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In-vitro evaluation of the marginal and internal fit of 3D printed interim implant crowns

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ABSTRACT

Aim: Interim restoration plays an integral part in success of implant treatment during both pre and post placement phase. This study aims to evaluate the marginal and internal fit of interim implant crowns fabricated using two different 3D printers (SLA and DLP) and CAD-CAM milling using the silicone replica technique.

Settings and Design: Comparative In-vitro study design

Materials and Methods: The study model made of implant analog in the right first molar region with hex type transfer abutment was scanned and a virtual crown was designed. The same design file was transferred to both the 3D printing and CAD-CAM milling systems for the fabrication of 45 interim crowns (15 per group). Marginal and internal discrepancies were measured using the silicone replica technique at 10 points after sectioning the silicone replica with the help of a customized cutting guide template and studied under stereomicroscope.

Results: Kruskal-Wallis Analysis of Variance (ANOVA) was used for the overall comparison and Mann-Whitney U test was used for comparison between each of the two groups. The highest discrepancy was noted at the occlusal region irrespective of the fabrication method, and the least discrepancy was noted at the marginal area. Moreover, the DLP 3D printing system was superior to the SLA 3D printing system and CAD-CAM milling system.

Conclusion: All 3 systems were suitable because they produced a marginal fit that was within the clinically acceptable range. 3D printing systems significantly enhanced the fit of interim crowns; particularly in the occlusal region. DLP based 3D printing system was found to be superior to the other 2 fabrication systems.

Key Words: CAD-CAM, Stereolithography, Direct Light Processing, Interim restoration, Implant

INTRODUCTION:

The fabrication of interim restorations for implant treatment is essential in most clinical scenarios. Interim implant crowns restore the shape and function of the original tooth and also play a significant role in maintaining the health and aesthetics of soft tissue while producing a prototype design of the definitive restorations.[1,2] It also helps to protect the abutment and maintain the appropriate occlusal scheme. To accomplish these goals, considerable care should be taken to ascertain the shape and fit of such restorations.[1]

It is observed that in case of poor fit, discrepancies can arise between the abutment and crown, which can cause clinical problems such as plaque retention, inflammation of soft tissues, loss of retention, abutment screw loosening, and mechanical issues.[1] The host tissue, such as bone tissue, is in direct touch with the implant surface. Therefore, the subsequent complex cell behaviour at the bone-implant interface in vivo and the cell response in vitro are mostly determined by the surface features. [3] Moreover, an increase in the internal gap decreases the fracture resistance and the thickness of the crown. As restorations with great precision minimize the need for adjustments and save clinical time, the finishing steps on the intaglio or occlusal surfaces can avert damage and improve the quality of restorations.[4] For that reason, the marginal and internal accuracy is a key factor for the long lasting success of implant restorations hence, an objective evaluation of the marginal and internal discrepancy is important.[1,5]

“Subtractive manufacturing” technique has dominated for many years in the fabrication of various prostheses in dentistry.[6] However, some of the shortcomings of CAD-CAM milling like unfavorable forces on build structure, high wastage of material, poor micro reproducibility in the concave region depending on the diameter of the cutting device, limited variations in the type of material that can be used, lack of ability in mass production has paved way for the 3D printing techniques also known as "additive manufacturing" and "rapid prototyping".[7-9]

3D printers are currently employed in many dental offices and laboratories to fabricate a wide array of diagnostic models, provisional restorations, implant surgical guides, occlusal splints, and frameworks for mandibular reconstruction, craniomaxillofacial and orthopaedic implants. [9-12] Affordable desktop 3D printers along with user-friendly 3D software provide scope for the use of polymer-based 3D-printed materials to replace the conventional fixed prosthodontic laboratory procedures.[12]

Since additive manufacturing is a recent and evolving technique, the assessment of marginal and internal adaptation of the 3D printed interim implant crowns is required for its judicial clinical use. Furthermore, to date, research comparing two SLA and DLP technology is scarce and not well documented. Hence the purpose of the study was to evaluate the marginal and internal fit of interim implant crowns fabricated using two different 3D printers (SLA and DLP) and compare it with that of the CAD CAM milling system using the silicone replica technique.

MATERIALS AND METHODS

The study models for this research were made in the Department of Prosthodontics, and the microscopic measurements were carried out in Central Research Laboratory of the Institute. Digitization and fabrication of crowns were done in Dental Ceramists (India) Pvt. Ltd. Mumbai. Sample size estimation is based on comparison between Milling, and two methods of 3D printing as per the article by wan sun Lee et.al., 2017.[7] Multiple combinations of the groups and points of measurement were seen and the sample size was estimated. The required sample size per group came out to be 10. Since the study involves only in-vitro methods and it was feasible to have a higher sample size, we increased the sample size to 15 per group. Increase in sample size was also done to compensate for any unexpected loss of sample during processing or during measurement of the parameters. Thus, the final sample size was 15 interim crowns X 3 groups = 45 units.

