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ORIGINAL ARTICLE

Effect of Dietary Simulating Solvents on the Mechanical Properties of Provisional Restorative Materials-An In Vitro Study

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Abstract The purpose of this investigation was to evaluate the mechanical properties of provisional restorative materials after storage in dietary simulating solvents. A total of 120 specimens, 40 specimens each of Luxatemp Star, Revotek LC and DPI Self Cure were prepared. The specimens were divided into four groups with 10 specimens each and stored in dietary simulating solvents for 7 days at 37 °C as follows: Group I—Control, Group II—Artificial saliva, Group III—0.02 N Citric acid and Group IV—Heptane. After 7 days, flexural strength was obtained using universal testing machine at a crosshead speed of 5 mm/min and the fractured specimens were immediately subjected to the microhardness test knoop hardness number by using Knoop microhardness tester (10 gm/15 s). The data were analyzed for difference by use of Kruskal–Wallis and Dunn's multiple comparison tests using a significance level of 0.05 to determine the mean differences. Significant effect was observed on the properties of provisional restorative materials after storage in dietary simulating solvents as compared to the control group ($p \leq 0.05$). Bisacryl resin based Luxatemp Star showed significantly superior flexural strength and hardness as compared to the Revotek LC and DPI Self Cure in dietary simulating solvents. Within the limitations of this study, it may be concluded that dietary simulating solvents showed significant influence on the mechanical properties of the provisional restorative materials.

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Introduction

Fixed provisional dental prostheses are an integral part of treatment modality for partially edentulous patients. Provisional restorations should function same as definitive restorations in all aspects, differing only in the material from which they are made [1]. Provisional restorations should primarily protect vital pulpal tissues, maintain positional stability and occlusal function and provide strength and esthetics for the prepared teeth [2]. They can also be used in correcting irregular occlusal planes, restoring vertical dimensions and altering the contours of the gingival tissues [3, 4]. In many instances, provisional restorations are used for a long period to assess the results of periodontal and endodontic therapies, during the restorative phase of implant procedures, full mouth rehabilitation, tissue augmentation, alveoloplasty and orthodontics [5]. Provisional restorations provide numerous adjunct benefits to definitive prosthodontic treatment. The provisional restorative materials used for these purposes must reflect the variable treatment demands and requirements [6]. The desirable properties of provisional restorative materials are biocompatibility, adequate strength and abrasion resistance, adequate wear resistance, dimensional stability during solidification, good esthetic appearance, color stability and acceptability to patient.

As the provisional restoration is subjected to masticatory forces in an oral environment, understanding the mechanical properties of the provisional restorative materials is necessary to determine whether the restoration will be able to survive repeated functional forces, over prolonged periods of time. The mechanical strength of a provisional restorative material is of particular importance, as this factor might influence the integrity of the provisional restoration during its time in situ (1–2 weeks up to several

Table 1 Provisional restorative materials under study

Provisional restorative material	Manufacturer	Chemical nature	Mixing ratio	Curing mechanism
Luxatemp Star	DMG, Hamburg, Germany	Bis-acrylate	10:1	Autopolymerizing
Revotek LC	GC dental products corp, Aichi, Japan	Urethane-dimethacrylate	–	Light polymerizing
DPI self cure	Dental products of India, Mumbai, India	Polymethacrylate	2:1	Autopolymerizing

months) [7–10]. The flexural strength (FS) and knoop hardness number (KHN) of provisional prosthesis are critical amongst the mechanical properties and can be used as possible predictors of the ability of the materials to function in the oral environment [11]. Flexural strength, which is also known as transverse strength, is a measure of the strength of a bar (supported at each end) under a static load [12]. The flexural strength of provisional materials is crucial because a fixed dental prosthesis is subjected to compressive, tensile and shear forces during mastication [13]. Surface hardness of a material is a complex mechanical property which affects several other properties, including strength, proportional limit, ductility, malleability and resistance to abrasion and cutting. Surface hardness can also be used as an indicator of density and resistance to wear and surface deterioration [14].

Oral environment causes degradation and aging of dental restorations due to constant contact with saliva, food components and different beverages [2]. Resin matrices of dental composites are softened by organic acids and various food and liquid components [15, 16]. Therefore, the chemical environment in the oral cavity may have a critical influence on the in vivo degradation of composite resins [2].

