The comparison of surface hardness, water sorption and staining resistance between thermoplastic nylon and heat-cured acrylic resin.

Abstract:

Aim: To evaluate and compare the surface hardness, water sorption and staining resistance of conventional heat cure and nylon denture base materials.

Materials and Methods: A total of 120 specimens, which comprises thirty from each denture base materials (Acralyn-H, DPI, Valplast and Flexident), were fabricated by investing metal specimen analogues of dimension 65x10x2.5mm strips for hardness, 50x0.5mm discs for water sorption and 20x1mm discs for staining resistance according to ADA specification no.12. The surface hardness was evaluated using Shore D Durometer. Water sorption was tested by the differences in the weight of the specimens by desiccating in calcium chloride and immersing in water for one week. The specimens were placed in a staining solution of 3% tartrazine for 7days. Staining resistance was evaluated by the optical density of the extraction solvent (ethanol) using spectrophotometer.

Results: Heat cure acrylic denture base materials demonstrated more surface hardness compared to nylonbaseddenture materials. Tukey's HSD showed significant differences ($p<0.05$) in the hardness of heat cure and nylon denture base materials. The water sorption values of Acralyn-H, DPI and Valplast were comparable and showed a statistically significant difference ($p<0.05$) in the water sorption with Flexident. In staining resistance test, Valplast demonstrated more optical density whereas the optical densities of the others materials were comparable. Valplast materials displayed significant differences ($p<0.05$) in staining resistance with heat cure denture base materials.

Conclusions: Both the heat cure denture base materials exhibited greatest surface hardness compared to the flexible denture base materials. Flexident displayed the lowest water sorption and Valplast had the least staining resistance.

Key words: Polymethylmethacrylate, nylon denture base materials, surface hardness, water sorption, staining resistance.

Introduction:

Polymer-based denture base materials are widely used for the fabrication of removable complete and partial dentures. Bakelite, Vulcanite, Cellulose nitrate, Polystyrene, etc., were the earlier polymers commonly used for this purpose. However, a new resin material such as Polymethylmethacrylate (PMMA) was introduced to the dentistry in 1937, and soon it replaced those earlier denture materials. [1,2] Though numerous materials have been developed to fabricate removable partial and complete dentures, PMMA remained the most preferred material of choice.The priority for the selection of PMMA resin as denture base material can be attributed to its ease of processing, inexpensive, low density, excellent aestheticproperties, low water sorption and solubility; and ability to berepaired easily. However, this resin possesses weak mechanical strength, high brittleness, poor thermal conductivity, and a high coefficient of thermal expansion; and these make this material more vulnerable to failure during the clinical service. [3-5]

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The quality and durability of the denture prosthesis depend on various physical and mechanical properties of the PMMA. Numerous studies have reported the mechanisms to improve the flexural

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strength of these resin materials. [4,6] Surface hardness is an essential mechanical property for the denture base materials to prevent the abrasion of the denture bases during regular cleansing and polishing procedures. The poor abrasion resistance creates surface irregularities on the prosthesis and encourages the sticking of food that results in an unhygienic denture and may cause stomatitis. In addition, denture base resins are notable for their tendency to absorb water. [7]This absorbed water may actas a plasticizer and reduces the mechanical properties,especially strength and hardness and also alters the dimensional stability. [8] Further, the absorption of the water or solutions may change the colour of the denture prosthesis over a period.

Several attempts have been made to improve the resistance to the abrasion and also to minimise the water sorption of denture base materials by modifying their composition or incorporating with new fillers. [4,6].Some potential alternative materials toPMMA such as nylon denture base polymers with superiorimpact strength may be used.Nylon is a crystalline polymer consist of polyamides. A condensation reaction between a diamine NH2-(CH2)6-NH2 and a dibasic acid, CO2H-(CH2)4-COOH produces the Nylon. The crystalline nature of Nylon improves resistanceto solubility insolvents, as well as resistance to heat and also increases strength along with high ductility. Also, nylonmaterials are characterized with higher elasticity, toxicologically safe and exhibit leastpolymerization shrinkage. [9-11] Recently newer versions of Nylon-based materials have been introduced to overcome the disadvantages of earlier versions. The disadvantages of previous versions of nylon-based denture bases include a tendency to undergo discolouration, staining, high water sorption and development ofa rough surface after a short perio. [10]This study was undertaken to evaluate and compare the surface hardness, water sorption and staining resistance of two commonly used flexible denture base resinswith conventional heat-cured PMMA denture base resinsavailable in the market and select the best denture base materialfor the clinical situation.

