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Comparative Evaluation of Colour Stability and Surface Roughness of Provisional Crowns Fabricated Using Additive and Subtractive Manufacturing Technique after Immersion in 3 Oral Ageing Solutions – An Invitro Study

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KEYWORDS

Colour Stability, Surface Roughness, Provisional Crowns Fabricated, Oral Ageing Solutions

ABSTRACT:

Aim – To evaluate the colour stability and surface roughness of provisional crowns fabricated using additive and subtractive method after immersion artificial saliva, cola and saliva with reduced Ph.

Methodology- 48 provisional crowns were fabricated by additive manufacturing and subtractive manufacturing and divided into 3 subgroups and immersed in artificial saliva, cola and saliva with reduced Ph. Surface roughness and colour measurements were made before and after immersion. Anova test was done to analyze the data followed by Bonferonii post-hoc multiple comparison and t test to determine statistical significance.

Results- After 3 days and 7 days of immersion all samples showed increase in surface roughness with additive manufactured samples showing a significant change. The subtractive manufactured samples showed increased colour change when immersed in cola as opposed to the additive manufactured crowns which had greater colour variations when immersed in saliva with reduced Ph.

Conclusion - Additive manufactured crowns show lesser surface roughness and good colour stability when subject to varying oral environment and hence can be suitably used especially in long term provisionalization

Introduction

Provisional fixed prosthesis is essential to maintain the masticatory function, prevent damage to pulp and periodontal tissues while maintaining esthetics and speech until the final prosthesis is delivered. They also play a role in treatment planning to determine the form, colour and gingival contour of the final prosthesis.[1,2] Interim prosthesis made of polymethylmethacrylate (PMMA) and bis-acryl composite resin have historically been effective due to their superior mechanical properties and relative ease of fabrication. However, concerns regarding their exothermic setting reaction, polymerization shrinkage and have raised doubts about their suitability for intraoral use.[3,4,5] With the advent of CAD CAM technology restorations with increased strength, better esthetics and the ability to deliver prosthesis on the same day has led to much effective workflow. It provides the operator with an array of different temporary restorative materials to be used with

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better functional and esthetic results.[4,6,7] Contrarily, Stereolithography (SLA) and Digital light processing has gained popularity in digital dentistry due to its increased efficiency and minimal cost with acceptable results.[8,9] Provisional restorations need to be adequately polished to avoid any surface irregularities. Increased surface roughness leads to greater plaque accumulation which can be deleterious to the oral hygiene of the patient.[10,11,12] This becomes even more important when temporary restorations are to be used in long term cases such as immediate provisionalisation following implant surgery.[13] With a greater demand for esthetics, colour stability is an important factor to consider while choosing the appropriate material for the provisional prosthesis. Various factors such as degree of polymerization, water sorption, surface roughness of the restoration, diet and oral hygiene are implicated in the discolouration of provisional restorations.[14,15,16,17,18] Discolouration of the prosthesis due to intrinsic or extrinsic staining is unacceptable when visually perceived and may require frequent replacement which is tedious and time consuming.[19,20,21] Although subtractive manufacturing of provisional restorations has shown reduced polymerization shrinkage partly due to the availability of homogenous pre polymerized milling blanks,[22] rapid development in additive manufacturing technology has led to an array of printable resin materials differing in their mechanical properties and chemical composition debating the relative merits of AM technology and CAD CAM fabrication of provisional restorations.[23,24]

Hence this study aimed at evaluating the colour stability and surface roughness of provisional crowns fabricated using CAD CAM and 3D printing technique after immersion in three different ageing solutions. The null hypothesis was that there would be no effect on the surface roughness and colour after immersion in artificial saliva, artificial saliva with reduced pH and cola staining solution.

Methodology

Crown Tooth Preparation and Digital model

A Maxillary right Central incisor was prepared on a typodont tooth (NISSIN DENTAL PRODUCTS INC) with 2mm of axial preparation and 2mm incisal reduction with shoulder finish line to receive an all ceramic fixed prosthesis. The prepared tooth was scanned with a laboratory scanner (Ceramill ® map400AmannGirrbach, Inc- AMANN GIRRBACH AG), the scanned file was then saved in the standard tessellation language (STL) file format. An Interim Fixed Prosthesis (IFP) was digitally designed by using a CAD-CAM software program (Ceramill®mind, AmannGirrbach, Inc-AMANN GIRRBACH AG). The digital design of IFP was also saved in the STL format.

