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REVIEW

Printing parameters of layer thickness in 3D printing digital light processing on absolute marginal discrepancy and marginal gap in hybrid ceramic-resin crown

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Keywords: Absolute marginal discrepancy, Hybrid ceramic-resin, Layer thickness, Marginal gap, 3D printing DLP

ABSTRACT

Marginal adaptation in the form of absolute marginal discrepancy and marginal gap is one of the parameters for long-term clinical success in single crown restorations. The use of 3D printing digital light processing (DLP) additive manufacturing technology can produce accurate and efficient restorations. However, one of the printing parameter, layer thickness, can affect the accuracy of marginal adaptation. This review aims to evaluate the effect of layer thickness variation on absolute marginal discrepancy and marginal gap in definitive hybrid ceramic-resin crown manufactured using 3D DLP printing technology. Results show that a layer thickness parameter of 50 µm is preferred for good fitting accuracy and small cumulative deviation. Smaller layer thickness will increase the number of layers, and manufacturing time but on the other hand will reduce accuracy. Optimalization of the layer thickness is required to obtain the best marginal adaptation of a single crown. (IJP 2025;6(1):60-63)

Introduction

The digital revolution has brought major changes in the field of dentistry, computer-aided design and computer-aided manufacturing (CAD-CAM) has been used in dentistry for more than a decade.[1] The advent of intraoral scanners, along with computer-aided design (CAD) software and manufacturing technologies have changed the way dental impressions are taken and prostheses are manufactured.[2] Examining the development of manufacturing technology in dentistry, there are currently two types of manufacturing technology, namely: subtractive manufacturing (SM) and additive manufacturing (AM).[1-8]

The subtractive manufacturing (SM) process is known as 'milling',[9] while additive manufacturing (AM) is more commonly known as '3D printing'.[9,10] 3D printing was first introduced by Chuck Hull (Charles W. Hull) in 1986.[11,12] According to EN ISO/ASTM 52.900 terminology standard, AM process is "The process of combining materials to create an object from 3D model data, usually layer by layer, as opposed to subtractive manufacturing methods.[13] The advantage of 3D printing technology when compared to milling technology and conventional manufacturing techniques lies in the ability of 3D printing to produce structures with complex geometries,[5] simultaneously in a shorter time (rapid prototyping),[1,12] with greater precision and less residual waste[1,3,10,14,15] and no need to change drill as in milling technology.[7,8]

3D printing DLP technology has occupied a leading position in dentistry.[16] Understanding the factors that can affect the end result of manufacturing is critical to achieving the maximum potential of this technology, factors such as: the type of 3D printing technology used,[9] printing materials and printing parameters (printing strategy). These factors are known as the 'manufacturing trinomial.[17] 3D printing DLP technology has important applications in the field of prosthodontics. So far, the application of 3D printing technology has been limited to the manufacture of crowns and interim bridges.[1,2,14] With the development of technology and materials, it has become possible to use chairside 3D printing DLP technology for manufacturing definitive fixed crown restorations with hybrid ceramic-resin materials.[2]

The success of a definitive crown restoration depends on four requirements: aesthetics, mechanical strength, biocompatibility and good marginal adaptation.[18,19] Adequate marginal adaptation ensures minimal cementation material thickness and thus prevents microleakage that could potentially lead to plaque accumulation, caries, gingival inflammation, and lead to decreased fracture resistance of the restoration.[8] The assessment of margin adaptation of a single crown focuses on two things, namely absolute marginal discrepancy and marginal gap[8]. However, little information is available on the margin adaptation of definitive crown restorations with hybrid ceramic-resin materials manufactured using 3D printing DLP technology.[1,2,8,17,20,21]

Understanding the properties of materials used in dentistry is essential to compare with conventional materials, verify manufacturers' claims or to determine the material's weaknesses.[14] Accuracy of margin adaptation is one of the parameters that affect the success

