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Original Article

Comparative Evaluation of Flexural Strength, Color Stability, Surface Roughness and Weight Change of Various Commercially Available Flexible Denture Base Materials at Various Time Intervals – An *In Vitro* Study

K Srinivas[1], D Hima Mounika[2], Y Ravi Shankar[3], M Hari Krishna[4], T Satyendra Kumar[4], R Sunitha[5]

[1]Professor, Department of Prosthodontics and Crown and Bridge and Implantology, Gitam Dental College, Visakhapatnam, Andhra Pradesh, India, [2]Post Graduate, Department of Prosthodontics and Crown and Bridge and Implantology, Gitam Dental College, Visakhapatnam, Andhra Pradesh, India, [3]Vice Principle, Professor and Head of the Department, Department of Prosthodontics and Crown and Bridge and Implantology, Gitam Dental College, Visakhapatnam, Andhra Pradesh, India, [4]Reader, Department of Prosthodontics and Crown and Bridge and Implantology, Gitam Dental College, Visakhapatnam, Andhra Pradesh, India, [5]Senior Lecturer, Department of Prosthodontics and Crown and Bridge and Implantology, Gitam Dental College, Visakhapatnam, Andhra Pradesh, India

Abstract

Introduction: Removable partials dentures are the standard treatment modality for edentulous patients. Conventional poly(methyl methacrylate) is still being used for the fabrication of dentures. Flexible denture base materials are the best alternative to conventionally used denture base resins, which provide excellent aesthetics, comfort, and flexibility.

Aim: The aim of this study is to evaluate and compare flexural strength, color stability, surface roughness, and weight change of four commercially available flexible denture base materials immersed in artificial saliva for various time intervals.

Materials and Methods: Stainless steel die prepared with the dimension 40 mm × 10 mm × 3 mm. One hundred and twenty samples were prepared and divided into four groups based on the materials. Materials used are Valplast, Breflex, TCS unbreakable, and Iflex. Initial measurements were recorded for color stability, surface roughness, and water sorption. For flexural strength, the initial measurements were taken as control. Samples were stored in artificial saliva for 1 month and 3 months, respectively, and final measurements were noted. Three-point bend test was done in universal testing machine for flexural strength; color stability with Vita easy shade spectrophotometer. Surface roughness with profilometer and the weight change was evaluated using an analytical balance.

Results: A statistically significant difference was seen ($P < 0.01$) between Valplast, Breflex, TCS, and Iflex for flexural strength, color stability, surface roughness, and weight change with significant difference between time intervals. An increase in surface roughness and weight with increased immersion from 1 month to 3 months was observed whereas flexural strength and color stability decreased from 1 month and 3 months.

Conclusion: Increase in immersion time increases the surface roughness, weight and decreases the color stability and flexural strength of Valplast, Breflex, TCS, and Iflex. Better properties were exhibited by Breflex after 1 month and 3 months of immersion in artificial saliva than Valpalst, TCS, and Iflex.

Key words: Artificial saliva, Breflex, Color stability, Flexible denture base materials, Flexural strength, Iflex, Surface roughness, TCS, Valplast, Weight change

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INTRODUCTION

A removable partial denture has become the most common mode of treating edentulousness as many of the patients choose them because of the cost and physiology.[1] They are fabricated with metal alloys, acrylic resins, and thermoplastic resin. Dr. Walter Wright and the Vernon

Corresponding Author: Dr. Y Ravi Shankar, Department of Prosthodontics and Crown and Bridge and Implantology, Gitam Dental College, Visakhapatnam, Andhra Pradesh, India.

brothers in the year 1937 introduced Acrylic resins which are mostly used material because of its processing technique, easily repairable, excellent aesthetics and also economical. Disadvantages with these prostheses are insertion in undercut areas, fracture of denture due to its brittleness, and the presence of monomer causes allergy.[2]

Various experiments were done by Arpad and Tibor Nagy to resolve the problems encountered with the usage of conventional denture bases and attain the elemental needs of retention, support, and stability and it provides beautiful aesthetics.[3] Thermoplastic resins are using in dentistry for very long period. These resins are softened by heating and hardened by cooling without any chemical change. They are broadly classified as thermoplastic acetal, thermoplastic polycarbonates, thermoplastic acrylic, thermoplastic nylon, and polyolefins.