The study model was comprised of implant analog in the right first molar region with hex type transfer abutment (TS Osstem implant systems, Korea) having diameter 5.0 mm, length 11.0 mm, gingival height (G/H) 4.0 mm, height 7.0mm [Figure 1a]. Scanning of the model was carried out with a non-contact blue light scanner (Identica Light 3D scanner, Medit, Seoul, Korea) and saved in a standard template library (stl) file [Figure 1b]. Scanned data were then used to design the virtual crowns for the abutment using dental CAD software (Exocad GmbH Julius-Reiber-Strasse, Darmstadt, Germany) with 30 μm of cementation space, starting 1.0 mm above the finish line. The same design file was then transferred to both the 3D printing and CAD-CAM milling systems for the fabrication of interim crowns [Figure 1c and d]. For the fabrication of CAD-CAM milled interim crowns the stl file was used in a 4-axial milling machine (XT-CERA X-Mill 300 4-AXIS, Shenzhen Xiang Tong Medical Technology Co., LTD, China). The same design file was then transferred to a SLA 3D printer (Form 2 SLA 3D Printer, Formlabs, Massachusetts, United States) and the study samples were fabricated by printing a biocompatible photopolymer i.e. temporary CB resin, (Formlabs, Massachusetts, United States).The stl file was later used in DLP 3D printer (Anycubic Photon S 3D printer, 3 Idea Imagine Create Print, China) and study samples were fabricated with biocompatible 405nm photosensitive resin (Anycubic Photon, 3 Idea Imagine Create Print, China). Marginal and internal discrepancies were measured to assess the fit of the completed interim implant crowns using the silicone replica technique. Each sample was measured at 10 points after sectioning the silicone replica in the mesiodistal direction. In this study, a customized cutting guide template was made to obtain the same cross-sectional planes in the sectioning replicas. The template included 2 parts: the upper section, which was a customized acrylic tray with guiding slots [Figure 2a]. The lower section, which was a dental stone base with the abutment attached to it with markings depicting the mesial, distal, buccal, and lingual surfaces of the crown [Figure 2b]. The markings of the upper and lower sections of the guide template were marked in alignment with each other. Light body impression material (Reprosil, Dentsply Sirona Ptv Ltd) was applied to the internal surface of the interim implant crowns and then they were placed onto the implant abutment, with the application of digital pressure from the occlusal surface. After the impression material had polymerized, the interim crowns were removed from the abutment. This resulted in a lining of light-body impression material attached over the internal surface of the crown that represents the amount of discrepancy between the interim implant crown and the implant abutment [Figure 2c]. The regular body silicone (Reprosil Impression Material, Dentsply Sirona Ptv Ltd) was applied over the abutment along with the upper section of the guide template to form a stable layer to support and strengthen the light body silicone. [Figure 2d]. After the polymerization of the regular-body silicone, the guide template with the replica was separated from the abutment. The replica was sectioned in the mesiodistal direction, using a surgical blade (surgeon sterile blade number 20, Kehr surgical private limited, India) following the slot in the tray walls of the guide template. For the quantification of marginal and internal discrepancies, the sectioned silicone replicas were examined under the stereomicroscope (LABOMED Luxeo Stereo Microscope, Labo America Inc., USA) having an eyepiece magnification of 10 x, zoom magnification of 3.5. The discrepancy of the measurement point was distinguished to determine the marginal, intermarginal, axio-gingival, axio-occlusal, and occlusal discrepancies.[13] 10 measurement points were considered that depicted the discrepancy at the specified 5 regions [Figure 3]. The discrepancies were initially recorded with the help of a calibrated scale which was attached to the eyepiece lens of the stereomicroscope and then the obtained values were converted into µm for further study purpose using the following formula [Figure 4].

$$\frac{\text{Number of units X 1000}}{\text{Eyepiece magnification X zoom magnification}}$$

The values obtained from various groups were tabulated into a Microsoft Excel spreadsheet and analysed for statistical significance.

