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The effect of various frequencies of ultrasonic cleaner in reducing residual monomer in acrylic resin

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ABSTRACT

Monomer remaining in denture base acrylic can be a major problem because it may cause adverse effects on oral tissue and on the properties of the material. The purpose of this study was to compare the effect of various ultrasonic cleaner frequencies on the amount of residual monomer in acrylic resin after curing. Forty-two specimens each of Meliodent heat-polymerized acrylic resin (M) and Unifast Trad Ivory auto-polymerized acrylic resin (U) were prepared according to their manufacturer's instructions and randomly divided into seven groups: Negative control (NC); Positive control (PC); and five ultrasonic treatment groups: 28 kHz (F1), 40 kHz (F2), 60 kHz (F3) (M = 10 min, U = 5 min), and 28 kHz followed by 60 kHz (F4: M = 5 min per frequency, U = 2.5 min per frequency, and F5: M = 10 min followed by 5 min per frequency, U = 5 min followed by 2.5 min per frequency). Residual monomer was determined by HPLC following ISO 20795-1. The data were analyzed by One-way ANOVA and Tukey HSD. There was significantly less residual monomer in the auto-polymerized acrylic resin in all ultrasonic treatment groups and the PC group than that of the NC group ($p < 0.05$). However, the amount of residual monomer in group F3 was significantly higher than that of the F1, F4, and PC groups ($p < 0.05$). In contrast, ultrasonic treatment did not reduce the amount of residual monomer in heat-polymerized acrylic resin ($p > 0.05$). The amount of residual monomer in heat-polymerized acrylic resin was significantly lower than that of auto-polymerized acrylic resin. In conclusion, ultrasonic treatment at low frequencies is recommended to reduce the residual monomer in auto-polymerized acrylic resin and this method is more practical in a clinical situation than previously recommended methods because of reduced chairside time.

1. Introduction

Acrylic resin is widely used in prosthodontics, as denture base material and for provisional crowns [1]. Denture base acrylic resin is used to support artificial teeth that replace missing teeth, and provisional crowns are used to provide immediate coverage of a prepared tooth to protect the pulp from thermal and chemical irritation, keep the tooth in position, maintain occlusal function, and provide esthetics before the definitive crown is delivered [2]. Denture base resin and provisional crowns are usually fabricated by the polymerization of pre-polymerized polymethyl methacrylate (PMMA) powder particles mixed with methyl methacrylate (MMA) monomer. When polymerization has occurred, the monomer remaining in the acrylic resin is known as residual monomer.

The residual monomer content of denture acrylic is highest in the first 24 h after polymerization and decreases over time [3,4]. However, residual monomer can be detected in denture base polymer even after the denture has been worn for 5–20 years [5,6]. Many studies have reported that residual monomer acts as plasticizer, which affects the physical properties of acrylic resin (e.g., decreasing the impact strength and causing color changes) [7–9]. Moreover, residual monomer has been reported to be toxic and can irritate the oral mucosa and cause tissue sensitivity [10–13]. For these reasons, the residual monomer in acrylic resin should be minimized as much as possible.

Many studies have demonstrated methods of reducing the residual monomer in acrylic resin that can be eluted into the environment using high watt microwave-polymerization, mechanical polishing, immersion in 55 °C water for 1 h or room temperature water for 24 h, coating the surface with resin, or curing under higher temperature and for a longer time [7,9,10,14–17]. However, the commonly used methods of immersion in room temperature water for heat-polymerized acrylic resin, performed during

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laboratory processing, and immersion in 55 °C water for auto-polymerized acrylic resin, done chairside, increase the amount of time before the prosthesis can be delivered to the patient.

Ultrasonic waves have been applied in many industries. In dentistry, ultrasonic waves are usually used for scaling and for instrument cleaning. The generator of an ultrasonic cleaner sends high frequency sound waves through an ultrasonic cleaning solution, resulting in the formation of numerous gas bubbles. When these gas bubbles implode, resulting in cavitation, they release a large amount of impact energy that rapidly increases the local temperature and produces a high-energy liquid stream that collides with the surface of the object being cleaned [18]. The operating frequency of an ultrasonic transducer has an effect on the amount of bubbles and their implosion. Lower frequencies generate fewer bubbles that are larger and release more energy. In contrast, higher frequencies generate more bubbles that are smaller and less release energy. A higher frequency may have less cleaning ability but generate greater fluid movement. In industrial applications, a single-frequency ultrasonic cleaner usually uses a 40 kHz ultrasonic transducer.

In many industries, ultrasonic waves are used to enhance the extraction rate of chemical substances from food and bacteria [19–21]. However, the effect of the frequencies used in dental ultrasonic cleaners to enhance the elution of residual monomer from acrylic resin has not been reported. The purpose of this study was to determine the effect of various ultrasonic frequencies on the amount of residual monomer eluted from heat-polymerized and auto-polymerized acrylic resin.

