Original Article

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Modification of curing technique of a 'self cure' injection molding acrylic resin: Effect on color stability

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Objective: To investigate color stability of a heat-cure, a self-cure, and a modified curing self-cure injection-molding denture base materials after immersing in distilled water and coffee for 7 days and 30 days.

Materials and Methods: Three groups of injection-molding denture base materials were fabricated as the disk specimens (diameter 50 mm and thickness 0.5 mm). Heat-cure SR Ivocap® High Impact were wet cured following the manufacturer instruction (100 ^{O}C for 35 min - Ivocap wet curing). Self-cure IvoBase® Hybrid were dry cured in an automated instrument, which the curing temperature started from 40 ^{O}C up to 120 ^{O}C for 35 min (IvoBase dry curing). The IvoBase® Hybrid material were also wet cured at 100 ^{O}C for 35 min (IvoBase wet curing). Ten specimens of each group were measured for baseline color (T_0) using a spectrophotometer. Five specimens of each group were immersed in distilled water and the other five in coffee. The color values of the specimens were remeasured at the 7th day (T7) and at the 30th day (T30). The mean color differences (ΔE) for the experiment groups were compared statistically by using Split-plot ANOVA, followed by Tukey's honest significant difference (HSD) test at 5% level of significance.

Results: Color differences (ΔE) of each experiment group were not significantly different when compared at the same immersion period within the same immersion solution ($p>0.05$). However, the color differences were significantly different between 7 days and 30 days of immersion for both immersion solution ($p<0.05$). The color differences were also found between the materials immersed in coffee and distilled water at the same periods of immersion time ($p<0.05$). Modified curing technique of IvoBase Hybrid material did not cause any significant color changes.

Conclusions: Longer immersion time and different immersion solutions resulted in color changes of Ivocap High Impact and IvoBase Hybrid. Modified curing of IvoBase Hybrid did not result in color changes.

Keywords: Color stability, Injection molding denture base material, Poly(methyl methacrylate), Staining solution

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Introduction

Poly(methyl methacrylate) or PMMA, commonly known as acrylic resin, is used for majority of removable and fixed denture fabrication. Acrylic resin can be classified according to the method of polymerization and processing technique. [1, 2, 14] Most heat-polymerizable acrylic resin system is manipulated by compression molding technique. Although this technique has many advantages such as low water sorption and solubility and high strength, a major problem is the dimensional change due to polymerization shrinkage. [3, 4, 5, 6] Injection molding technique has been developed to reduce polymerization shrinkage by continuous injection method and applying hydraulic pressure to a reservoir of polymerized fluid polymer. [5, 6, 7] Therefore, the injection molding denture base material has good dimensional accuracy , smooth and glossy surface, low free-monomer content, and good

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impact strength. However, the disadvantages include low craze resistance and difficulties associated with the attachment of teeth to the denture bases. [2, 6, 7]

SR Ivocap® High Impact (Ivoclar Vivadent) heat-cure PMMA was introduced in 1972. This material was based on the injection molding technique wherein the dough stage of denture base is injected into a closed flask. An injection pressure of 6 bars is maintained in boiling water (100°C) in a water bath for 35 mins during the entire polymerization. This procedure is deemed unsurpassed and has served as the standard technique for more than 30 years. [8] In 2012, the IvoBase® system (Ivoclar Vivadent) has become available as a self-curing denture base material. This system is polymerized by IvoBase® automated Injector with the initial polymerization PMMA resins at 40°C for 35 mins. [9]

Color stability is an important clinical character of denture bases. The denture base materials should have smooth and glossy surfaces with only a slight change in color after a long use. [1] Color changes are noticeable for aging and damaging of denture base. [6, 11, 12] Many studies have demonstrated that denture base polymer tends to have discoloration during use in oral environment. Color change is caused by intrinsic and extrinsic factors. [22] Intrinsic factors, such as excessive residual monomer, unfavorable micro-surface characteristic of materials and the water sorption, contribute to changes in the chemical and physical properties of material. The aging process of the material and the porosity caused by overheating and deficiency pressure on polymerization also contribute in the color change of denture base polymer. [6, 10, 11, 13]

The extrinsic factors which contribute to discoloration include staining by adhesion or penetration of colorants such as coffee, tea, wine, artificial dyes, cleaning agent, nicotine, and composition of saliva. [6, 10, 11, 12] One or more factors may contribute to visibly detectable or aesthetically unacceptable color changes of the prosthesis. [10]

Although there were many studies regarding the color stability of the different denture base materials, the effect of staining solutions on the auto-polymerizable and heat-polymerizable injection molding denture base polymers have never been studied before. IvoBase® Hybrid was developed from SR Ivocap® High Impact with initial polymerization temperature of 40°C. According to ISO 20795-1:2013, IvoBase® Hybrid was categorized as an auto-polymerizable material. From many studies, auto-polymerizable acrylic resin exhibits incomplete polymerization, so these materials have a large quantity of residual monomer causing decreased transverse strenght, increased tissue irritant, and increased color instability. [1, 14, 20]

Therefore, the aim of this study was To investigate color stability of a heat-cure (Ivocap High Impact), a self-cure (IvoBase Hybrid), and a modified curing self-cure (IvoBase Hybrid) injection-molding denture base materials after immersing in distilled water and coffee for 7 days and 30 days.