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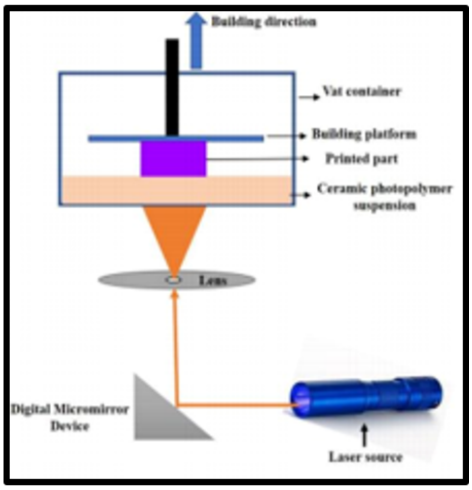

Figure 1. **Schematic illustration of bottom-up DLP 3D printing**

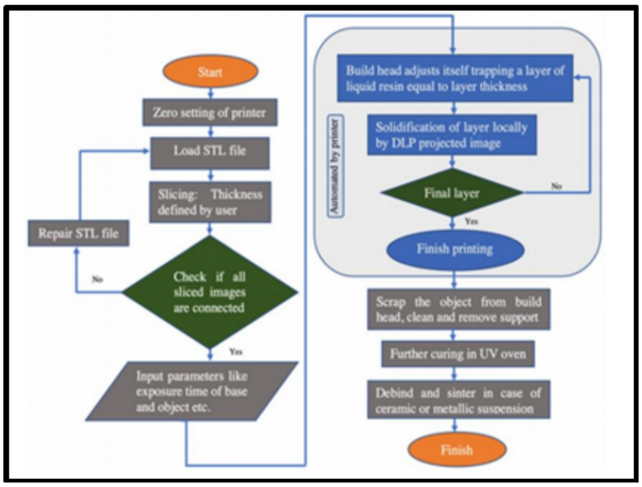

Figure 2. **Schematic flowchart of the 3D printing DLP process**

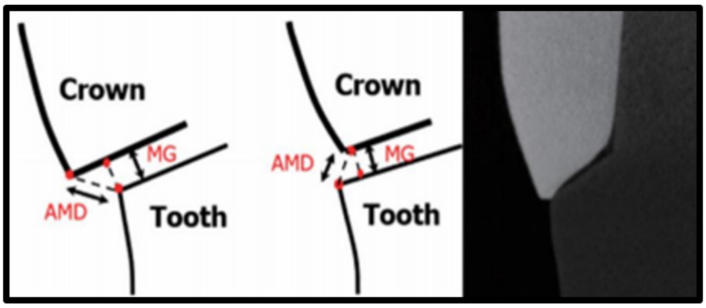

Figure 3. **Measurement of marginal adaptation (perpendicular distance between the crown and the margin of the master die). AMD: absolute marginal discrepancy, MG: marginal gap**

of a definitive restoration, so further research is needed to determine the effect of layer thickness as a printing parameter that can affect the absolute marginal discrepancy and marginal gap of hybrid ceramic-resin crown, so the purpose of this review is to explain the variation in layer thickness that can affect the absolute marginal discrepancy and marginal gap in hybrid ceramic-resin crown manufactured with 3D printing digital light processing (DLP) technology.

Literature Study

Digital Light Processing

3D printing DLP is part of the vat-photopolymerization additive manufacturing (AM) technology that uses a digital light projector with short light waves (380 nm to 405 nm)[13] which is projected by a digital micromirror device (DMD),[17,22] to then harden the material in a container (VAT), layer by layer at a time to form a three-dimensional object.[6]

Working Principle of Digital Light Processing

In a DLP 3D printing system, there are three unit parts: a light source, a printing platform, and a container (VAT) containing photosensitive material. The process starts with the projection of an image of each layer of the three- dimensional model onto a container (VAT) containing photosensitive resin. The exposed areas of resin harden, while the platform moves slowly providing space to form the next layer. This continues until the entire three-dimensional object is fully formed.[14,22,23]

Here's how 3D printing DLP works:[22,24,25] The designed CAD model is sliced into layers using slicing software to generate data. Subsequently, this data will be reflected as image slices by a DLP with a light source at a specific wavelength; The view of a certain part of the layer is projected on the surface of the resin and thin layers of resin start to solidify and harden due to photochemical reactions activated by photons; After hardening, the printing platform will move upwards and the other display parts will be projected on the resin to harden and form the next layer; The light distribution and intensity are modulated depending on the light exposure required to harden the resin to a certain thickness; Repeated exposure to light hardens the resin layers and the stack of layers is controlled by the printing platform until the object is fully formed; Once the object is formed and released from the printing platform, object will be clean, and post-polymerization processing to be performed to complete the polymerization process. Each printer technology and tool will have its own post-processing techniques recommended by the manufacturer.