Acetal resins can resist occlusal wear and maintain vertical dimension during provisional restorations. However, strong acetal does not have the natural translucency and vitality as thermoplastic acrylic and polycarbonate. Polycarbonates are ideally used for provisional restorations. They are not suitable for partial denture frameworks. poly(methyl methacrylate) (PMMA) polymerized thermally demonstrates high porosity, water absorption, volumetric changes, and residual monomer content.

Nylon polyamides were first introduced for the construction of denture bases in the 1950s.[4] The generic name for thermoplastic polymers is Nylon belonging to the class known as polyamides. Polyamides are formed by the condensation reaction between a diamine and a dibasic acid. In certain conditions, where the undercut present on the buccal aspect of the maxillary tuberosity region, the flexibility of nylon is advantageous for easy insertion. The composition of molding powder, the temperature, and pressure used to inject the material determines the flexibility of nylon.[5]

Thermoplastic resins are polyamides, polyolefins, polyesters, and acrylics. Polyolefins are polypropylene or polyethylene, is used in recent years to fabricate for flexible partial dentures. These are light in weight and translucent materials have good chemical and fatigue resistance, coupled to high flexural strength.[6]

MATERIALS AND METHODS

The study consists of 120 samples, divided into thirty samples for each group for the type of material used. The thirty samples were subdivided into ten samples each based on the materials for 3 intervals, i.e. 1 day, 1 month, and 3 months. A stainless steel die prepared with a dimension of 40 mm × 2 mm × 10 mm. Four flexible denture base materials used in this study are VALPLAST, BREFLEX, TCS unbreakable, and IFLEX manufactured by different companies.

Preparation of Samples

Putty impressions were made for the die, and melted wax was poured into the putty impression. The softened modeling wax was allowed to become rigid. The prepared wax samples were flasked in die stone and allowed to sit for 45 min. Injection molding system was used to fabricate the flexible denture materials in specially designed flasks [Figure 1].

The injection molding procedure was done similarly for all the flexible denture base materials following the manufactures instructions of respective materials. After processing all the samples were trimmed using stone burs and rubber wheels in a unidirectional manner for about 10–12 times and polishing was done using pumice with rag wheel. Samples were checked for any porosities and irregularities under light. If any defect was detected, that the samples were discarded. After completing finishing and polishing, the samples were marked from 1 to 10 according to their respective groups so that it makes easier to test the sample for initial and final values after completing the immersion period.

Samples were placed in artificial saliva for 16 hours a day, simulating the time during which the patient uses the denture and the rest 8 hours a day time during which the patient removes the denture to sleep.[7] 1 month and 3 months samples were immersed in artificial saliva and make sure that all the samples were completely dipped [Figure 2]. All the samples except the samples that are to be tested immediately after one day of fabrication, remaining were placed in artificial saliva to simulate the oral environment.

Figure 1: Specially designed flasks and injection moulding system

Figure 2: samples stored in artificial saliva for 1 month and 3 months

Ten samples from each group were tested immediately for flexural strength after 1 day without immersion in artificial saliva. For surface roughness, color stability, and weight change, the initial values were taken for each sample before immersion in artificial saliva. After completion of the immersion period, the samples were washed thoroughly under tap water and wiped with tissue paper and tested for color stability, surface roughness, and weight change after 1 month and 3 months in artificial saliva, respectively. The same samples were tested for flexural strength, and the obtained values were tabulated.

Testing Procedures

Flexural strength

All the samples were subjected to a three-point bending test to evaluate the flexural strength. It was done using universal testing machine (UTM)- Dak system Inc Series 7200 [Figure 3]. Distance between the two supporting wedges is 30mm and the cross-head speed was set at 5mm per min. Force is applied perpendicular to the center of the specimen and the samples were gradually loaded using a UTM. Load and the deflections of each sample were noted. The flexural strength of each specimen was determined by applying increasing load until a permanent deformation occurs. The flexural strength of the samples was calculated as follows:

$$S= 3PL/2BD^2$$

where,
S - flexural strength in MPa
F - fracture load in Newton
L - span length in mm
B - specimen width in mm
D - specimen thickness in mm

Color stability

Color stability measurements were recorded before immersion and after completing the immersion period. The samples were thoroughly rinsed under tap water after immersion and make sure that they are completely