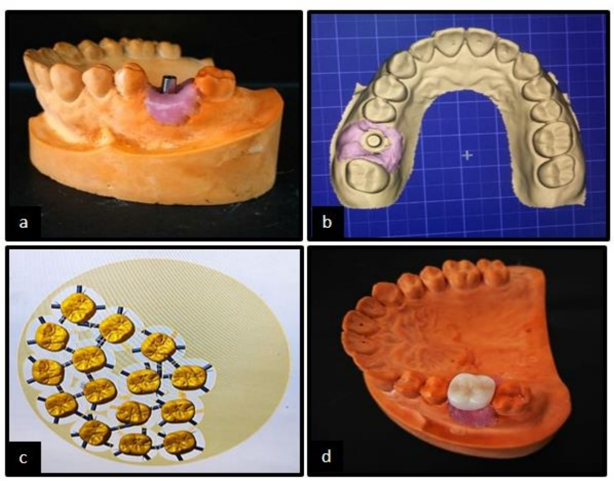


Figure 1: (a) Study model (b) stl file of study model obtained after optical scanning (c) Designing of the virtual crowns using dental CAD software (d) Computer aided manufactured interim crown

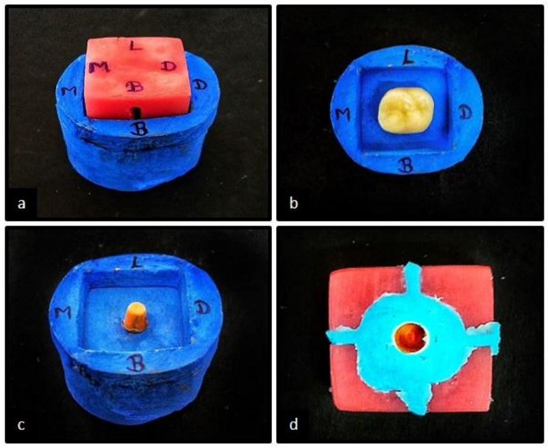


Figure 2: Silicone replica technique: (a) Upper section comprising of customized acrylic tray with guiding slots (b) Lower section comprising dental stone base with the abutment attached to it with markings depicting the mesial, distal, buccal, and lingual surfaces of the crown (c) Lining of light body impression material representing the internal discrepancy (d) Regular body silicone in the upper section of the guide template to form a stable layer to support the light body silicone.

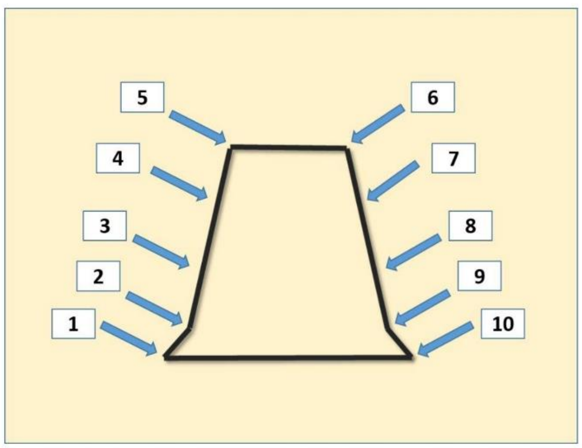


Figure 3: Depiction of 10 points of measurement for the assessment of marginal and internal discrepancy. Marginal (1,10) Intermarginal (2,9) Axio-gingival (3,8) Axio-occlusal (4,7) Occlusal discrepancies (5,6)

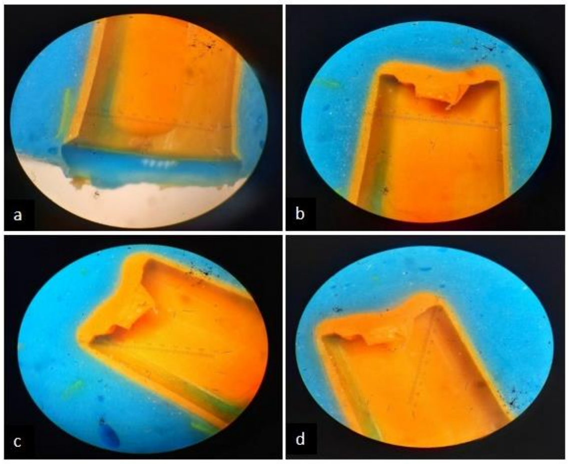


Figure 4: Quantification of marginal and internal discrepancies of the sectioned silicone replicas using the stereomicroscope. (a) Marginal (b) Axio-occlusal (c and d) Occlusal discrepancies.