There are two different configurations of 3D printing DLP systems: top-down and bottom-up.[24] Research has shown the advantages of bottom-up 3D printing systems over top-down 3D printing systems, especially in terms of material usage, accuracy, and the types of materials that can be used. Bottom-up 3D printing systems require less material, thus reducing costs and waste compared to top-down systems.[25] Bottom-up and top-down config-

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urations have their own advantages, but the advantages of bottom-up DLP 3D printing to handle complex geometric objects with high accuracy and less resin usage make it a superior choice.[25,26]

Parameter Printing Layer Thickness

3D printing DLP layer thickness refers to the height of each layer of resin polymerized during the manufacturing process. In the context of making dental prostheses, bridges and crowns, thinner layer thicknesses result in better detail and smoother surfaces, because in thinner layers the pattern formed by the stacked layers will produce a smoother stair-step effect, resulting in more accurate reproduction and finer detail.[3,15] A study comparing coating thicknesses for dental prostheses and crowns found that the use of a 100 μm coating thickness resulted in more surface accuracy deviations compared to a 50 μm coating thickness.[3,16] Layer thickness selection in 3D printing DLP should consider accuracy, mechanical performance, and manufacturing efficiency. The decision should be based on the application and the desired properties of the object being manufactured.

Hybrid Ceramic-Resin

Dentistry has a long history with resin materials, and by the mid-20th century, composite resins had replaced silicate cements as an aesthetic material for direct restorations. Buonocore invented an etching technique using orthophosphoric acid to bond acrylic resin to enamel.[27] A study conducted by Sabih and Jasim (2024) comparing the fracture resistance between dental crowns produced with technology using Vericom mazic duro hybrid ceramic-resin material, and dental crowns made from zirconia, showed that zirconia has the highest fracture resistance, but hybrid ceramic-resin crown have satisfactory fracture resistance, so they can be used as an alternative for making definitive dental crowns.[28] Jeong et al (2024) also found that although the photopolymer material in 3D printing has the lowest flexural strength, it can still meet the ISO requirement of 65 MPa.[5] Suksuphan et al (2023) evaluated the marginal fit and fracture resistance of milling and 3D printing hybrid ceramic-resin crown with varying occlusal thicknesses, finding that all tested hybrid materials showed clinically acceptable marginal adaptation. Notably, the 3D printed crowns outperformed the milled crowns in terms of marginal fit, while the milled crowns showed better fracture resistance under load.[18]

Marginal Adaptation

Imprecise marginal adaptation leads to plaque build-up, sensitivity of vital abutment teeth and bacterial infiltration that cause secondary caries. In implant-supported restorations marginal inaccuracy increases the risk of inflammation of the peri-implant tissues. Some literature specifies that the ideal margin gap should not exceed 25 μm, but some studies also suggest that marginal discrepancies of up to 150 μm are still clinically acceptable.[2] An in vivo study by McLean and Von Fraunhofer on 1000 restorations over 5 years concluded that 120 microns is a clinically acceptable marginal discrepancy, but to date there is no definitive definition of an appropriate marginal discrepancy size for clinical use.[19]

Marginal gap

Marginal gap refers to the vertical distance between the restoration and the vertically prepared tooth. Research shows that the marginal gap can vary depending on the manufacturing technique. A study by Refaie et al. (2023) comparing the marginal gap and internal fit of monolithic zirconia crowns 3D printed with milling, showed that although both methods produced clinically acceptable marginal gaps, milling crowns provided better accuracy, especially in internal fit.[29] A study conducted by Emam & Metwally (2023) who also examined the marginal gap in posterior dental crown copings of different materials, zirconia and polyether-ether-ketone (PEEK), emphasized that dental crown copings manufactured by 3D printing DLP method showed comparable or even better marginal gap when compared to copings made by conventional methods, especially in zirconia copings, which showed good marginal gap due to its high stiffness and stability properties during the DLP printing process.[30]