Materials and methods

Two injection molding denture base materials were used in this study: (SR Ivocap® High Impact and IvoBase® Hybrid (Ivoclar Vivadent, Schaan, Lichtenstein). Their main compositions are powder of poly(methyl methacrylate) and dibenzoyl peroxide and liquid of methyl methacrylate. [8, 9]

The disk specimens were fabricated using circular stainless steel molds with a flat cover. The mold had a diameter of 50 mm and a depth of 1.0 mm with passageway to inject material in. The mold was placed into the lower half of the denture flasks, which were filled with gypsum. The stone was coated with the separating media and the flat stainless steel cover was placed on the mold. Then the upper half of the denture flask

was placed atop of the lower part of the denture flask and the stone poured into the flask.

Processing of the specimens in the three experiment groups are listed in Table 1.

All specimens were polished with silicon carbide abrasive papers from no. 100, 200, 400, 600, 800, and 1000 (TOA, Samutprakarn, Thailand) until smoothness and the required dimensions were attained. According to the International Organization for Standardization (ISO 20795-1:2013), [1] the thickness of each specimen was measured by a micrometer and the diameter by the dial caliper. Ten specimens of each experiment group were divided into 2 subgroups of five.

Before immersion, the color values (T0) of all specimens were measured. Five specimens in the experiment group were immersed in distilled water at 37°C and other five specimens in coffee (2 g/100 ml, Nescafe Red cup, Nestle, Thailand) at 37°C. The solutions were changed every day throughout the 30 days period. The color differences (ΔE) of the same specimen were measured at 7 days (T_7) and 30 days (T_{30}) by a spectrophotometer (Ultrascan XE®, Hunter LAB, USA). Mean values were calculated and recorded on the CIELAB color difference (ΔE) with lightness: white-black (L), redness-greenness (a), and yellowness-blueness (b) as follows [20]:

$$\Delta E = [(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2]^{1/2}$$

The ΔE data were analyzed by Split-plot ANOVA and Tukey's honest significant difference (HSD) test. All statistical analysis were conducted at 5% level of statistical significance.

Results

Means of color differences (ΔE) with standard deviations are presented in Table 2.

The ΔE of Ivocap® wet curing, IvoBase® dry curing, and IvoBase® wet curing after being immersed in distilled water for 7 days were 1.37±0.27, 1.50±0.12, and 1.58±0.22, respectively. After 30 days, the results were 2.70±0.71, 2.73±0.35, and 2.86±0.45, respectively. The color differences (ΔE) of each material when immersing in coffee were 4.28±0.45, 4.61±0.74, and 4.47±0.45 after 7 days, respectively; and 6.97±0.89, 6.51±0.70, and 7.00±0.93 after 30 days, respectively.

Split-plot ANOVA showed that the ΔE were not significantly different among the test materials when compared at the same time period (T_7 and T_{30}) in the same immersion solution ($p>0.05$). The ΔE of each test material were significantly different between T_7 and T_{30} immersion period when each material was evaluated in the same immersion solution ($p<0.05$). There were also differences between ΔE of the material immersed in coffee and distilled water when was compared at same time period ($p<0.05$).

Table 1 Processing of the three groups of injection molding denture base materials

Material (n=10)	Processing method	Powder : Liquid ratio
SR Ivocap® High Impact (Group 1-Ivocap wet curing)	Place mold in water bath, heat to 100°C and boil for 35 minutes. Then cool in cold water for 30 minutes.	20 g : 30 ml
IvoBase® Hybrid (Group 2-IvoBase dry curing)	Dry curing following the program in the automated injection unit: initial cure at 40°C then at 120°C for 35 minutes. Then cool in cold water for 15 minutes.	34 g : 20 ml
IvoBase® Hybrid (Group 3-IvoBase wet curing)	Place mold in water bath, heat to 100°C and boil for 35 minutes. Then cool in cold water for 30 minutes.	34 g : 20 ml

Table 2 Mean ΔE and standard deviation of the specimen after immersion in distilled water and coffee for 7 days and 30 days; n=5