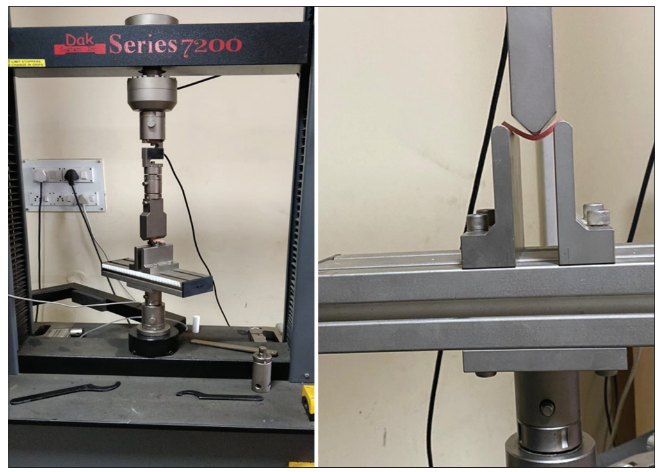


Figure 3: Flexural strength testing and deflection of samples under load

dry. Color stability of the sample was evaluated with Spectrophotometer VITA easy shade [Figure 4]. The measuring tip should rest properly on the calibration block and is not lifted up before the signal tone that indicates it is the end of the white balance. Place the measuring tip again as requested. A minimum of three readings was taken for each sample. The mean was calculated and recorded with the CIE Lab system (Commission Internationale de L Eclarirage). In the CIE Lab system, L* represents light-dark shade (value), a* is green-red, and b* is yellow-blue (hue and chroma).

The magnitude of the two samples color difference was represented by a single number in the CIE Laboratory system using a formula $\Delta E = (\Delta L^2 + \Delta a^2 + \Delta b^2)^{1/2}$. To relate the color differences to the clinical environment the color data were quantified by National Bureau of Standards (NBS) units using the formulae NBS units $=\Delta E^* \, 0.92$.

Surface roughness

Surface roughness measurements were recorded just before and after the immersion. The samples were thoroughly rinsed under tap water after immersion and make sure that they are completely dry. Make sure that the testing surface of the sample is marked on one side for initial roughness testing so that the same surface of the sample can be tested for final roughness. The samples are placed under Profilometer [Figure 5] for testing the surface roughness. Profilometer consists of a diamond stylus that moves to and fro up to a distance of 3 mm, and R_a values were noted for all samples.

Water sorption

Water sorption leads to weight gain and it was measured using analytical balance [Figure 6] for the control group without immersion in artificial saliva. Samples to be stored are weighed before and after immersion for 1 month and 3 months in artificial saliva. Water sorption is calculated with the formula:

$$\text{Water sorption} = 100\ (W_n - W_0)/W_0$$

W_n is the weight of the sample after immersion in gms and W_0 is the weight of the sample before immersion.

Figure 4: VITA easy shade to test color stability

Figure 5: Profilometer for surface roughness

RESULTS

All the results were subjected to statistical analysis. One-way ANOVA test paired *t*-test was performed to measure the significance of the different materials used in the study.

The mean flexural strength of Valplast in control, 1 month and 3 months is 20.56, 18.67, and 16.84. The mean flexural strength of Breflex in control, 1 month and 3 months is 27.57, 26.87, and 25.07. The mean flexural strength of TCS Unbreakable in control, 1 month and 3 months is 26.92, 25.61, and 22.24. The mean flexural strength of Iflex in control, 1 month and 3 months is 24.92, 22.15, and 18.48, respectively [Table 1]. Highest difference in flexural strength is seen from control to 1 month and 3 months in Iflex compared to Valpalst, breflex, and TCS [Graph 1].

Color stability of all the materials the mean difference of Valplast, Breflex, TCS Unbreakable, and Iflex is 0.838, 0.606, 0.900, and 0.943, respectively, at 1 month and 1.071, 0.753, 1.161, and 1.296 at 3 months intervals. There is a slight color change in samples immersed in artificial saliva for Three months than the samples immersed for a period of 1 month and the color change is statistically significant in all the materials $P < 0.001$ [Table 2]. Highest difference in color is seen from control to 1 month and 3 months in Iflex compared to Valpalst, breflex, and TCS [Graph 2].

The mean difference of surface roughness in Valplast, Breflex, TCS Unbreakable, and Iflex is 0.630, 0.540, 0.870, and 0.830 at 1 month and 1.680, 1.530, 1.890, and 1.740 at 3 months intervals respectively. Surface roughness difference between 1 month and 3 months is statistically significant $P < 0.001$ [Table 3]. Highest difference in surface roughness is seen in Iflex compared to Valpalst, Breflex, and TCS from 1 month to 3 months [Graph 3].