Several scientific investigations have dealt with the determination of mechanical properties of provisional restorative materials at progressive points in time after setting [10, 11, 17–20]. However, very few studies have shown that the mechanical properties of provisional restorative materials are adversely influenced by dietary simulating liquids [2, 4]. Therefore, there is further need to evaluate the effects of dietary simulating solvents on the mechanical properties of provisional restorative materials. Hence, the purpose of this investigation was to evaluate and compare the flexural strength and hardness of three types of provisional restorative materials after storage in dietary simulating solvents.

Materials and Methods

Three provisional restorative materials were selected as listed in Table 1. A custom-made split 3-piece steel mould (Fig. 1) was fabricated to prepare specimens with uniform dimensions of 65 × 10 × 3 mm [21].

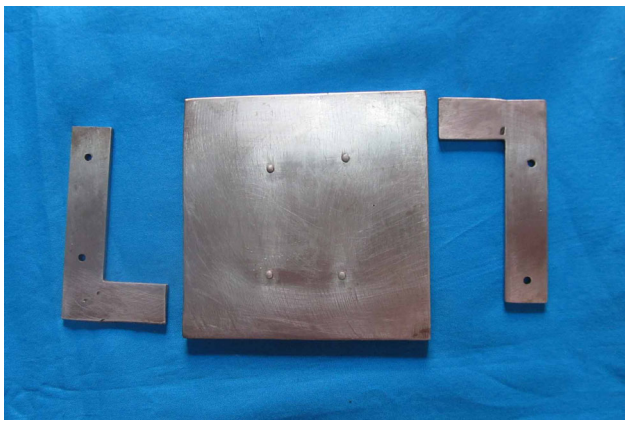


Fig. 1 Custom-made split 3-piece steel mould

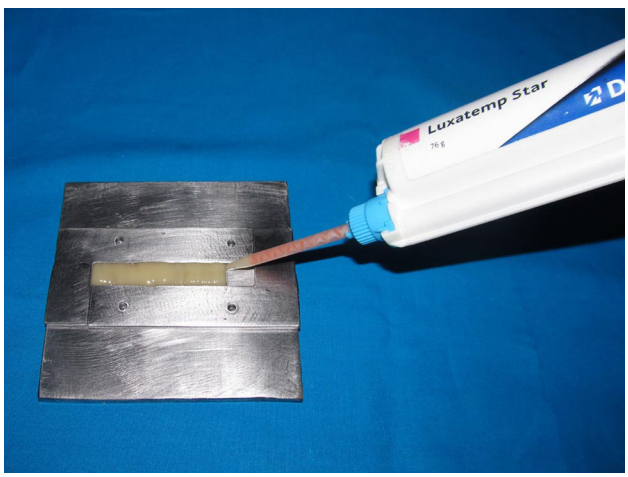


Fig. 2 Dispensing of Luxatemp Star using automix dispenser into the mould

The specimens were prepared by manipulating the provisional material according to the manufacturer's instructions. Luxatemp Star was manipulated using automix cartridge loaded to an automix dispenser. The mixing tip of the cartridge was held at one end of the mould and material was expressed into the mould moving the automix dispenser slowly to the other end to avoid incorporation of air bubbles while dispensing the material in the mould (Fig. 2).

Revotek LC putty stick was kneaded gently with fingers to soften it, dispensed and packed into the mould avoiding air bubbles or defects (Fig. 3). Care was taken to prevent over kneading of the material.

