorations established using evidenced-based criteria. Finish line design around the entire circumference and angle of convergence were the primary areas where the dentists had difficulty with the preparation. The authors concluded that inadequate tooth preparation for CAD-CAM zirconia crowns will lead to premature failure.

Renne et al. [38, 39•], in two separate studies, evaluated the importance of tooth preparation for CAD-CAM crowns utilizing two different fully integrated chairside systems. In the first study [38], the authors, after calibrating 62 dentists of varying experience on ideal crown preparation using accepted criteria established in the textbooks of Rosenstiel et al. [40] and Shillingburg et al. [41], had the dentists prepare a Typodont maxillary molar tooth with either a modified shoulder diamond or heavy chamfer diamond. Seventy-five crowns were milled with an E4D milling system in a standard mode and evaluated for marginal fit using the replica technique. The results showed marginal gaps ranging from 38.5 microns for ideal preparations with no errors to poor preparations with multiple errors averaging marginal gaps of 90.1 microns. The author concluded that quality of the preparation had a significant effect on the marginal gap of the E4D CAD-CAM lithium disilicate crowns. They found lipped margins, sharp line angles, beveled, spiked, and undulating finish lines were not able to be milled precisely especially when the flaw or defect was smaller than the diameter of the diamond. This will create misfit and larger marginal gaps. Additionally, they concluded the modified shoulder diamond produced better finish lines and marginal fit than the preparations done using the heavy chamfer diamond and clinical errors in preparation of the margin can be better managed when a dental lab technician utilizes the lost wax technique for fabrication compared to milling.

In the second study by Renee et al. [39•], forty dentists of varying clinical experience were calibrated for ideal preparation of a maxillary central incisor typodont tooth using the same criteria in the first study. The difference in this study was two chairside systems (E4D Planscan and CEREC Omnicam) were used to determine if the milling units influenced the marginal fit outcomes. As in the first study, similar results were obtained with poor preparations having marginal gaps of 104 microns to 36.6 microns for excellent preparations. There was no statistical difference between marginal gap of crowns fabricated by the milling systems as the quality of the preparation was the significant factor.

In a recent systematic review and meta-analysis of finish line design for ceramic crowns [34••], the authors found a significant difference in marginal gaps with better outcomes of teeth prepared with modified rounded shoulder diamond compared to the chamfer diamond finish line. The evidence suggests that the tilted surfaces of a chamfer prepared finish line create difficulties in the fabrication and finishing of ceramic restorations. Since in the design of CAD-CAM ceramic crowns, the margins are bulked out to compensate for chipping and defects, the correction of this design during finishing is more difficult to resolve with a chamfer finish line preparation. The authors also concluded that ceramic crowns with chamfer finish lines showed smaller internal gaps than those with rounded shoulder. A study by Hmaidouch and colleagues [42] demonstrated premature contact between restoration and internal prepared tooth surface caused by a smaller internal space with a chamfer finish line may result in larger marginal gaps during the cementation process. Other studies [43–45] have shown that CAD-CAM crowns prepared with a modified rounded shoulder had significantly smaller gaps and misfit that those measured with a chamfer finish line.

Yet, despite these findings, the authors of the systematic review [34••] believed chamfer diamond is the preferred choice for ceramic restorations. It is imperative yet difficult to agree, based on the evidence, what will have the greatest impact on the integrity of the final restoration.

Concepts to Improve Clinical Outcomes of CAD-CAM Ceramic Restorations

Based on the evidence presented, marginal gap caused by a variety of factors, with tooth preparation being the most important, is more critical, especially for CAD-CAM restorations, than all other elements for success. Clinicians must utilize the evidence to alter their protocols for optimal long-term outcomes.