Study Groups and Sample Fabrication

A total of 48 samples were fabricated and tested. The study groups included crowns fabricated by subtractive methodology i.e. CAD CAM milled crowns (n – 24) and crowns manufactured by additive method i.e. 3D printed crowns (n- 24). These specimens were further divided into 3 groups (n-8) based on the storage media used and tested for surface roughness at baseline, at 2 days and at 7 days interval.

Subtractive Method - Polymethyl methacrylate disks (Ceramill TEMP ML, A1/A2 71xS Inc-AMANN GIRRBACH AG) were used to mill 24 IFPs by using a 5-axis dental mill (Ceramill ® map400AmannGirrbach, Inc- AMANN GIRRBACH AG) from the STL file of IFP using burs of standard dimension as prescribed by manufacturer.

Additive Method - A DLP 3D printer (Anycubic Photon M3 Max 3D Printer) was used to fabricate 3D-printed IFP from photopolymer resin (Savi Dental resin) from the saved STL file. All 3D-printed IFPs were removed from the build plate and cleaned with isopropyl alcohol (99.9% isopropyl alcohol; REDCOP). The post processing polymerization was done in a light polymerizing unit (Asiga® flash curing Unit; Asiga Inc) for 40 minutes (450mW).

All milled and 3D-printed IFDPs were then grounded with 1200-grit silicon carbide abrasive paper using a low speed handpeice (NSK) for 20 s at 100 rpm and then polished with aluminum oxide polishers (Enhance PoGo Complete Kit; Dentsply Sirona) for 30 seconds under pressure by a single operator to remove any possible residues and get uniform surface throughout. The samples were then embedded into a silicone mould (Hydrorise silicone putty, Zhermack INC).

Storage Medium and Immersion time period - The IFP were then divided into 3 subgroups (n-8) to be

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immersed in their respective staining solutions, Cola type soda (Coca-Cola©, The Coca-Cola Company), artificial saliva (pH 6.3), artificial saliva with reduced pH (pH 4). All samples were immersed for two-time intervals for 3 days (T2) and 7 days (T3) after which values for surface roughness and colour stability were recorded.

Surface Roughness Analysis - Surface roughness measurements (Ra) were done using a profilometer (Taylor Hobson Form Taly Surf 50^{R}). The measurements were made on 3 locations on the labial surface of each IFP the first measurement from the incisal one third, the second measurement from the middle one thirdsurface of the specimen, and the third measurement from the bottom third of the surface of the samples The mean of these measurements was calculated for the mean baseline Ra value of the specimen.

Colour Stability Analysis - A clinical spectrophotometer (VITA Easyshade V, VITA Zahnfabrik, KG, Germany) was used for colour measurements of samples and recorded according to the CIELAB system as L*, a*, b*. The coordinate L* corresponded to the lightness of the material and the differences between the brightness and darkness. The coordinate a* and coordinate b* corresponded to differences in red-green axis and yellow-blue axis. The device was calibrated according to the manufacturer's instructions and colour measurement of each specimen was performed three times, and the average L*, a*, and b* values were recorded at baseline (T1). The spectrophotometer's tip was set perpendicular to the labial middle third of each IFP against a white background and measured by a single operator.

The colour difference (DE*) was calculated according to the following formula

$$\Delta E00=(kLSL\Delta L')2+(kCSC\Delta C')2+(kHSH\Delta H')2+RT(kCSC\Delta C')(kHSH\Delta H')$$

where DL*, Da*, and Db* are the differences of L*, a*, and b* colour parameters at T2 and T3 respectively.

Statistical Analysis - Statistical analysis was conducted using SPSS software (type of software). These measurements were analyzed using 1-way ANOVA with a Bonferonii post-hoc multiple comparison and t test to determine statistical significance.

Results

All the IFP samples fabricated by subtractive method showed significant change in surface roughness (p value-<0.001) at 7days of immersion in coke, artificial saliva and saliva with reduced pH (pH-4). No significant changes were observed in these samples at T2 except for the samples immersed in saliva with reduced pH

All the additive manufactured samples showed significant increase in roughness at T2 and T3 but no significant change was observed in samples treated with artificial saliva from T2 to T3.