2. Materials and methods

2.1. Sample preparation

Forty-two disc shaped specimens each of heat-polymerized acrylic resin (Meliodent, Heraeus Kulzer, Sandan, Germany) and auto-polymerized acrylic resin (Unifast Trad Ivory, GC Corp., Tokyo, Japan) were prepared by mixing the powder and liquid according to the manufacturer's instructions (Meliodent, 2.2 g powder (Lot No. 33May105) to 1 mL liquid (Lot No. 140411); Unifast, 2.0 g powder (Lot No. 1309122) to 1 mL liquid (Lot No. 1202011). At the dough stage, the resin was packed into circular stainless steel molds (50 mm diameter × (3.0 ± 0.1) mm deep), and the molds were placed in dental stone in dental flasks (Internal diameter 10 ± 0.1 cm). The two parts of the flask were pressed in a hydraulic press at 300 kPa. Heat-polymerized acrylic resin was pressed for 1 h at 25 °C and 9 h at 73.9 °C; auto-polymerized acrylic resin was pressed for 3 min at 25 °C. After processing, the specimens were kept in the dark for 24 ± 5 h.

Both sides of the specimens were wet-ground to a thickness of 2.0 ± 0.1 mm with P500 metallographic grinding paper (TOA, Thailand), the edge was polished with P1200 paper until smooth, and stored at −28 °C until used. The specimens of each material were divided into seven groups ($n = 6$) as shown in Table 1. The specimens were stored in the dark for 24 ± 1 h prior to the monomer extraction procedure.

2.2. Residual monomer extraction procedure following ISO 20795-1 (2013)

Each specimen disc was first broken into small pieces. A digital scale (Sartorius BP110s, Sartorius, Germany) was used to weigh approximately 650 mg of broken disc pieces to four decimal places that were added to a 10 mL volumetric flask (Duran, Germany) for each sample solution. The broken pieces from each specimen were distributed into three sample solutions for the pass/fail determination test for residual monomer following ISO 20795-1 (2013). Tetrahydrofuran diluting solution (Merck KGaA, Darmstadt., Germany) was added to a 10 mL final volume. Each flask was stirred using a clean 3-mm polytetrafluoroethylene-coated magnetic stirring bar (Cowie Technology, Middlesbrough, UK) on a magnetic stirrer (PMC 509C, Barnstead, USA) for 72 ± 2 h at room temperature. Two mL of the resultant slurry was transferred to another 10 mL volumetric flask with a micropipette. Methanol diluting solution (M, Bangkok, Thailand) was added to a 10 mL final volume and the solution shaken to precipitate the resin. Five mL of the solution from each flask was transferred to glass centrifugation tubes, centrifuged at 3000 rpm for 15 min at 25 °C (Avanti J-E,

Table 1
Groups of experiment and mean amount of residual monomer (%mg ± standard deviation).

Groups*	Materials	Treatment			Residual Monomer Mean ± SD
		Water Temperature (°C)	Ultrasonic frequency (kHz)	Time	
MNC	Meliodent	–	–	–	1.20 ± 0.16 [a]
MPC	Meliodent	Room	–	24 h	1.21 ± 0.08 [a]
MF1	Meliodent	50	28	10 min	1.16 ± 0.05 [a]
MF2	Meliodent	50	40	10 min	1.20 ± 0.10 [a]
MF3	Meliodent	50	60	10 min	1.25 ± 0.06 [a]
MF4	Meliodent	50	28	5 min	1.24 ± 0.12 [a]
			Followed by 60	5 min	
MF5	Meliodent	50	28	10 min	1.23 ± 0.15 [a]
			Followed by 60	5 min	
UNC	Unifast Trad	–	–	–	3.27 ± 0.09 [C]
UPC	Unifast Trad	50	–	1 h	2.03 ± 0.14 [A]
UF1	Unifast Trad	50	28	5 min	2.01 ± 0.08 [A]
UF2	Unifast Trad	50	40	5 min	2.11 ± 0.10 [A,B]
UF3	Unifast Trad	50	60	5 min	2.28 ± 0.08 [B]
UF4	Unifast Trad	50	28	2.5 min	2.07 ± 0.18 [A]
			Followed by 60	2.5 min	
UF5	Unifast Trad	50	28	5 min	2.17 ± 0.08 [A,B]
			Followed by 60	2.5 min	

The groups with identical letters were not significantly different (capital and small letters represent separate analyses).

* MNC = Meliodent Negative Control; MPC = Meliodent Positive Control; MF1 = Meliodent, F1 ultrasonic treatments; MF2 = Meliodent, F2 ultrasonic treatments, MF3 = Meliodent, F3 ultrasonic treatments, MF4 = Meliodent, F4 ultrasonic treatments; MF5 = Meliodent, F5 ultrasonic treatments; UNC = Unifast Trad Negative Control; UPC = Unifast Trad Positive Control; UF1 = Unifast Trad, F1 ultrasonic treatments; UF2 = Unifast Trad, F2 ultrasonic treatments; UF3 = Unifast Trad, F3 ultrasonic treatments; UF4 = Unifast Trad, F4 ultrasonic treatments; UF5 = Unifast Trad, F5 ultrasonic treatments.