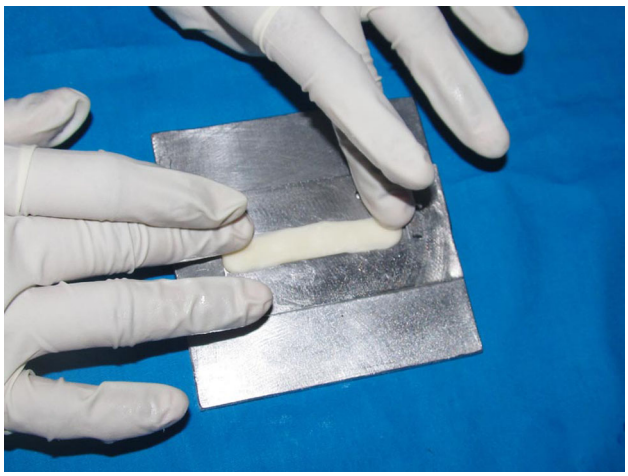


Fig. 3 Revotek LC dispensed into the mold

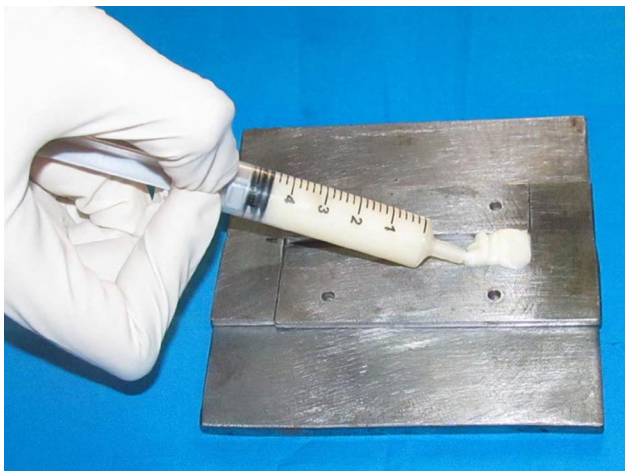


Fig. 4 DPI self cure dispensed into the mold

A required amount of the DPI Self Cure powder and liquid were measured in the ratio of 2:1 by volume, respectively, using a measuring cylinder and dispensed in a resin-mix bowl [22]. The polymer-monomer was hand mixed to a homogenous consistency using a stainless steel mixing spatula (Fig. 4). The paste was then filled into a 5 cc disposable syringe and dispensed into the mould avoiding air bubbles.

After completely filling the mould with the provisional restorative material, a clean lubricated glass slab was placed over the material and a 10 kg weight was placed on the glass slab to extrude excess material [2]. After the recommended setting time, the specimens were carefully separated from the mould and inspected for any defects or air bubbles. Likewise, 40 specimens were fabricated from each of the three provisional restorative materials (total 120 specimens). All 120 specimens were measured for accurate dimensions by using digital vernier calliper. The specimens of every provisional restorative material were randomly

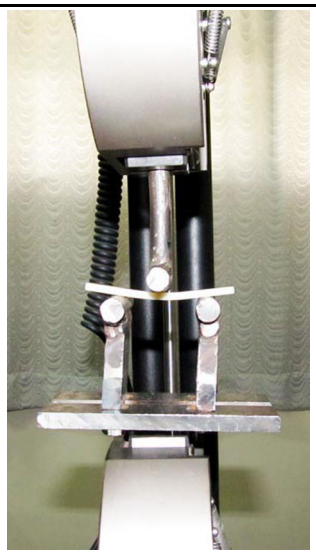


Fig. 5 Specimen subjected to three-point bending test in the Instron universal testing machine

divided into four groups of 10 specimens each. Each group represented the dietary simulating solvent in which specimens were stored and one group was selected as the control group (in air). The dietary simulating solvents selected were artificial saliva, 0.02 N citric acid and heptane. The specimens were stored in these solvents and control group specimens were stored in air, for 7 days at 37 °C in an incubator [2, 4].

At the end of 7 days, span and width of the control specimens was remeasured using the digital vernier calliper. The specimens from the dietary simulating solvents were washed under running water, air-dried and remeasured like control specimens. All the specimens ($n = 120$) were subjected to three-point bending test in a universal testing machine (Instron 4467, Norwood, USA) at a crosshead speed of 5 mm/min using 40 mm support span (Fig. 5). The maximum load exerted on the specimen until it breaks was recorded for each of the specimen. The flexural strength was calculated by using the formula $FS = 3\ PL/2\ WH$ [2], where FS = flexural strength, P = maximum load applied to the specimen, L = distance of the support span, W = width of the specimen and H = height of the specimen [12]. Each of the fractured specimens from the three-point bending test was immediately subjected to the microhardness test by applying indenter load of 10 gm at a dwell time of 15 s, using the Knoop microhardness tester (Mitutoyo, Japan) (Fig. 6). The KHN was measured at three different points on the specimen and the mean KHN was determined by calculating the average of the three values. Three indentations at different sites were placed on each specimen to allow for variations caused by the effect of filler particles on the sample surface.

For the statistical analysis, data were analyzed for difference by use of Kruskal–Wallis and Dunn's multiple

Fig. 6 Fractured specimen subjected to microhardness test

comparison tests using a significance level of 0.05 to determine the mean differences.