RESULTS

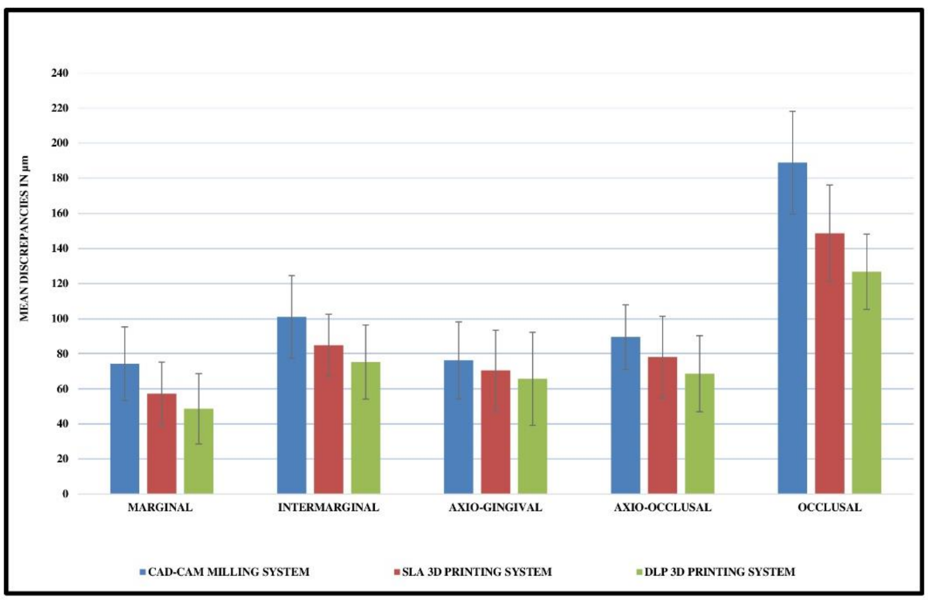
All the statistical analysis was performed using the IBM SPSS 20 (IBM SPSS Statistics Inc., Chicago, Illinois, USA) statistical software version. All the data were presented in the form of tables and bar diagram. For the overall comparison of marginal and internal fit of interim implant crowns between the three groups, the Kruskal-Wallis Analysis of Variance (ANOVA) was used and for comparisons between each of the two groups, the Mann-Whitney U test was used.

On comparing the interim implant crowns fabricated by the CAD CAM milling system with the SLA 3D printing system the values for the marginal and occlusal discrepancies differed significantly. When the CAD CAM milling system was compared with the DLP 3D printing system, a significant difference was observed in the axio-occlusal points of measurements, a moderately significant result was observed in the marginal and intermarginal points and a highly statistically significant difference (p value < 0.00001) was noted in the occlusal points of measurement. However, when the SLA 3D printer was compared with the DLP 3D printer a significant difference was only observed at the occlusal points of measurements. Based on the results of the Kruskal-Wallis Analysis of Variance test a statistically significant difference was noted in the intermarginal points of measurements (p value 0.01947). A moderately significant result was observed in the marginal points of measurements (p value 0.00927) and a highly statistically significant difference was noted in the occlusal points of measurements (p value 0.00004) [Table 1 and Graph 1].

Measurement points	CAD–CAM milling system Group A	SLA -3D printing system Group B	DLP -3D printing system Group C	H	P Value
Marginal discrepancy	74.27±20.99	57.14±18.06	48.56±20.06	9.3617	0.00927 (**p)

Intermarginal discrepancy	100.94±23.59	84.75±17.66	75.23±21.16	7.8779	0.01947 (*p)
Axio-gingival discrepancy	76.18±21.92	70.46±23.01	65.70±26.49	1.0582	0.589
Axio-occlusal discrepancy	89.51±18.41	78.08±23.24	68.56±21.63	5.491	0.0642
Occlusal discrepancy	188.86±29.26	148.56±27.50	126.65±21.42	20.1206	0.00004(***p)

Table1: Comparison of marginal and internal discrepancies at different measurement points using Kruskal *p < 0.05(Significant), **p < 0.01(moderately significant), and ***p < 0.001(highly significant) Wallis analysis of variance test (mean±SD µm)



Graph 1: Overall comparison of the marginal and internal discrepancies at different measurement points for interim implant crowns fabricated by CAD CAM milling system, SLA 3D printing system, and LCD 3D printing system.

