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A Study of the Effect of Layer Thickness on the Accuracy of Fixed Dentures by 3D Printing

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Background: The precision of fixed dentures (FPDs) plays a crucial role in the success of dental treatments and, with the progress made in computer assisted design and production technologies (CAD CAM) both subtractive (like milling machines) and additive (for instance 3D printing) now present as viable fabrication choices. However, the effect of layer thickness on the accuracy of FPD formation, by 3D printing has yet to be thoroughly investigated.
Method: In the study setup section of the research project described herein a total of 40 fixed denture (FPD) samples were created. This sample set included milled specimens, for comparison, alongside 3D printed counterparts produced at varying layer thicknesses; 20 µm, 50 µm and 100 µm. The root mean square (RMS) deviation metric was utilized to evaluate the accuracy of each FPD specimen compared to a model across multiple surfaces including overall fit external appearance, internal structure, margins and occlusal surface. A thorough statistical examination was carried out to compare deviations observed among the groups tested in the study.
Result: The results indicated that milled FPD (Fixed Partial Dentures) exhibited the level of accuracy, with the RMS (Root Mean Square) deviation across all surfaces tested in the study. When it came to 3D printed FPDs there was an increase in deviation when thicker layers were used, at 100 micrometers. Significant disparities in RMS deviations were noted between milled FPDs and printed groups at layer thicknesses for both outer surfaces (statistically significant at $p < 0.05$). However, the accuracy on edge surfaces was found to be similar, across the manufacturing techniques. In terms of printing resolution, thinner layers (20 micrometers) resulted in precision compared to layers but still fell short of the accuracy achieved through milling processes.
Conclusion: Using layers in 3 printing may enhance precision but milling offers better accuracy, on intricate surfaces at present time. Adjusting layer thickness could potentially establish 3D printing as an option, for use; however, milling is still favored for precise temporary restorations of high quality. In the realm of technology advancements, like 3D printing and milling play a crucial role in fabricating interim fixed partial dentures. The use of CAD CAM technology ensures precision and accuracy in creating these devices by controlling factors such, as trueness and layer thickness.
Keywords: Additive Manufacturing, Printing Layer Thickness, Interim Fixed Partial Dentures (FPDs), 3D Printing.

1. Introduction

CAD-CAM systems typically go through a three-step process which includes capturing data using a scanner and converting it into a stereolithography(STL) before moving on to manufacturing using subtractive or additive techniques. Subtractive manufacturing (SM) on the hand entails crafting objects, from a block or disk using methods, like milling, grinding and polishing.[1,2] For a while now SM has had a connection, with CADCAM. When it comes to dentistry there has been a rise in the use of manufacturing (AM) or 3D printing for creating casts and other dental devices like surgical guides and implant-supported prostheses for implants and orthodontic tools due, to its flexibility. [3]

Additive manufacturing builds items step by step using information. Provides benefits such, as optimized material utilization and decreased waste compared to traditional manufacturing methods like subtractive manufacturing (SM).[4] Additionally AM allows for the production of sizeable structures. The American Society for Testing and Materials (ASTM) classifies additive manufacturing into seven techniques with stereolithography (SLA) which involves solidifying resin with ultraviolet light emerging as the prevalent choice, in dental applications. A different used method called digital light processing (DLP) uses a laser to shine on light reactive monomers that then combine to create the intended shape.[5-7]

Temporary dental restorations play a role, in ensuring the success of rehabilitation by offering both biological and mechanical protection along with positional stability. Methacrylate polymers like polymethyl methacrylate (PMMA) are commonly utilized for these restorations due, to their cost effectiveness and user nature. Nevertheless, PMMA comes with its set of challenges including polymerization shrinkage, marginal discrepancies and heat generation that make direct use complicated. To overcome these issues CAD CAM technologies. Whether subtractive or additive. offer a precise way to fabricate temporary dental restorations compared to traditional techniques. [8,9] When it comes to the quality of 3D printed items there are factors that can play such a role, as the type of technology used, the speed and intensity of the laser, the way it is placed for printing and how thick each layer is.[10] Although the impact of printing orientation is well researched not much attention has been given to how layer thickness affects the precision of 3D printed temporary dental restorations. Previous studies have mainly looked into areas like how these restorations fit and any internal spaces present without comparing 3D printed interim restorations, to those made through milling processes. This laboratory study was aimed to assess how the thickness of printed layers impacts the accuracy of 3-unit PMMA fixed dentures (FPDs) by comparing 3 dimensional printed outcomes, with those that are milled instead. The basic assumption here is that the thickness of layers and the method of fabrication do not impact the accuracy of these FPD units (3 units each).