Observations and Results

A total of 120 specimens, 40 specimens each of Luxatemp Star, Revotek LC and DPI Self Cure were tested. The specimens were divided into four groups with 10 specimens each as follows: Group I—Control, Group II—Artificial saliva, Group III—Citric acid and Group IV—Heptane. The mean FS and KHN values of the provisional restorative materials after conditioning in dietary solvents are shown in Tables 2 and 3, and Graphs 1 and 2.

The results of the Kruskal–Wallis test for mean FS and KHN revealed a significant difference between all groups ($p \leq 0.05$). Mean FS and KHN values of all three materials were significantly influenced ($p < 0.05$) by the dietary simulating solvents as compared to control group.

In artificial saliva, comparison of mean FS and KHN of the three provisional materials showed statistically significant difference to control group ($p < 0.05$) (Tables 4 and 5). Insignificant difference ($p > 0.05$) was found between mean FS of Revotek LC and DPI Self Cure.

The comparison of mean FS and KHN of Luxatemp Star with Revotek LC and DPI Self Cure showed statistically significant difference ($p < 0.05$) in citric acid. However, difference between mean FS of Revotek LC and DPI Self Cure was statistically insignificant ($p > 0.05$).

In heptane, statistically significant decrease ($p < 0.05$) in FS and KHN values was observed in all three provisional materials as compared to the controls.

Discussion

Saliva, food components, beverages and different oral fluids from the oral environment have adverse effects on the dental restorations. Artificial oral environments try to simulate a choice of oral parameters under time lapsed conditions and therefore allow a preclinical estimation of material properties for oral application [18, 23]. Most of the studies [8, 14, 14, 24–27] on provisional restorative materials evaluate the effect of only water storage and saliva whereas only two studies [2, 4] assess the effects of dietary simulating solvents on the provisional materials. Heptane used in this study simulates butter, fatty meats and vegetable oils whereas citric acid simulates beverages, vegetables, fruits, candies and syrups according to FDA guidelines [28]. Artificial saliva was included to simulate wet oral environment provided by saliva. The 7 days conditioning period without interruption may be rather extensive as the restorations contact with foods only briefly during eating and drinking until teeth are cleaned [4]. Therefore, the test results might exaggerate the effects of dietary simulating solvents on the properties of provisional materials. However, continuous exposure could occur as chemical agents can be trapped around the margins and connectors of inadequately fabricated or improperly finished provisional prostheses and in porosities of poorly manipulated materials. In addition, they can be absorbed by adherent debris such as calculus or food particles at the margins of restorations or they can be produced by the decomposition of debris [4].

The negative effects of dietary simulating solvents on provisional materials can be due to the solubility parameter of this solvents [15]. The dietary simulating solvents cause damage to the subsurface of the composite materials [16]. The amount of damage depends on the penetrability of the

Table 2 Comparison of mean FS of three provisional restorative materials in four groups (Kruskal–Wallis test)

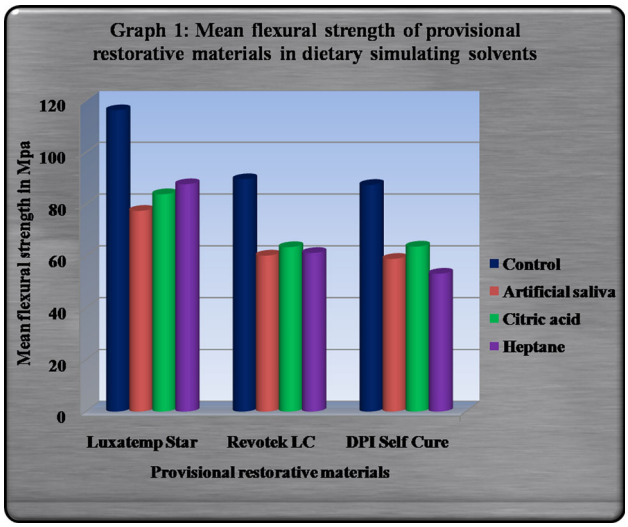
PRM	Control		Artificial saliva		Citric acid		Heptane	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Luxatemp Star	116.27	12.6	77.47 s	4.55	83.87 s	5.95	87.73 s	4.59
Revotek LC	89.67	7.41	60.2 s	3.02	63.46 s	3.91	61.2 s	2.71
DPI self cure	87.47	4.23	58.93 s	4.16	63.66 s	4.85	53.2 s	4.26