DISCUSSION

Various methods have been used to assess the marginal fit alone or in combination with the internal fit of the dental prosthesis.[1,14] Sorensen advocated 4 methods: direct visual inspection method, cut and viewing the cross-section method, the visual observation by the probe, and method to evaluate after the impression taking.[15] Molin and Karlsson reported that the silicone replica technique avoids deformation as the core portion is not required to be sectioned.[16] A customized guide template was utilized for sectioning the silicone replicas in this study to set a similar reference plane in all the silicone replicas because earlier studies have reported that a change in sectioning planes can result in overestimation or underestimation of fit.[17] Rahme et al proposed that using low-viscosity silicone for the silicone replica technique can simulate the film thickness of a cemented crown applying glass-ionomer cement and reported statistically insignificant difference when silicone replica technique and sectioning technique were compared for measuring the marginal gap of Procera crowns.[18] To date, quantitative assessment of marginal and internal fit has yet not been standardized, and formerly published studies varied concerning the measurement method used and the acceptable range.[1] Att et al noted that a marginal discrepancy of <100µm is suitable for application in clinical trials, [5] whereas Jemt reported that a marginal discrepancy of 50 to 120 µm is clinically appropriate.[19]

In the present study, mean marginal discrepancies of 74.27±20.99µm for CAD CAM milling group, 57.14±18.06µm for SLA 3D printing group, 48.56±20.06µm for the DLP 3D printing group were found. When intermarginal discrepancy of CAD-CAM milled interim crowns were compared with SLA and DLP 3D printed interim implant crowns, there was a statistically significant difference among the groups with most discrepancy noted in the CAD-CAM milled interim crowns and least in the DLP 3D printed interim crowns although there was a statistically insignificant difference when both 3D printed interim crowns were compared with each other. On comparison of axio-gingival and axio-occlusal discrepancies, no statistically significant difference was observed on the overall comparison of the three fabrication techniques. Statistically, a significant result was only observed in the axio-occlusal region when the CADCAM milled interim crown was compared with DLP 3D printed crowns. The occlusal surface showed the greatest discrepancy among all the groups studied. There was a highly statistically significant difference ($p < 0.00001$) when the CAD- CAM milled interim crowns were compared with 3D printed interim crowns.

Apart from the marginal fit, the occlusal surface fit also plays a crucial role in the success of an interim implant prosthesis since it affects the structural durability of the prosthesis. Similarly, the axial wall fit is also significant because it can alter the maintenance requirements for an interim restoration.[1,4] This study has validated the clinically appropriate ranges for intermarginal, axiogingival, and axio-occlusal discrepancies. However, the internal occlusal discrepancy was found to be wide.

The occlusal discrepancy was most evident in the CAD-CAM milled crowns. Accordingly, the cutting motion range and bur size are limiting factors in the manufacturing of CAD-CAM milled crowns.[20] The 3D printing technique enables the manufacturing of objects with complex structures, without the requirement for the artificial modification of the design.[13] These findings suggest that a difference in the fabrication mechanism affects the fit of the restoration, especially at the occlusal region.[17]

The findings of the present study were coinciding with other previously conducted study by Martins et al, the internal discrepancy at the occlusal surface is wide in most of the clinical situations.[21] Furthermore, the study conducted by Parks et al considered the occlusal discrepancy value of 197.87 ± 42.18 for interim implant restoration as acceptable. [1] Comparable to the results of the present study, other investigators also observed that the 3D printing technique significantly enhanced the fit of interim crowns, particularly in the occlusal region.[17,22] According to Park et al interim implant restorations fabricated by additive manufacturing technique with digital light processing were superior to the other interim implant restorations fabricated by the conventional system with thermoplastic resin and subtractive manufacturing system. [1] Pompa et al concluded in their study that the 3D printing method was superior to the conventional fabrication methods in terms of marginal adaptation. [20]

The way that digitization is impacting dentistry, it seems inevitable that additive manufacturing will continue to grow into a go-to prototyping and production method. Taking the advantages of its controllability, cost-effectiveness, and acceptable resolution, DLP 3D printing can have a great potential to fabricate 3D interim implant supported fixed partial denture crowns. The limitations of the study was that only a cross-sectional quantitative analysis in 2 dimensions was made to assess the marginal and internal discrepancies and the findings of this study are limited to pre-cementation marginal adaptation only. Prospective research should be directed towards studying the influence of different cement types on the microleakage and mechanical properties of printed restorations.

CONCLUSIONS

In this study, among all the groups compared the greatest discrepancy was showed by the crowns fabricated by CAD-CAM milling method followed by SLA 3D printing system and least by DLP 3D printing system. The mean occlusal discrepancy was larger than the mean intermarginal, axio-gingival, and axio-occlusal discrepancies in all three groups studied. The accuracy of interim implant crowns fabricated using DLP based 3D printing system was comparable with that of the SLA based 3D printing system. Thus, the DLP based 3D printing system could be an alternative approach to fabricate interim implant crowns.

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