Descriptive							Comparison :baseline-48-72hrs	
MATERIAL			Mean	Std. Deviation	95% Confidence Interval for Mean		Repeated Measures ANOVA- p value	Post hoc analysis- Bonferroni test
					Lower Bound	Upper Bound		
CAD CAM	Coke	baseline	0.0706	0.0106	0.062	0.079	<0.001	Baseline-72 hrs 48hrs- 72 hrs are significant
		@48hrs	0.0877	0.0217	0.070	0.106		
		@72hrs	0.1709	0.0311	0.145	0.197		
	Artificial Saliva	baseline	0.0663	0.0102	0.058	0.075	<0.001	Baseline-72 hrs 48hrs- 72 hrs are significant
		@48hrs	0.1044	0.0350	0.075	0.134		
		@72hrs	0.1520	0.0165	0.138	0.166		
		baseline	0.0594	0.0296	0.035	0.084	<0.001	

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	Reduced pH	@48hrs	0.1123	0.0352	0.083	0.142		Baseline-48hrs Baseline- 72 hrs 48hrs- 72 hrs are significant
		@72hrs	0.1661	0.0399	0.133	0.199		
3D PRINTED	**Coke**	baseline	0.1224	0.0064	0.117	0.128	0.005	Baseline-48hrs Baseline- 72 hrs 48hrs- 72 hrs are significant
		@48hrs	0.1631	0.0127	0.153	0.174		
		@72hrs	0.2139	0.0152	0.201	0.227		
	Reduced pH	baseline	0.1273	0.0122	0.117	0.137	<0.001	Baseline-48hrs, Baseline- 72 hrs 48hrs- 72 hrs are significant
		@48hrs	0.1732	0.0094	0.165	0.181		
		@72hrs	0.2275	0.0245	0.207	0.248		
	Artificial Saliva	baseline	0.1278	0.0064	0.122	0.133	<0.001	Baseline-48hrs, baseline-72 hrs are significant
		@48hrs	0.1453	0.0090	0.138	0.153		
		@72hrs	0.1519	0.0077	0.145	0.158		

Although no disparity was noted in the colour of all the specimens after T2 , significant discolouration was observed in CAD milled specimens immersed in all three-storage media with coca cola showing highest colour change (ΔE_{00} – 3.04) followed by artificial saliva (ΔE_{00} - 2.31) and saliva with reduced pH (ΔE_{00} - 2.29) when checked at T3. Contrarily 3D printed specimens showed highest discolouration after immersion in saliva with reduced pH (ΔE_{00} - 4.91) followed by immersion in coca cola (ΔE_{00} - 4.76) and artificial saliva (ΔE_{00} - 4.65) at T3.

COKE	CAD CAM	3D PRINTED
T2	1.66 (STD DEV: 0.26)	2.68 (STD DEV: 1.09)
T3	3.04 (STD DEV: 0.79)	4.76 (STD DEV: 1.43)

ARTFICIAL SALIVA	CAD CAM	3D PRINTED
T2	1.58 (STD DEV: 0.14)	3.03 (STD DEV: 0.07)
T3	2.31 (STD DEV: 0.49)	4.65 (STD DEV: 1.51)

REDUCED PH	CAD CAM	3D PRINTED
T2	1.50 (STD DEV: 0.00)	3.10 (STD DEV: 0.15)
T3	2.29 (STD DEV: 0.55)	4.91 (STD DEV: 1.25)

Discussion

This study evaluated the surface roughness and colour stability of provisional crowns manufactured with subtractive computer-aided design and milling (CAD/CAM) technology to that of additively fabricated 3 dimensionally printed provisional crowns. The results of the study depicted that CAD CAM manufactured provisional restorations have superior colour stability

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and decreased surface roughness after immersion in oral cavity simulants like saliva and cola hence the null hypothesis was rejected. Pre polymerized resin milling blocks which have superior mechanical and optical properties when compared to conventional provisional materials [4] were used for fabrication of provisional crowns by subtractive methodology. Digital light processing method involves using a digital micromirror to cast a single light-mask image across the whole print surface for every layer. The properties of the 3D printed object are influenced by the composition of liquid resin used; hence this study evaluated the optical and surface properties of new dental resin (Savi Dental resin) used for provisionalization. The surface roughness of provisional crowns is an integral factor predisposing to accumulation of plaque and is detrimental to oral health of the patient. The range of surface roughness which affects the microbial adhesion ranges between 0.1-0.4μm. Since the oral cavity is subject to constant salivary pH variation and extrinsic stainability such as during consumption of acidic beverages and also in patients with gastric regurgitation symptoms, it is essential that provisional restorations have adequate resistance to loss of surface texture and good long-term colour stability. Hence artificial saliva with a reduced pH (4.75) and coca cola aerated drink were considered in the study so as to simulate conditions within the oral environment over longer time periods.