Weight change in all the four materials after 1 month of immersion in artificial saliva is –0.080 for Valplast, –0.045

Figure 6: Analytical balance to measure weight change

for Breflex, and -0.077 for TCS unbreakable and Iflex. It shows that there is a statistically significant change in weight in all the materials before and after immersion [Table 4]. Moreover, among all the materials highest weight change is seen in Valplast and least in Breflex [Graph 4]. Weight change in all the four materials after 3 months of immersion in artificial saliva, the mean difference was –0.079 for Valplast, –0.060 for Breflex, –0.091 for TCS unbreakable, and –0.1010 for Iflex. It shows that there is a statistically significant change in weight in all the materials before and after immersion [Table 4]. Moreover, among all the materials highest weight change, is seen in Iflex and least in Breflex [Graph 5].

Table 1: Comparison of Flexural strength of all the materials at various time intervals i.e, control, 1 month, and 3 months after immersion in artificial saliva using RM ANOVA

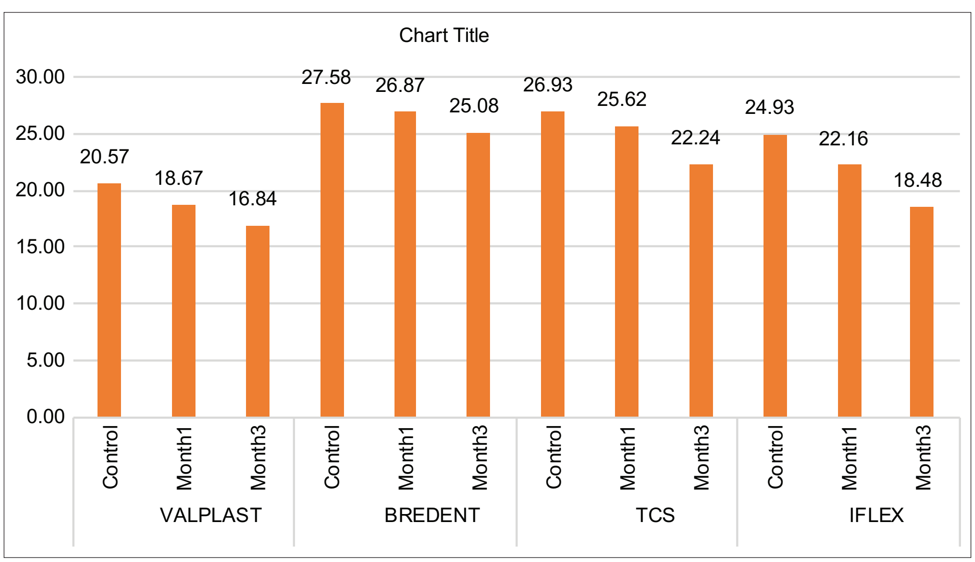
Flexural Strength	Mean	Std. Deviation	RM ANOVA F-value	*P*-value
Valplast				
Control	20.5682	0.88076	122.182	0.001*
1 Month	18.6700	0.58531		
3 Months	16.8435	0.49812		
Breflex				
Control	27.5759	1.23557	25.175	0.001*
1 Month	26.8735	0.72221		
3 Months	25.0769	0.72250		
TCS unbreakable				
Control	26.9298	1.42497	341.312	0.001*
1 Month	25.6192	1.29492		
3 Months	22.2449	1.28639		
Iflex				
Control	24.9287	0.71354	109.959	0.001*
1 Month	22.1589	0.46614		
3 Months	18.4824	0.61409		

ANOVA: Analysis of variance

DISCUSSION

In dentistry, the loss of tooth is the important problem that should be controlled, otherwise treated successfully for healthy living of the patients. Removable partial denture, fixed partial denture and dental implants are many treatment options that are available currently for replacing missing teeth; Every possible treatment option has its own advantages and disadvantages. With the introduction of acrylic polymers and chrome cobalt alloys, removable partial dentures became popular in dentistry many decades ago. Many patients choose removable partial dentures as they are low cost when compared to the other options available.[3]