2. Methodology

In this laboratory study , how changing the thickness of the printing layers affects the accuracy of making 3-unit bridges using 3D printing technology were compared to traditional methods was examined

Specimen preparation

The model of the jaw, with teeth prepared to fit a bridge made up of three units – the right first premolar and first molar had a chamfer finish line that was 1mm wide for the fitting purpose was used . The model was scanned using a scanner (model i500 by Medit) which converted it into an STL (Standard Tessellation Language). This digital model was then used to design the bridge, in CAD software (Dental CAD 2. 2 evoked GmbH). The plan included a 30-micron gap, for cement placement and connectors measuring 9 millimeters alongside a customized ridge lap design. The STL file was utilized as a guide (referred to as RIFPD STRL) to produce samples using two manufacturing methods. Additive Manufacturing (3D printing) and subtractive manufacturing (milling).

Creating prosthetics in the interim phases.

Thirty temporary dental crowns were created through 3D printing (AM) using Nextdent C&B MFH resin with layer thicknesses. 20 µm, 50 µm and 100 µm (10 samples, for each thickness). The design file was loaded into the DLP printing software from SprintRay Inc. with supports positioned at a 45° angle for detailing on the chewing surface. After printing was completed, the crowns were cleaned in isopropyl alcohol using a rinse, then cured under a 405 nano meter LED light using the Pro Cure unit, from SprintRay Inc.

Ten temporary dental prostheses were crafted by subtractive manufacturing using a milling machine, from PMMA blocks provided by Upcera Dental Technology Corp in Shenzhen. Following the milling process with the machine, by Wieland Dental + Technik GmbH & Co KG. the support structures were taken off and surfaces refined to ensure accurate alignment.

Gathering Data and Superimposition

The finalized temporary fixed partial dentures were digitized using a scanner to create 3D models, in STL format for each FPD unit completed during the study process. To evaluate accuracy and precision of the digitized models produced by the scanner compared to the reference master model of the FPD units fabricated traditionally with methods. The 3-dimensional deviation analysis was carried out by aligning each model with the master model using software for 3-dimensional analysis. Medit Link by Medit company. Root mean square deviation values were calculated to determine the accuracy of the structure and specific areas such as surfaces and internal fits along, with margins and occlusal surfaces of the interim FPD units using a method based on aligning key points and allowing for a tolerance range of ±10 micrometers.

Analyzing statistics

RMS data was examined using a Kruskal Wallis test to identify any variations among groups, followed by conducting pairwise comparisons between groups using Wilcoxon tests with Bonferroni correction ($\alpha=0.05$). Significance was considered at $p < 0.05$.

3. Result

Table 1: Median and Mean ± Standard Deviation RMS Values (mm) by Surface Type

Surface Type	Control (Milled)	20 mm	50 mm	100 mm
Overall (n=10)	5a (6.3 ± 2.1)	65b (67.0 ± 9.5)	63b (64.1 ± 9.0)	83c (84.2 ± 8.5)
External (n=10)	10a (9.8 ± 2.2)	57b (56.8 ± 8.2)	53b (52.1 ± 7.9)	68c (67.4 ± 8.0)
Intaglio (n=10)	18a (18.2 ± 7.5)	17a (17.5 ± 3.1)	14a (15.2 ± 4.2)	22a (21.8 ± 6.9)
Marginal (n=10)	4a (4.1 ± 2.0)	5a (4.9 ± 1.3)	3a (3.3 ± 1.1)	3a (3.2 ± 1.2)
Intaglio Occlusal (n=10)	3a (3.1 ± 0.8)	31b (30.9 ± 5.0)	30b (31.3 ± 4.1)	39c (37.8 ± 4.6)