Short term laboratory studies help determine the functionality of these restorations in oral environment. This study used a profilometer to evaluate the surface texture of temporary crowns of an incisor tooth so as to best simulate conditions in the oral cavity after delivery of temporary prosthesis.

Hamouda et al[26] reported intake of beverages with low pH tend to have erosive effects on the surface of restorations. Consequently, the current study also showed an overall increase in surface roughness after immersion of the provisional crowns fabricated by both additive and subtractive method irrespective of the storage media used. This is in consensus with previous studies by Haselton et al[27] and Fay et al[28] who concluded that hydrolytic degradation of resin leads to deterioration of their surface texture. Significant difference in the surface character was found among the fabrication method employed in this study. Aldahian[29] et al reported similar results of greater surface wear on 3D printed resin compared to CAD milled interim crowns. Crowns fabricated by 3D printing had an increasingly porous surface which could be attributed to the fact that additively manufactured resin have larger filler particles in comparison with homogenous industrially pre polymerized milling blanks used in subtractive fabrication method. Alharbi et al[30], emphasized on printing orientation and its effects on the mechanical properties such as Microhardness and surface roughness of resin. Vertically orientated samples with layers oriented perpendicular to the load direction presented with greater flexural strength, reduced microhardness and surface roughness. The post polymerization processing could also play a major role in achieving a greater homologous surface across the resin material.

Colour stability is commonly associated with insufficient polymerisation, water sorption, oral hygiene, and the restoration's smooth surface the degree of colour change and surface topography can also be influenced by the type of immersion solution and the length of time the materials are exposed to the staining solution. [9] All samples were immersed in respective storage medium and the colour change was detected after 2 days and 7 days. Colour stability can be evaluated using instrumental and visual methods. Instrumental method eliminates the possibility of subjective judgement when comparing colours visually. Various devices such as colourimeter and spectrophotometers are used for colour measurements. Clinical spectrophotometer was the device of choice to check for colour parameters on provisional restorations using the CIELAB system. The current study demonstrated a discolouration of additive manufactured crowns when exposed to acidic environment and beverages with lower pH and those with inherent stains. Ceci et al [29] reported a ΔE_{00} greater than 3.7 to be discernible when visually observed. The additive manufactured samples showed colour difference greater than the average accepted range ($\Delta E_{00} > 3.7$). Staining may differ depending on the type and degree of polymerisation, as well as the composition of the intermediate material, water sorption, size and distribution of the polymethylmethacrylate particles, the effectiveness of the initiator system, the amount of filler, and the degree of cross-linking. Interestingly higher tendency of colour change was observed in crowns manufacture by the additive methodology. Song et al [14]

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also reported similar values of colour difference in milling blanks. Shin et al [30] also observed the higher staining tendency of additive manufactured prostheses when immersed in various colourants. The milling blanks used in subtractive methodology are processed under ideal temperature and pressure conditions leading to well polymerized molecular structure. In contrast to this additive manufacturing involves building one layer over the other and regardless of the post polymerization processing, these materials never achieve near total polymerization leading to greater spaces between molecules. These spaces tend to absorb water and inherent stains of the immersion media. The values of the additively made crowns were above what is considered clinically acceptable. This could be attributed to the material properties and staining solutions used. Based on these results it can be concluded that additive manufactured crowns exhibit greater surface roughness especially in acidic environment which can ultimately lead to greater pores on their surface and higher tendency to accumulate plaque and various colourations from oral media.

Conclusion-Subtractive manufacturing of interim fixed prosthesis showed lesser surface roughness and good colour stability when subjected to different ageing solutions and hence be considered a suitable choice for long term temporization owing to their superior mechanical properties and availability as homogenous pre polymerized blanks.

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