Therapeutic usage of thermoplastic materials has been increasing recently in this decade. The recent new materials are used to manufacture prosthetic appliances by injecting them after they are softened with heat, without monomer. These Nylon materials have opened new horizons in the fabrication of removable partial dentures.[8] Flexible partial dentures are indicated in ridges where bilateral undercuts as they utilize the undercuts in the ridge for retention. They are also indicated in patients allergic to acrylic monomers. Clasps in esthetic zone like on maxillary canine, Patients whose economical conditions limit the use of implant and patient who does not want fixed prostheses. In patients who have nickel allergy and where large bony exostoses cannot be removed, flexible partial dentures show good retention without the removal.[3]



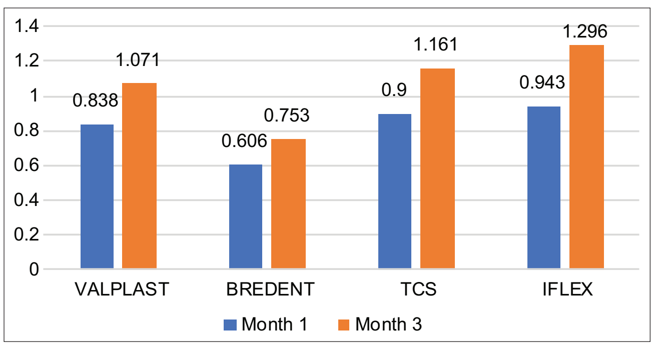
Graph 1: Schematic representation of comparison of Flexural strength of all samples at different time intervals (control, 1 month and 3 month) by using analysis of variance test

Polyamides are promoted as a denture base material on the basis of its good flexural strength, which allows it for engaging certain degree of undercuts for the purpose of retention. They are mainly indicated in conditions such as tori, tuberosities, protuberances, and extremely bulging alveolar processes, especially in the maxillary anterior region posing problems of esthetics along with retention and as an alternative to patients who are allergic to monomer.[9]

Table 2: Comparison of color stability at 1 and 3 months of time interval in all the four materials using One-way ANOVA

Color stability	Mean	SD	ANOVA F-value	*P*-value
1 Month				
Valplast	0.838	0.071	72.170	0.001*
Breflex	0.606	0.062		
TCS Unbreakable	0.900	0.037		
Iflex	0.943	0.047		
3 Months				
Valplast	1.071	0.046	117.224	0.001*
Breflex	0.753	0.063		
TCS Unbreakable	1.161	0.092		
Iflex	1.296	0.061		

ANOVA: Analysis of variance

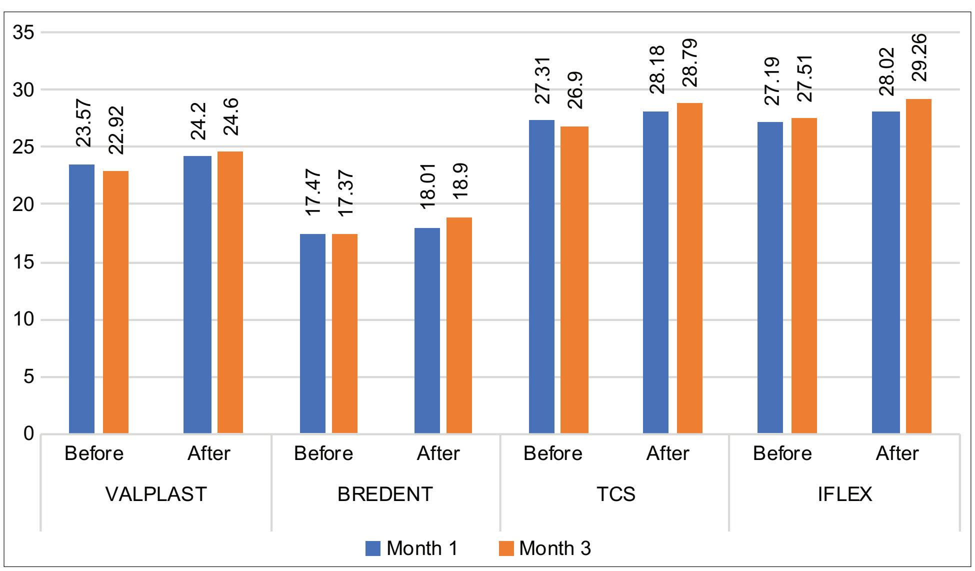


Graph 2: Schematic representation of comparison of Color stability at various times intervals (1 month and 3 month) by using analysis of variance test