Materials and methods:

Two conventional heat-cure acrylic resin materials and two Nylon denture basematerials were used in the present study, and the details of these materials are given in table 1.

A total of 120 specimens, thirty from each material, were fabricatedby investing the metal specimen analogues with the dimensions of 65×10×2.5mm strips for hardness, 50×0.5mm discs for water sorption and 20×1mm disc for staining resistance according to ADA specification number 12. After the investment material has been set, the metal specimen analogues were carefully removed.Acrylic resin powder of each material was mixed with theirrespective monomers as per the manufacturer's recommendations. The acrylic dough was filled into themold cavities andpolymerized using short curing cycles in a curing bath or acrylizer, (ConfidentA-73, India), for heat cure acrylic resins.

Specimens with Nylon denture base materials were fabricated using Aluminium flasks with sprue channels. The meltingcylinder was preheated for 20 minutes in a digital furnace at a temperature of 550°F. The resin cartridge was then placed withcrimp end into the melting cylinder, and the preselectedbronze disc was inserted against the end of the resin cartridge.The resin cartridge was allowed to melt for a preset 11 minutes'cycle at 550°F in the furnace. The tightened aluminium flaskwas positioned with the sprue end up directly under the shaftof the super injector. After 11 minutes, the melting cylinder wasplaced on the projection of the sprue end.Then, the levers of thesuper injector were turned with a rapid and steady motion toapply firm pressure, and the resin was injected into the flask.The pressure was maintained for 3 minutes.

The hardness of the specimens was evaluated using Shore D durometer as per ASTM D 2240. Measurements were taken atleast 12mm from the edge of specimen and 10mm apart. A total of six readings were made for each sample, and the average of these readings was taken as the shore D Durometer hardness of the specimen [12].

The water sorption of the specimens was measured by weighing the specimens after immersing them in the water (12).The specimens were transferred into a desiccatorand stored in an incubator for 24 hours. The specimens were then removed and weighed using a digital balance, and it was recorded as conditional mass m1. The volume of the discs was calculated using the formula;Volume = 2pr2 + 2prh

Where r- radius of the disc obtained by the mean diameter divided by 2, and h- thickness ofthe disc.

The specimens were then immersed in distilled water and stored in an incubator at 37°C for seven days. The water was changed daily. After seven days, the specimens were removed and dried using laboratory tissue papers and weighed using a digital balance, and it was recorded as mass after immersion in water m[2]. Thevalue of water sorption was calculated using the formula;Wsp = m2 – m1/ V

The synthetic food colorwas used to evaluate the resistance to staining of the specimens. The food color used in the study was Tartrazine CI. 19140 (Mallya fine chem. Pvt. Ltd, Bengaluru, Karnataka, India, Lot no. 543). Tartrazine is FD and C yellow number. The specimens were immersed in 3% tartrazine solution in 200ml beakers and stored for seven days at a temperature of 37°C. The specimens were hung to avoid specimen to specimen contact and to ensure all the specimen surfaces were exposed to the staining solution. After seven days, the specimens were removed and wiped with the laboratory tissues and placed in an extraction solvent of ethanol for 24 hours. The concentration of the dye in the extraction solvent was evaluated using an absorption spectrophotometer.

The spectrophotometer was set up at the wavelength of 485nm. Using plain distilled water, the transmission was set at 100% and the absorbance at 0%. The sample compartment consists of holding chambers for two cuvettes. The standard reference solution was placed in one of the cuvettes, and the optical density was set at 0. In the second cuvette, 1.5ml of extraction solvent with dissolved dye was placed. The optical density of the test solution was recorded.

The obtained data were subjected to One-way ANOVA and TukeyHSDtests for statistical analyses using SPSS for Windows,Version 12.0., SPSS Inc.