The location of the finish line preparation may also affect the marginal fit of CAD-CAM crowns. Keeling et al. [46] demonstrated scanning and capturing the sharpness (curvature) and clarity of the margin using a commercially available unit was affected by the wand positioning, presence of adjacent teeth, and the proximity of the margin to the gingival tissue. Intraoral conditions such as reduced jaw opening, uncontrolled hemostasis, excess saliva flow, and muscular soft tissue will decrease the quality of the scan leading to fabrication errors and misfit. Supragingival margins improve scanning precision. The paper did not assess quality of the tooth preparation.

Systematic reviews [47••, 48] on the accuracy of intraoral scanners concluded that reducing the intraoral span of the scan, avoiding subgingival margins, eliminating localized bleeding, and having minimal irregularities of the scanned tooth surfaces will reduce inaccuracies. Nedelcu et al. [49•] evaluated finish line distinctiveness and accuracy between seven different intraoral scanners and conventional impressions with supragingival and subgingival finish lines. The authors concluded that depending on the scanner there was both higher and lower finish line distinctiveness and accuracy compared to conventional impressions. Technical limitations exist between different scanners especially with subgingival margins.

For improvement in marginal integrity of tooth preparation and crown adaptation, not only will the shape of the diamond make a difference, but the diamond grit sizes will as well. Li and colleagues [50] concluded that finer grit diamonds produce smoother surfaces and crowns with enhanced internal adaptation. The authors recommend preparation of teeth should follow a definitive sequence starting with coarse grit then medium grit and finishing the tooth surfaces with a fine grit diamond. The type of handpiece may also affect finish line accuracy. Geminiani et al. [51] demonstrated that the electric handpiece produced smooth surfaces than the air-driven turbine surfaces regardless of the diamond grit.

Two studies [52, 53] evaluated the effect of using sonic oscillating instrumentation on cervical microleakage of porcelain veneer restorations compared to a traditional high speed handpiece both with a fine grit diamond. They concluded that dentin preparation finishing using sonic oscillating instrumentation significantly reduced cervical microleakage of porcelain veneer restorations.

There are definitive advantages of using oscillating sonic handpieces and diamonds with tooth preparation including minimal gingival damage and less-aggressive tooth preparation when finishing margins [54•]. Precise margins achieved with sonic instrumentation improve the accuracy of preparation which can result in improved impressions and adaptation of the final restoration. Elimination of lipped margins, undercuts, sharp line angles, beveled, spiked, and undulating finish lines may become simpler using a sonic handpiece and corresponding sonic diamond especially under higher magnification.

A dental microscope can significantly enhance a clinician's precision and accuracy [55]. Higher magnification achieved with a dental microscope can enhance post space preparation after endodontic therapy [56], the diagnosis of cracks and caries, preparation irregularities, and documentation of patient conditions. In two meta-analyses, Setzer et al. [57, 58] concluded that endodontic procedures performed with the microscope demonstrated significantly better cumulative success rates than the studies that only utilized loupes. Tsesis et al. [59] confirmed in a systematic review, that both microscope and endoscope-assisted procedures had significantly more successful outcomes compared to loupes. Based on the success of endodontic therapy utilizing the dental microscope, implementation in restorative dentistry can enable the clinician to achieve greater precision with treatment [60, 61].

A clinical case was performed comparing preparation and crown margins between loupes and the dental microscope on the same teeth (Fig. 1). Both loupe and microscope preparations were accomplished with a modified or rounded shoulder coarse diamond and finished with a fine grit modified shoulder diamond with an air-driven handpiece as well as sonic oscillating handpiece and corresponding modified shoulder fine diamond (Fig. 1a). Tooth preparation was first accomplished with 3.0 magnification using dental loupes (Fig. 1b, c). Intraoral scan was taken, and zirconia crowns fabricated (Fig. 1d) and tried-in for evaluation under the microscope (Fig. 1e). The teeth were then re-prepared utilizing the dental microscope with magnification ranging from 5 to 20 magnification (Fig. 1f). Intraoral scans were taken of the microscope preparations (Fig. 1g, h). Clinical evaluation of the crown