Absolute marginal discrepancy

Absolute marginal discrepancy refers to the distance formed as a result of the angular combination of marginal gap and extension error (either over-extension or under-extension), measured from the cavosurface margin of the preparation to the cervical margin of the crown.[19] A study by Liang et al (2023) compared marginal discrepancies in fixed dental bridges with ceramic materials fabricated using conventional and digital technologies. The study highlighted the advantages of digital techniques, which resulted in smaller marginal discrepancies compared to conventional methods. This study demonstrates the importance of digital technology to produce precise dental restorations.[31] These findings suggest that 3D printing DLP, if optimized, can provide clinical outcomes comparable to other manufacturing methods. Research by Zhao et al (2023) emphasized the importance of controlling resin flow and post-printing procedures in 3D printing DLP. This study showed that improper resin flow can cause absolute marginal discrepancy, due to uneven layer thickness and incomplete curing.[32]

Discussion

Mangano et al (2024) found that there was no significant difference between crowns produced through three manufacturing methods (printing, milling and conventional), All restorations showed good margin quality, occlusal and interproximal contacts. These data are consistent with those reported by recent studies, which validated the digital approach in the manufacture of definitive dental restorations in different materials, such as zirconia, lithium disilicate, and more recently, hybrid ceramic- resin.[2] Sebastian et al. assessed the feasibility of digitization in edentulous jaws and concluded that although digitization is a welcome change in denture manufacturing, the accuracy is still variable and requires further research. Molinero et al. have made 3D printed interim crowns with polylactic acid material from scanned mold models and achieved good marginal accuracy. A number of studies have compared digital and conventional impressions and found that digitally made impressions and interim restorations have fewer marginal and internal discrepancies.[33]

Previous studies have shown that the marginal adaptation of CAD-CAM restorations depends on the type of material used.[8] In the case of interim dental crowns manufactured by 3D printing, factors that affect margin accuracy include; printing speed, build orientation, number of layers, printer type, shrinkage between layers, post-manufacturing process, manufacturing time, and layer thickness. Layer thickness in 3D printing is a controllable parameter that affects the accuracy of interim crowns, so proper adjustment of layer thickness is important to achieve maximum clinical results. Layer thickness can be controlled between 20 and 150 μm in 3D printing systems.[6]

In a study conducted by Zhang et al (2019) found that for 3D printing DLP technology, a layer thickness of 50 μm is the best choice in accuracy and deviation during manufacturing, besides that the study also states that DLP printers are superior when compared to SLA printers in terms of printing accuracy with the same layer thickness with better printing speed.[12] On the other hand, research by Kim et al. reported the opposite result that the accuracy of DLP is lower than SLA, this result was obtained probably because in the study there were different layer thickness settings, 50μm in SLA printers, and 75μm in DLP printers.[12] According to Zhang et al. the problem arises when increasing the number of layers will increase the cumulative deviation which reduces the accuracy, at a layer thickness of 100 μm, although the cumulative deviation is reduced due to the smaller number of layers, high fitting accuracy cannot be achieved because the layer thickness will limit the curing process. Therefore, a layer thickness of 50 μm is considered to be the best option considering the fitting accuracy and cumulative deviation, where the smallest gap can be observed at the marginal and internal areas.[6]

Yang et al (2022) evaluated the influence of build orientation and layer thickness on the marginal fit and absolute marginal discrepancy of a three-unit fixed dental bridge (FPD) manufactured by 3D printing, reporting that the marginal fit of the restoration was not significantly affected by the difference in layer thickness. His study quantified the marginal fit of interim restorations manufactured with two different thicknesses (50 and 100 μm) on implant-supported abutments using micro-CT scanning techniques.[6] In contrast, Çakmak et al. evaluated the trueness and hardness of interim restorations manufactured in different thicknesses and focused on marginal and internal fit.[6] The results showed significant differences in the marginal and internal gaps of interim crowns manufactured with varying layer thicknesses. This is contrary to the study conducted by Yang et al. This may be due to the limited range of thicknesses, different methods of evaluating marginal fit, and different types of restorations (FPD or single crowns on implants or abutment teeth) are possible explanations for the different results. Gad & Fouda, Yang et al., Yao et al., Ryu et al., and Beuer et al. reported marginal gap ranges of 150-280, 58-113, and 100-150 μm for interim crowns, respectively. In addition, Peng et al. also reported an average marginal gap of 240 μm in interim crowns made with PMMA material by manufacturing using 3D printing.[6]