Results:

The means and standard deviations of hardness, water sorption and staining resistance of the four materials used in the study are given in Table 2. Acralyn-H demonstrated more hardness (82.5±3.779) among the materials tested, and Valplast showed the least hardness (66.0±2.789). Both the heat cure acrylic materials exhibited more hardness compared to Nylon-based denture base materials. In multiple comparisons (Tukey HSD) between the four denture base materials (table 3), both the heat-cure acrylics and Nylon denture base materials showed significant differences between them ($p<0.05$) in the hardness tests. However, no significant differences were observed ($p>0.05$) in the hardness between the Nylon-based denture base materials (Table 3)

More amount of water sorption was observed with the Acralyn-H (9.73±3.779) denture base material. However, the water sorption of Acralyn-H, DPI and Valplast were comparable. In Tukey HSD analysis, significant differences ($p<0.05$) were observed between the Nylon denture base materials in water sorption (table 3). The Flexident denture base material specimens displayed significant differences with both the heat-cure acrylic resin materials. However, the Valplast material exhibited no significant differences with both the heat-cure acrylic resins (table 3).

In the staining resistance test, the Valplast material demonstrated with the more optical density (0.044±0.009661). Whereas, the other three materials used in the study displayed comparable optical density. Repeated ANOVA analysis showed significant differences ($p<0.001$) between the four materials in all the three properties tested (table 2). Significant differences ($p<0.05$) were observed between the Nylon denture base materials in Tukey HSD analysis (table 3). TheValplastdenture base material specimens displayed significant differences with both the heat-cure acrylic resin materials. In contrast,Flexident denture base material did not show significant differences with both the heat-cure acrylic resins (Table 3).

Discussion:

PMMA resin is a widely used material for the fabrication of the denture bases. [2] Fracture of the acrylic denture base may occur during function due to lack of adequate mechanical properties. The denture base must be strong enough to allow the prosthesis to withstand functional forces. To overcome the shortcomings of the PMMA denture base materials like nylon denture base materials have evolved. Nylon is a generic name for certain types of thermoplastic polymers belonging to the class known as polyamides and based primarily on aliphatic chains.[11,13] Numerous researchers evaluated and compared the flexural strength of flexible dentures with heat-cure denture base resin materials. [11] However, the research was not focused much on the surface hardness and colour stability of the flexible denture base materials. The surface hardness is also an essential property along with strength. Heat-cure denture base materials have poor resistance to wear and they undergo abrasion during regular cleaning of the dentures. This abrasion results in the formation of surface roughness, which causes plaque accumulation, and the denture becomes unhygienic. [14]Hence, this study was designed to evaluate and compare the surface hardness of the heat-cure acrylics with flexible denture base materials.

In the present study, heat-cure acrylic resin materials displayed more surface hardness compared to flexible denture base materials. Posthoc analysis showed significant differences ($p<0.05$) between the heat cure denture base materials and also between the heat-cure and flexible denture base materials. However, no significant differences ($p>0.05$) were observed between flexible denture base materials. The less surface hardness for flexible dentures can be attributed to their more ductility compared to conventional heat-cure acrylic resins. Therefore, the polymer chains in the flexible denture base materials deform easily under indentation. [9]

The results of this study were in accordance witha study conducted by Utami M et al. (2009). [15] They suggested that the flexible denture bases have less surface hardness compared heat-cure denture base materials. This could be due to the more cross-linking between the polymer chains in heat-cure resin materials. The cross-linking increases the surface hardness as it resists the indentation forces to a greater extent. [2,5,9] Whereas, the ductile character of polymer chains in flexible dentures cannot resist the indentation forces.

In contrast, Wieckiewicz M et al.(2014)[14] reported that PMMA based denture materials showed more surface roughness compared to the flexible denture materials after immersing in various beverages.The difference in surface roughness values between both the materials and they suggested that the increase in surface roughness in PMMA denture material was due to the processing errors. However, the specimens were stored only in distilled water for seven days at 370C, in this study. Immersion in water did not affect the surface hardness of the PMMA denture base materials as it could not influence the crosslinking of polymer chains. [2]

Water sorption is another important property that affects the mechanical properties of denture base resin materials. The polymers have a tendency to absorb water and acts as a plasticizer by pushing the polymer chains apart, thereby reducing the strength and hardness. The rate of watersorption depends on the polarityof resin molecules, the concentration of polar sites available to form hydrogen bonds with water and network topology. [12,16] Hence, an ideal denture base material should exhibit least or no water sorption. According to ISO standards specification 1567:1999, the maximum allowable water sorption by both heat and self-cure denture base materials must be 32µg/mm. [12,17]In the present study, all the denture base materials showed the least water sorption. Statistically, only Flexidentmaterial showed significant differences ($p<0.05$) with the other denture base materials. This can be attributed to the composition of the Flexidentdenture base material that enhances the polarity towards the water.The water sorption results of this study arecomplywith the results indicated by Alla RK et al. (2018, [12]