Table 2: Adjusted P-values and Estimated Differences (mm) by Surface Type

Comparison	Overall RMS	External RMS	Intaglio RMS	Marginal RMS	Intaglio Occlusal RMS
Control vs 20 mm	.001 (-60.3)	.001 (-46.2)	> .05 (1.8)	> .05 (1.9)	.001 (-28.2)
Control vs 50 mm	.001 (-57.0)	.001 (-44.1)	.89 (3.4)	> .05 (3.5)	.001 (-29.3)
Control vs 100 mm	.001 (-79.5)	.001 (-58.1)	> .05 (-2.8)	> .05 (-3.2)	.001 (-34.7)
20 mm vs 50 mm	> .05 (2.5)	> .05 (3.2)	.47 (2.1)	.10 (1.6)	> .05 (-0.3)
20 mm vs 100 mm	.015 (-18.2)	.021 (-12.3)	.24 (-5.1)	.11 (-4.8)	.018 (-7.6)
50 mm vs 100 mm	.001 (-21.1)	.01 (-15.7)	.064 (-6.8)	> .05 (-)	

Table 1 shows the middle ± deviation of root mean square (RMS) variation measurements, across various surfaces for interim fixed partial dentures (FPDs) made by milling and 3D printing at different layer thicknesses (20mm, 50mm and 100mm). The milling group (control) demonstrated the variation in overall RMS values at, around 6 mm ± 2 mm indicating a level of accuracy. The group, with a layer thickness of 100 mm showed the highest variation (83c, 84.2 ± 8.5) which suggests increase in layer thickness with decreased accuracy.

The RMS values, for the external surface showed a pattern. The milled control exhibited smaller variations (10a with 9. 8 ± 2. 2) While the printed groups had fluctuations; notably the 100 mm group displayed the deviations (68 c with 67. 4 ± 8. 0). This suggests that the milled samples were better at preserving external surface shapes compared to their printed counterparts when dealing with larger layer thickness, in particular.

Intaglios and marginal surfaces did not display differences, in RMS values between the groups as there were deviation levels observed across various manufacturing techniques utilized. When focusing on the intaglio occlusal surface specifically; the milled group consistently showed the RMS deviations (3a and 3.l ± 0.8) contrasting with the deviations seen in the 100 mm printed group (about 39c and 37.8 ± 4.6). This pattern highlights that higher layer thickness could potentially impact the accuracy of printed FPDs. Based on this information, as a whole; thinner layers in 3d printing seem to enhance precision; however, milling is still more effective for ensuring accuracy, across various surfaces.

Table 2 shows the revised p-values and estimated variations, in RMS deviations when comparing surfaces for printed and milled FPD samples in pairs. Significant differences were noted in overall and external RMS deviations between milled control samples and printed FPD samples of varying layer thicknesses (p=0.001). This implies that milled FPD samples generally exhibit higher accuracy compared to printed FPD samples, across different layer thicknesses.

For profiling RMS values, on the intaglio surface area of both milled and printed samples were found to be quite similar without any differences noted between the two methods used. The marginal RMS values showed no discrepancies between the groups except for a slight variation spotted in the control group when compared to the 50 mm layer thickness group. On the contrary intaglio occlusal RMS values displayed an increase in all printed groups when compared with the milled group (at p value of 0.001) especially noticeable at higher layer thickness settings. This suggests an impact of layer thickness, on occlusal accuracy.

When comparing printed groups, with each other in pairs of two groups at a time showed clear distinctions between the 50 mm and 100 mm groups (with a statistical significance of p=.001). These differences were observed in the RMS values for intaglio occlusal surfaces – indicating that thicker layers have a significant impact on accuracy levels especially for larger and more prominently visible areas. This emphasizes the importance of using thin layers in 3D printing to achieve precision, to milling processes – particularly when working on intricate surfaces.