The study by Dimitrova et al. (2023) stated that 3D printed polymers for prosthodontic applications, found that the improvement in manufacturing accuracy was closely related to material selection and manufacturing process. Interestingly, although DLP technology has good accuracy, post-manufacturing procedures can significantly affect the accuracy margin, so attention is needed in the handling and curing process to avoid the occurrence of discrepancies and shrinkage of the manufactured object.[34] A study by Farkas et al (2023) to evaluate the tensile and compression tests performed on a micro filled hybrid resin material (Next Dent C&B MFH) showed that reducing the layer thickness can improve accuracy, as with thinner layers a more detailed reproduction can be achieved. This study also found that the angle formed from the printed layer affects the accuracy of the final product, if using a smaller layer thickness with a build angle of 45⁰ will result in the largest deviation.[14] Unfortunately, the research conducted by Farkas et al. focused more on the mechanical characteristics of the hybrid material without involving margin adaptation. Research conducted by Yilmaz and Çakmak (2023) found a correlation between margin adaptation and the mechanical characteristics of the material. The findings of Gracis et al (2023), corroborate the results of previous studies, highlighting that finer layer thicknesses improve the accuracy of the digital workflow, particularly in implant-supported restorations. This study emphasized that coating thickness directly affects the overall surface smoothness and accuracy of the restoration margins.[35]

Dimitrova et al. study (2023) explains the correlation of greater layer thickness to increased absolute marginal discrepancy, this is due to the stair-step effect, where the transition between layers will create a rougher surface. This study shows that reducing layer thickness improves fitting, while increasing manufacturing time and material utilization, resulting in a trade-off between efficiency and accuracy.[34] Layer thickness has an inverse effect on object accuracy and manufacturing duration; lower layer thickness is required to obtain high accuracy, while higher layer thickness will shorten manufacturing time.[15] In the case of manufacturing with complex anatomy such as dental crowns, it seems that a smaller layer thickness is required to obtain more accurate results.

Theoretically, a smaller layer thickness could result in better surface quality and overall accuracy. Studies on additively fabricated interim crowns confirm these results, as smaller layer thicknesses are reported to result in higher trueness.[15] Thinner layer thickness will increase the number of layers, and resolution in the Z-axis.[16] However, in a study by Favero et al, it was argued that the accuracy of the printing model would decrease as the thickness decreases.[16] In line with the study conducted by Zhang et al (2019) using a special resin material for dental models, they found that if the layer thickness is reduced to 30 and 20 μm, the accuracy of the printed object will decrease. This may occur because there are areas of deviation so that the potential for error increases with the increase in the number of layers, as it is known that the resin material will shrink during polymerization with the increasing number of layers, the deviation

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that appears shrinkage will be greater. This phenomenon may occur because the distance between atoms of low molecular weight monomers is reduced during the polymerization process, which in theory would lead to a reduction in the chemical distance between atoms[6] which manifests as shrinkage in the material during the polymerization process. Therefore, to obtain accurate printing results an operator should not only use the parameters provided by the manufacturer, but should also be determined by scientifically evaluating the trueness of the printing object.[16]

The main cause of the difference in results is due to the use of different 3D printing techniques, different printers, and various other factors such as build orientation, type of support structure, type of material used for crown fabrication, tooth model, design variations, different final margins, number of cement gaps, and measurement methods,[6] making comparisons between one study and another difficult.[20] It is important to consider the impact of layer thickness on manufacturing with 3D printing DLP on marginal adaptation.

Conclusion

Several researchers have stated the advantages of DLP technology in terms of manufacturing speed and cost, but there is still controversy over the accuracy of objects manufactured with 3D printing DLP technology. The printing parameter setting of layer thickness significantly affects the accuracy of marginal adaptation, especially the absolute marginal discrepancy and marginal gap. The printing parameter setting of 50 μm layer thickness is a good choice considering the marginal accuracy and minimal manufacturing deviation. Literature discussing chairside additive manufacturing technology and hybrid ceramic-resin materials is relatively scarce, as these materials are newly introduced.

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