Immersion solution	Material and processing technique	T_7	Immersion time T_{30}
Water	Ivocap wet curing	$1.37 \pm 0.27^{(a,A)}$	$2.70 \pm 0.71^{(b,B)}$
	IvoBase dry curing	$1.50 \pm 0.12^{(a,C)}$	$2.73 \pm 0.35^{(b,D)}$
	IvoBase wet curing	$1.58 \pm 0.22^{(a,E)}$	$2.86 \pm 0.45^{(b,F)}$
Coffee	Ivocap wet curing	$4.28 \pm 0.45^{(x,U)}$	$6.97 \pm 0.89^{(y,V)}$
	IvoBase dry curing	$4.61 \pm 0.74^{(x,W)}$	$6.51 \pm 0.70^{(y,X)}$
	IvoBase wet curing	$4.47 \pm 0.45^{(x,Y)}$	$7.00 \pm 0.93^{(y,Z)}$

Note: 1. SR Ivocap® High Impact; polymerization at 100°C (Ivocap® wet curing), IvoBase® Hybrid; initial polymerization at 40°C up to 120°C (IvoBase® dry curing), IvoBase® Hybrid; modified polymerization temperature to 100°C (IvoBase® wet curing).

2. Means with the same letter were not significantly different at p=0.05. Small letters (vertical) show differences between materials. Capital letters (horizontal) show differences between times.

Discussion

The SR Ivocap® High Impact and Ivobase® Hybrid chosen in this study are both injection-molding acrylic resin, but the curing process of the two materials are different. The SR Ivocap® High Impact was polymerized at 100°C in boiling water so the material was wet cured. The Ivobase® Hybrid was dry polymerized at initial temperature 40°C and heated up to 120°C in the automated injector unit. According to ISO20795-1:2013, the Ivobase® Hybrid is classified as a auto-polymerization material [1, 8, 9] while the SR Ivocap® High Impact is classified as heat-cure material. Because of the cost of the automated injector unit, this study investigated whether the SR Ivocap® Hybrid could be polymerized using the same curing process as the SR Ivocap® High Impact or not. The reason was that both SR Ivocap® High Impact and Ivobase® Hybrid has the same main compositions (poly(methyl methacrylate) powder, dibenzoyl peroxide, methyl methacrylate monomer, and dimethacrylate).

The ΔE of SR Ivocap® High Impact cured at 100°C (Ivocap® wet curing), IvoBase® Hybrid cured at 40°C up to 120°C (IvoBase® dry curing), and the modified curing method of IvoBase® Hybrid which cured at 100°C (IvoBase® wet curing) were not significantly different when compared among the test materials at 7 days and 30 days. Storage of the specimens in coffee resulted in more color changes than when they were stored in distilled water. Color stability is an important factor for patients. The color of denture base should have glossy surface and be matched with that of the underlying soft tissue. Color changes are noticeable during aging with the damaging of denture base. [6, 11, 12] Many studies had demonstrated that denture base polymer tends to have discoloration during use in oral environment and are affected by many parameters.

According to the study of May et al. [15] and Bohra et al. [16], acrylic resin that contains aromatic or aliphatic amine accelerator presents more color change because of the oxidation of amine. Both SR Ivocap® High Impact and Ivobase® Hybrid do not contain amine accelerator but contain dibenzoyl peroxide. The color differences of the two materials were not significantly different.

Coffee as hydrophilic solution had a significant effect on the color change of acrylic resin. According to Polyzois et al. [19], after immersing visible light cured and self-cured acrylic resin in tea and coffee for a 7-day period, both of them showed color perceptibility difference. In this study, the color of all specimens changed significantly when the materials were immersed in coffee compared to when they were immersed in distilled water.

Imirzalioglu et al. [6] investigated the color change of heat-polymerized, injection-molded, and auto-polymerized acrylic resin for 7 and 30 days after immersion in tea, coffee, and nicotine. They found that coffee caused color change which was perceivable by the human eye in heat-polymerized and injection-mold acrylic resin. The color of specimens in coffee changed significantly over time, particularly after the 7th day.

Color difference thresholds are divided into two aspects. One is perceptibility threshold where observers can detect the color difference between the specimens and other is acceptability threshold wherein the color difference is acceptable. [23, 24] The values of ΔE over 1 will be considered perceivable by the human eye, and values below 3.7 will be considered to be clinically acceptable. [24, 25] The sensitivity of the human eye in observing color differences is limited. Khashayar et al., [24] evaluated the perceptibility and acceptability thresholds for color differences in dentistry and found that 44% of research used perceptibility threshold of ΔE=1 and 35% of studies used acceptability threshold of ΔE=3.7.

In this study, it was found that the discoloration of 3 groups of denture base material after immersion in distilled water for 7 and 30 days were referred to as perceptible color change but were clinically acceptable. The color change of all materials after immersion in coffee for 7 and 30 days were referred to as clinically unacceptable.

Conclusion

Longer immersion time and different immersion solutions resulted in color changes of Ivocap High Impact and IvoBase Hybrid. Modified curing of IvoBase Hybrid did not result in color changes.

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