PRM—provisional restorative material; SD—standard deviation; S—significant

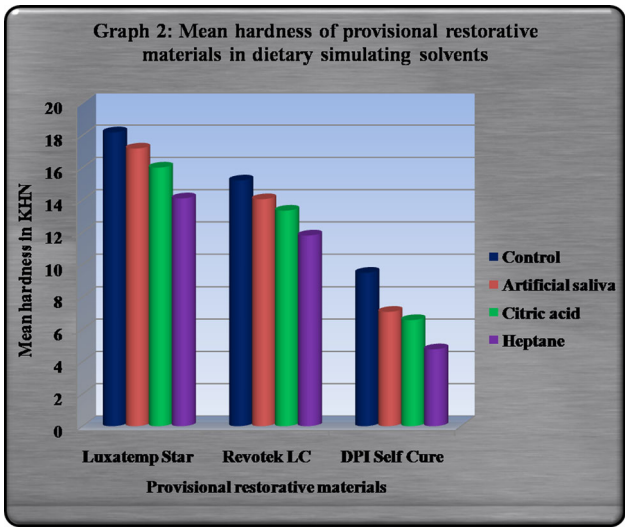
Table 3 Comparison of mean hardness (KHN) of three provisional restorative materials in four groups (Kruskal–Wallis test)

PRM	Control		Artificial saliva		Citric acid		Heptane	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Luxatemp Star	18.18	0.73	17.18 s	0.88	16 s	0.75	14.09 s	0.81
Revotek LC	15.2	0.77	14.04 s	0.53	13.33 s	0.66	11.79 s	0.58
DPI self cure	9.48	1.03	7.08 s	0.52	6.57 s	0.72	4.76 s	0.57

PRM—provisional restorative material; SD—standard deviation; S—significant



Graph 1 Graph showing mean flexural strength of three provisional restorative materials in dietary simulating solvents



Graph 2 Graph showing mean hardness of three provisional restorative materials in dietary simulating solvents

dietary simulating solvent components and interfacial bonding between the organic matrix and the fillers of provisional materials. Dietary solvents can penetrate the organic polymeric network of composite resin; causing swelling and separation of the filler and matrix phases [29]. There is also disintegration of silane coating which causes cracks between fillers and matrix of the composite resins. The dietary solvents induce softening of the polymers and initial swelling of the provisional materials followed by loss of substance in the oral environment and chemical dissolution [30]. The biodegradation caused by the solvents is dependent on various parameters like the type of material, solution and time.

In artificial saliva and citric acid, all three provisional materials showed significant reduction ($p < 0.05$) in flexural strength and hardness as compared to control group. Major component of these solvents is water which can be the cause of this deleterious effect. These results are in accordance with the previous studies [2, 10, 20]. Lang et al. [20] found that PMMA showed water absorption up to 32 μg/mm, primarily because of the polar properties of the resin molecules, and acts as a plasticizer reducing the fracture strength of the material.

Luxatemp Star is a composite materials having silane coating on the fillers, which improves the bond between filler and resin matrix. This bond between fillers and matrix is not stable under oral conditions and so there is a leakage of filler elements from composites. This may be the cause of decrease in FS and KHN of Luxatemp Star after storage in dietary simulating solvents. At the same time, higher values of flexural strength and hardness of Luxatemp Star than Revotek LC and DPI Self Cure can be due to bis-acryl resin matrix which contains bifunctional acrylates that cross-link to provide increased mechanical strength and resistance to weakening in the presence of solvents [11]. This capacity of cross-linking with another monomer chain provides a flexible cross-linked polymer structure, imparting strength and hardness to the material [2, 10]. The inorganic fillers further increase their resistance to abrasion and decrease the polymerization shrinkage [14]. The bis-acryl resin composite is hydrophobic [2], ensuring minimal water uptake, thus reducing the plasticizer action. In addition, vinyl copolymers are added in this material to increase the flexural strength [29]. Soderholm [31] showed that storage of composites in water leaches sodium ions out of the soda lime glass filler of the composites and the action of water was faster for PMMA based composites than for

Table 4 Multiple comparison of mean flexural strength (MPa) of three provisional restorative materials in four groups (Dunn's multiple comparison test)

Comparison	Control		Artificial saliva		Citric acid		Heptane	
	p value	Result	*p* value	Result	*p* value	Result	*p* value	Result
Luxatemp Star versus Revotek LC	0.011	S	0.0002	S	0.0002	S	0.0002	S
Luxatemp Star versus DPI self cure	0.0006	S	0.0002	S	0.0002	S	0.0002	S
Revotek LC versus DPI self cure	0.5959	NS	0.4712	NS	0.5438	NS	0.0003	S