4. Discussion

This research examined how various methods of creating and different thicknesses of layers affect the precision of 3-unit fixed dentures (FPDs). The results suggest that although both milled (made by removing material from a block. Subtractive manufacturing process) and 3D printed (additive Manufacturing process temporary FPD models exhibit decreased root mean square (RMS) deviations, on particular surfaces milled FPD models demonstrate better overall accuracy.

In Table 1 of the study report indicates that the milled (control group consistently showed the lowest RMS deviation on all surfaces, compared to groups and had an overall RMS deviation of 5mm (with a range of 6 to 4). This suggests a level of accuracy in maintaining the design specifications intact throughout the manufacturing process.[11-15] On the hand the 3D printed groups displayed deviations in comparison with the milled group especially at the layer thickness of 100 mm where there was an exceptionally high RMS deviation of 83c (84.2 ± 8.5).[16] These highlights variations in measurements, across surfaces. The rise, in deviation as the layers get thicker suggests that the precision of 3D printing is influenced by layer thickness directly; thicker layers lead to decreased accuracy. [12,3,17]

There were distinctions observed on the surface between the milled and printed groups in terms of surface quality differences – the control group exhibited minimal RMS deviation (10a; 9. 8 ± 2. 2) Whereas the printed groups displayed deviations at a thickness of 100 mm (68 c; 67. 4 ± 8. 0). This implies that using 3D printing, with layers could present challenges in maintaining surface details on visible areas, like the exterior surface. [18,19]

The intaglio and marginal surfaces exhibited comparable RMS deviations, in both the printed groups as indicated in Table 1. This could be attributed to the characteristics of these surfaces which may make them easier to replicate irrespective of the manufacturing method or layer thickness used. On the surface of the restoration similar patterns were noticed as seen on the overall and outer surfaces. In this case milled FPDs exhibited the variations (3a, 3.1 ± 0.8)while for the 100 mm printed group the variations were about 39c, (37.8 ± 4.6),highlighting how layer thickness affects accuracy, in intricate areas. [12,14,20]

Table 2 displays variations, in RMS deviations between the milled and printed groups for both external surfaces through pairwise comparisons with p values below 0. 05 Indicating significance. It is worth noting that there are distinctions in trueness levels between milled and printed FPDs across layers in terms of overall and external RMS measurements. These findings suggest that milled FPDs exhibit superior trueness compared to their printed FPDs on critical surfaces. There were no distinctions, between the milled and printed groups when it came to intaglio and marginal surfaces; suggesting that the type of surface could influence how layer thickness affects precision. [21,22]

In the end results showed that comparing group prints proved that the thickness of the layers does impact accuracy significantly; between 50 mm and 100 mm layer thicknesses, across overall surfaces like external and intaglio occlusal areas stand out with differences observed. These results suggest that while using layers in 3D printing can enhance precision levels; milling continues to offer accuracy on intricate surfaces which confirms its dependability, in clinical settings demanding high levels of exactitude. [19,23]

According to this research finding; When producing FPD (fixed denture) using 3d printing technology with less layers results, in better accuracy and approaching the precision level of milled FPD'sAlthough milling is still the preferred method to achieve high precision especially on detailed or visible areas Future studies should focus on refining layer settings in 3d printing to reach acceptable accuracy levels, for different dental restoration purposes.

5. Conclusion

The research showed that the thickness of the layers has an impact, on how 3D printed interim fixed partial dentures (FPDs) turn out. Thinner layers lead to better precision. While using 3D printing with layers can almost match the accuracy of milled FPDs; milling is still better at keeping accuracy on all surfaces and especially on tricky and visible areas. For tasks, in clinics that need restorations done well; milled FPDs are currently the reliable option available. With the progress, in 3D printing technology adjusting the thickness of each layer could enhance the precision of additive manufacturing to meet the precise specifications needed for different dental repairs providing a practical and adaptable option compared to conventional milling methods.

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