As the time increased, there is a decrease in flexural strength which was correlated with the research studies of Yunus *et al.* who showed that water or humid environment has a statistically significant effect on the polymers which decreases the physical properties. Water molecules act as a plasticizer in polymer structure when immersed in water. The absorbed water molecules can interfere with the polymer chains entanglement that results in the plasticization of polymer.[10-12]

Discoloration of denture base resins might be due to various factors. The degree of conversion and residual monomer content, porosity caused by overheating or pressure during processing are intrinsic factors that can influence the color stability. Eating habits and certain external factors such as cleaning solutions, tobacco, composition of saliva, and denture hygiene habits have the effect on color stability of the denture.[13]

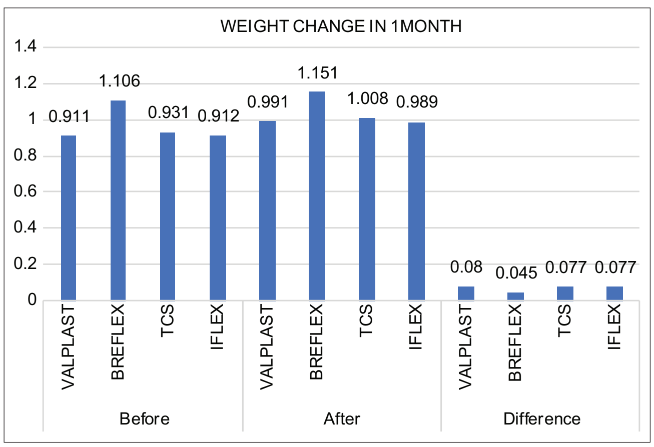
It was observed that at 1 month of immersion in artificial saliva there is not much difference between each material except Breflex which shows statistically significant difference when compared with the other three materials. At 3 months of immersion, there is a statistically significant difference between all the materials including Breflex, but this difference is not clinically acceptable according to the NBS. Increase in color change in Flexible materials with time was correlated with the studies conducted by Song *et al.* similar to the present study.[14-16] Oxidation of tertiary



Graph 3: Schematic representation of Surface roughness of all the samples immersed in artificial saliva at various time intervals (1 month and 3 months) using one way analysis of variance

Table 3: Comparison of Surface roughness difference (before and after immersion) at 1 month and 3 month interval of all the four materials using paired t-test

Surface Roughness	Mean	SD	Mean Difference	Paired *t*-test *t*-value	*P*-value
Valplast					
1 Month	0.630	0.106	–1.050	–19.649	0.001*
3 Month	1.680	0.132			
Breflex					
1 Month	0.540	0.070	–0.9900	–17.593	0.001*
3 Month	1.530	0.164			
TCS unbreakable					
1 Month	0.870	0.106	–1.0200	–18.623	0.001*
3 Month	1.890	0.137			
IFLEX					
1 Month	0.830	0.067	–0.9100	–18.200	0.001*
3 Month	1.740	0.143			



Graph 4: Schematic representation of weight change of all the samples immersed in artificial saliva for 1 month

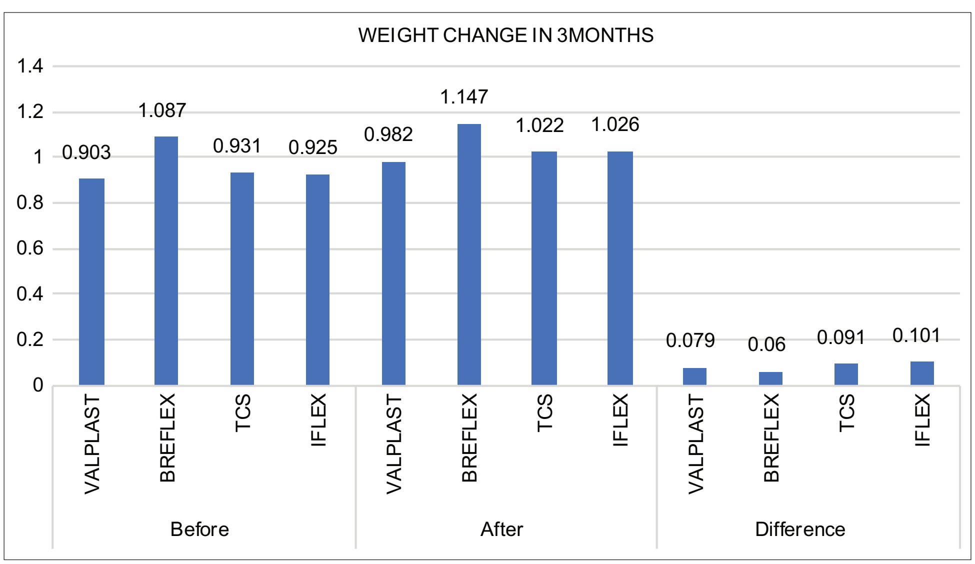
amines present in the denture base resins is one of the reasons for color change.