S—significant; NS—non-significant

Table 5 Multiple comparison of mean hardness (KHN) of three provisional restorative materials in four groups (Dunn's multiple comparison test)

Comparison	Control		Artificial saliva		Citric acid		Heptane	
	p value	Result	*p* value	Result	*p* value	Result	*p* value	Result
Luxatemp Star versus Revotek LC	0.0002	S	0.0002	S	0.0002	S	0.0002	S
Luxatemp Star versus DPI self cure	0.0002	S	0.0002	S	0.0002	S	0.0002	S
Revotek LC versus DPI self cure	0.0002	S	0.0002	S	0.0002	S	0.0002	S

S—significant; NS—non-significant

those based on Bis-GMA due to differences in diffusion of water in the two resin matrices.

The decrease in FS and KHN of DPI Self Cure specimens after storage can be attributed to their composition. DPI Self Cure is a conventional PMMA based resin which is monofunctional, low molecular-weight, linear molecule with no fillers, which are all responsible for its poor flexural strength and hardness. The polarity of PMMA resin facilitated water absorption from the aqueous solutions (artificial saliva and citric acid) which in turn acts as a plasticizer and interferes with polymer chain entanglement. The degree of polymerization is also very low, leading to high residual monomer, which also acts as plasticizer and further decreases the strength and hardness [2]. In addition, if such methacrylates are not polymerized under pressure, air bubbles will be trapped and decrease their strength [11, 14].

Revotek LC appeared to be inferior to Luxatemp Star in terms of flexural strength and hardness and superior to DPI Self Cure in terms of hardness in citric acid. Revotek LC contains UDMA matrix and crystalline silica powder as filler. The UDMA matrix may be more susceptible to dissolution by dietary simulating solvents than bis-acryl resin matrix [29]. Also it has fewer amounts of filler particles [30, 32] and these glass fillers are slowly leached out in presence of saliva and other fluids [30]. Revotek LC was found to be more resistant to effects of artificial saliva as compared to DPI Self Cure. Braden [33] also found that composite material based on UDMA resin showed less water uptake than triethylene glycol dimethacrylate based materials.

The adverse effects of heptane on the provisional materials may be explained by the potential damage caused by heptane to the resin matrix [34]. Degradation of the inorganic fillers may also occur after storage in heptane. As emphasized by Roulet and Walti [35], the leakage of filler constituents may produce cracks at the resin–filler interface; it may also lead to weakening of the material. Possible explanation for the superior quality of Luxatemp Star in heptane can be again attributed to the bis-acryl resin matrix. The Bis-GMA molecule has a rigid central structure that reduces its ability to rotate and participate in the polymerization process [36] and so these materials might be less influenced than other resins during the polymerization process. The UDMA based resin matrix in Revotek LC and PMMA based resin matrix in DPI Self Cure may be more susceptible to dissolution by dietary simulating solvents than the Bis-GMA matrix [28].

Within the limitations imposed by an in vitro environment of the present study, it is observed that dietary simulating solvents have significant effects on the provisional restorative materials. Patients who have long-term provisional restorations should be aware of the possible detrimental effects of dietary components such as butter, fatty meats, oily substances and beverages, vegetables, fruits, candies and syrups [2]. Therefore, clinicians might advice their patients to limit the intake of these kinds of nutrients when the provisional restorations must function in the oral environment for long periods.

As is the case in all in vitro studies, properties measured on a laboratory bench cannot be accurately extrapolated to in vivo clinical conditions. Moreover, the shape of the

specimens does not reflect the shape of a fixed dental prosthesis. With regard to preparation of specimens for testing; homogeneity of mix, presence of internal porosity, pressure and the release of stresses during finishing and polishing procedures cannot be controlled despite following standard protocol for preparing, curing and finishing.

Conclusion

Within the limitations of this study, it may be concluded that dietary simulating solvents showed significant detrimental influence on the mechanical properties of the provisional restorative materials. Bis-acryl resin based Luxatemp Star showed significantly superior flexural strength and hardness as compared to the Revotek LC and DPI Self Cure in control as well as in dietary simulating solvents. Polymethyl methacrylate based DPI Self Cure appeared to be the most adversely affected provisional restorative material by the dietary simulating solvents. Light-activated urethane dimethacrylate based Revotek LC was less affected by the dietary simulating solvents as compared to the DPI Self Cure.

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