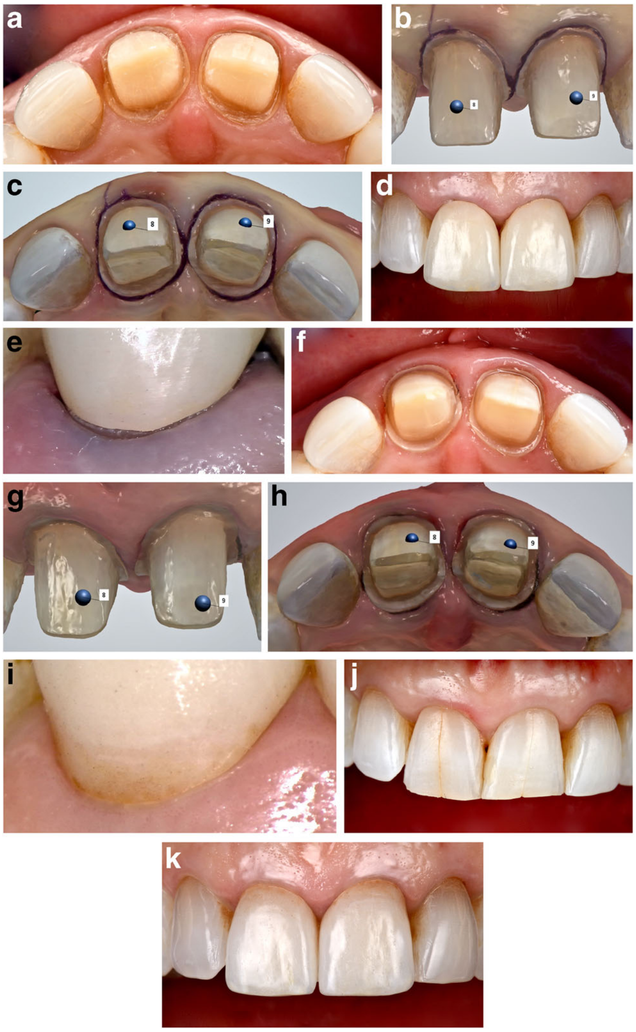

Fig. 1 **a** Loupe preparation occlusal aspect. **b** Loupe preparation scan facial aspect. **c** Loupe preparation scan occlusal aspect. **d** Loupe preparation zirconia crowns try-in. **e** Loupe preparation facial margin of zirconia crown try-in under 20 magnification. **f** Microscope preparation occlusal aspect. **g** Microscope preparation scan facial aspect. **h** Microscope preparation scan occlusal aspect. **i** Microscope preparation facial margin of zirconia crown try-in at 20 magnification. **j** Preoperative facial aspect. **k** Postoperative zirconia crowns facial aspect. *Zirconia crowns created by Michael Bergler, CDT, MDT

margins of the final preparations under the microscope at 20 magnification revealed improved adaptation and marginal integrity of the crowns prepared with the microscope (Fig. 1i). The preoperative image (Fig. 1j) and postoperative image (Fig. 1k) demonstrate the natural result and healthy gingival response.

Conclusion

The rapid rise of digital technologies and ability to fabricate computer-aided design and computer-aided manufactured (CAD-CAM) crowns is transforming the dental profession dramatically. However, it is clear from the evidence presented in this review that the ability to deliver a long-term successful restoration is dependent upon many factors not experienced in the traditional fabrication methods. Furthermore, tooth preparation technique may be the critical component in the digital workflow for CAD-CAM crown fabrication. Solutions were presented on techniques and protocols to achieve the preparation accuracy required to obtain clean unaffected finish lines and margins for scanning and milling success. This also includes treatment planning material selection based on milling and crystallization compromises, when it is best to use intraoral scanners versus conventional impressions, utilizing electric handpieces over air-driven turbines, implementing the correct sequence of diamond shape and grit, and understanding the impact of restorative microscopy for the ultimate precision treatment outcome.

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflicts of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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