Rougher surface can cause discoloration and can be a source for the accumulation of biofilm causing discomfort to the patient.[17] All the materials showed an increase in surface roughness in all the materials which was in accordance with the study conducted by Ayaz *et al*., and Mohsin *et al*. showed that there in increase in surface roughness of polyamide samples when compared with PMMA samples after thermocycling. This might be due to physical properties of the materials and the presence of amide groups on the main chain and provide the hydrophilic nature to the material. Immersion in water and immersion in artificial saliva may cause swelling of the samples and deposition of salts in artificial saliva which increases its R_a (mean surface roughness). As the size of the crystal inflexible material is large which makes it difficult to polish.[11,18]

There is change in weight among all the materials and absorption of water molecules has impact on other properties. This was correlated with the research study conducted by Hamanaka *et al*. and Lai *et al*. who showed that flexible materials are hydrophilic in nature when immersed in water absorbs water and these water molecules interfere with the polymer structure that results in water absorption. This water sorption had a statistically significant effect on flexural strength and elastic modulus.[13,19]

Limitations of the Study

1. As this is an in-vitro study, the samples tested were not able to simulate the oral environment as it might slightly alter the results



Graph 5: Schematic representation of weight change of all the samples immersed in artificial saliva for 3 months

Table 4: Comparison of weight change in all the four materials after 1 month and 3 months of immersion in artificial saliva using paired *t*-test

Weight Change	Time	Mean	SD	Mean difference	Paired *t*-test *t*-value	P-value
1 month						
Valplast	Before	0.911	0.032	–0.0800	–5.316	0.001*
	After	0.991	0.035			
Breflex	Before	1.106	0.026	–0.04500	–4.011	0.001*
	After	1.151	0.024			
TCS	Before	0.931	0.017	–0.077	–7.765	0.001*
Unbreakable	After	1.008	0.027			
Iflex	Before	0.912	0.045	–0.077	–3.795	0.001*
	After	0.989	0.046			
3 months						
Valplast	Before	0.903	0.038	–0.0790	–5.103	0.001*
	After	0.982	0.031			
Breflex	Before	1.087	0.045	–0.0600	–3.152	0.001*
	After	1.147	0.040			
TCS	Before	0.931	0.024	–0.0910	–7.676	0.001*
Unbreakable	After	1.022	0.029			
Iflex	Before	0.925	0.034	–0.1010	–6.279	0.001*
	After	1.026	0.037			

2. Operator variables might alter for surface roughness, as mechanical operator method of polishing would be consistent without any human error
3. Injection temperature and pressure of the material may vary with the manufacturers might alter the properties of the materials
4. Samples were not subjected to thermocycling to simulate the oral environment.

CONCLUSION

Within the limitations of the above-conducted study, the following findings were drawn:

1. Samples immersed in saliva for 3 months show increase in flexural strength when compared to control and 1 month. The highest flexural strength was seen in Breflex, followed by TCS unbreakable, Iflex, and Valplast, and the difference was statistically significant
2. Samples immersed in saliva for 3 months show the highest difference in Color stability than 1-month samples. The highest color stability is seen in Breflex, followed by Valplast, TCS Unbreakable, and Iflex the difference was statistically significant
3. 3 months of immersion shows the highest difference in surface roughness compared to 1 month of immersion. The highest surface roughness is seen in TCS Unbreakable, followed by Iflex, Valpalst, and Breflex the difference was statistically significant
4. 3 months of immersion showed the highest difference in weight change compared to 1 month of immersion. All the materials showed a statistically significant difference for 1 month and 3 months before and after immersion
5. Among time intervals, there is an increase in surface roughness and water sorption and a decrease in color stability and flexural strength as the time of immersion increases. The samples immersed for 3 months have shown statistically significant differences in all the properties compared to 1 month of immersion and control samples
6. Among all the materials Breflex showed superior properties when compared to Valplast, TCS Unbreakable, and Iflex.

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