Denture base materials absorb water and other fluids slowly over time and may discolour the denture bases. [14, 18] There is a limited study in the staining effect of food colouration on the denture base materials. Tartrazine is a synthetic dye that was used in this study. It is the most common colouring agent used in medication, pharmaceuticals and various food products. The resin specimens absorbing these colorant solutions may undergo staining. In this study, traces of dye concentration were detected in the extraction solvent of all the test specimens. The Valplastexhibited more staining than the other denture base materials tested while other materials showed comparable staining.

Similarly, Wieckiewicz M et al.(2014)[14] reported that the flexible denture base materials were more susceptible to discolouration than the PMMA materials. They studied the colour stability of various denture base materials in different beverages. The discolouration of flexible denture base materials can be attributed to the presence of yellow colorants with different polaritiesand probably might be both adsorbed and absorbed dueto compatibility of the polymer phase with the colorants. Further, the acidic pH of the colorants and polarity of the resins also cause staining the denture bases[14] In the present study, the food colorant used wasTartrazine dye, which is an organic trisodium salt of tartrazine acid. [19] The pH and polarity of this colorant towards the resin materials might be caused the discolouration in the specimens.

Similarly, the results of this study are in compliance with the results indicated by Goiato MCet al.(2010). [20] They also reported that the Valplastflexible materials demonstrated more discolouration compared to other denture base materials. On the other hand,it was evident that adequate oral hygiene maintenance and professionalcare can considerably reduce the problemof staining. [21,22]

Limitation of the study only conventional and nylon type denture materials were tested and it was invitro evaluation. Further studies are need with denture materials

Legends for illustrations:

Table 1. Heat-cure and Nylon denture base materials used in the study.

Denture base materials	Commercial Names	Manufacturer
Heat-Cure acrylic resins	Acralyn-H	Asian Acrylates, Mumbai, India.
	DPI Heat-cure	Dental Products of India, Mumbai , India.
Nylon denture base material	Flexident	Talladium Co., U.K.
	Valplast	Valplast Int. Corp. N., USA.

Table 2. The one-way ANOVA for surface hardness, water sorption and staining resistance of acrylic materials used in the study. Where SD is Standard Deviation.

Materials	Hardness (D)		Water sorption (µg/mm^3)		Staining resistance	
	Mean ± SD	P	Mean ± SD	p	Mean ± SD	p
Acralyn-H	82.5±3.779	<0.001	9.73±3.779	<0.001	0.024±0.005164	<0.001
DPI	76.9±4.771		9.714±4.771		0.027±0.006749	
Flexident	67.4±1.955		7.106±1.955		0.026±0.005164	
Valplast	66.0±2.789		9.68±2.789		0.044±0.009661	

Table 3. The Tukey HSD analysis for surface hardness, water sorption and staining resistance of acrylic materials used in the study.

Group		Hardness (D)		Water sorption		Staining resistance	
		Difference of means	p	Difference of means	p	Difference of means	p
Acralyn-H	Valplast	16.5	<0.05	0.948	>0.05	0.02	<0.05
	Flexident	15.1	<0.05	2.626	<0.05	0.002	>0.05
	DPI	5.6	<0.05	0.018	>0.05	0.003	>0.05
DPI	Valplast	10.9	<0.05	0.966	>0.05	0.017	<0.05
	Flexident	9.5	<0.05	2.612	<0.05	0.001	>0.05
Flexident	Valplast	1.4	>0.05	2.574	<0.05	0.018	<0.05

Conclusion:

From the results obtained in this study, the following conclusions can be drawn:

1. The conventional heat cure denture PMMA resins exhibited superior hardness than the nylon-based denture base materials.
2. Water sorption of all the materials tested was within the ISO 1567: 1999 specification limit. Water sorption of all the materials tested was comparable, and Flexidenthad the lowest water sorption of all the materials tested.
3. Valplast had the more staining characteristic than the other materials tested.

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