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Properties of injection-molded thermoplastic polyester denture base resins

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Abstract

Objective. This study investigated the properties of injection-molded thermoplastic polyester denture base resins. ***Materials and methods.*** Two injection-molded thermoplastic polyester denture base resins (polyethylene terephthalate copolymer and polycycloalkylene terephthalate copolymer) were tested. Specimens of each denture base material were fabricated for flexural properties testing, Charpy impact testing and shear bond testing ($n = 10$). The flexural strength at the proportional limit, elastic modulus, Charpy impact strength and the shear bond strength of the two denture base materials were estimated. ***Results.*** The polycycloalkylene terephthalate copolymer denture base resin had significantly lower flexural strength at the proportional limit, lower elastic modulus, higher impact strength and lower shear bond strength compared to the polyethylene terephthalate copolymer denture base resin. ***Conclusion.*** The properties of the injection-molded thermoplastic denture base resins composed of polyethylene terephthalate copolymer and polycycloalkylene terephthalate copolymer were different from each other. The polycycloalkylene terephthalate copolymer denture base resin had significantly lower flexural strength at the proportional limit, lower elastic modulus, higher impact strength and lower shear bond strength compared to the polyethylene terephthalate copolymer denture base resin.

Key Words: *Injection-molded thermoplastic polyester denture base resin, polyethylene terephthalate copolymer, polycycloalkylene terephthalate copolymer, mechanical properties, shear bond strength*

Introduction

Recently, removable partial dentures (RPD) without metal clasps fabricated from an injection-molded thermoplastic resin have been used in dental practice [1,2]. The advantage of this type of denture is that problems resulting from the metal clasps, such as poor esthetics and metal allergies, are eliminated [3].

Conventional RPDs are commonly retained at the undercuts of the abutment teeth using metal clasps; the undercut value is between 0.25–0.75 mm. Although the retentive clasp arm is deflected during the insertion and removal of the RPD, the denture base material does not deflect. In contrast, RPDs without metal clasps are retained at the undercuts of the abutment teeth by means of the denture base material. Therefore, the flexibility of the injection-molded thermoplastic resin affects the ease of insertion and removal of the RPD, retention of the RPD and the stress to the abutment teeth [4]. An investigation of the flexibility of the injection-molded thermoplastic resin is, thus, important for dental practice.

Some injection-molded thermoplastic resins (polyamide, polyester and polycarbonate) used as denture base materials for RPDs without metal clasps have been tested [3–15]. The mechanical properties of polyamide [4–6,12–14], dimensional accuracy of polyamide [9,12] and bonding strength of auto-polymerizing repair resin to polyamide [3,15] were studied. The residual monomer, water sorption, water solubility of polyester [10], mechanical properties of polyester [4,11,13,14] and bonding strength of auto-polymerizing repair resin to polyester [15] have also been investigated. The mechanical properties of polycarbonate [4,7,13,14], dimensional accuracy of polycarbonate [8] and bonding strength of auto-polymerizing repair resin to polycarbonate [3,15] were examined as well.

In previous studies [4,14,15], the mechanical properties and bonding strength of auto-polymerizing

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Table I. Denture base resins used in this study.

Material	Manufacturer	Processing method	Constituent	Lot number
EstheShot	i-Cast Co. Ltd., Kyoto, Japan	Injection molding technique; heat processed at 230°C for 20 min, injected at 1 MPa pressure and bench cooled for 30 min	Polyester; Polyethylene terephthalate copolymer (PET)	IKB
EstheShot Bright	i-Cast Co. Ltd., Kyoto, Japan	Injection molding technique; heat processed at 280°C for 20 min, injected at 1 MPa pressure and bench cooled for 30 min	Polyester; Polycycloalkylene terephthalate copolymer (PCAT)	2A6277240
Acron	GC Corp., Tokyo, Japan	Heat-polymerized, compression molding technique; heat-processed at 70°C for 90 min, then at 100°C for 30 min and bench cooled for 30 min	Polymethyl methacrylate (PMMA)	(P)1004123 (L)1003191

resin to two injection-molded thermoplastic polyamide denture base resins (Nylon 12 and Nylon PACM12) were compared. Although the constituents of both polyamide denture base resins are similar, their properties are different.

There are currently two injection-molded thermoplastic polyester denture base resins (polyethylene terephthalate copolymer and polycycloalkylene terephthalate copolymer) used clinically for RPDs without metal clasps; the compositions of these denture base resins are nearly the same. Polyethylene terephthalate copolymer denture base materials have been investigated [4,10,11,13–15]. However, there is insufficient information about polycycloalkylene terephthalate copolymer denture base resin and their properties compared to the two polyester denture base resins have not been extensively investigated.

The purpose of this study was to investigate the properties of two injection-molded thermoplastic polyester denture base resins. The null hypothesis was that the properties of these denture base resins do not differ from each other.

Materials and methods

Mechanical properties

Two injection-molded thermoplastic polyester denture base resins were used in this mechanical properties study (Table I).

The flexural properties and Charpy impact strength of the denture base materials were measured according to ISO 1567 [16] and ISO 1567:1999/Amd 1:2003 [17].

Specimens

The flexural properties specimens of each denture base material were fabricated according to the manufacturers' instructions in gypsum molds with cavities (65 mm long × 10 mm wide × 3.3 mm high). Each specimen was polished with 600-grit SiC paper. The accuracy of the dimensions was verified with a micrometer at three locations for each dimension to within a 0.05-mm tolerance for width and height.

The specimens of each denture base material for Charpy impact testing were fabricated according to the manufacturers' instructions in gypsum molds with cavities (50 mm long × 6 mm wide × 4 mm high). Each specimen was polished with 600-grit SiC paper and the accuracy of each dimension was verified with a micrometer to within a 0.2-mm tolerance for width and height at three locations. A notch (type A) was cut in the middle of each specimen, as described in ISO 179 [18]. An edgewise notch was cut 1.2 mm deep, leaving a residual depth of 4.8 mm beneath the notch.

The flexural properties specimens were held at 37°C for 50 h in distilled water and the Charpy impact test specimens were stored at 37°C for 7 days in distilled water. Half of the specimens were then thermocycled between 5–55°C water for 50,000 1-min cycles. Ten specimens were fabricated per group in each denture base material–thermocycling combination.

Flexural properties

The flexural strength at the proportional limit (FS-PL) [19–23] and elastic modulus of the specimens were tested. Each specimen was placed on a 50 mm-long support for three-point flexural testing. A vertical load was applied at the mid-point of the specimen at a crosshead speed of 5 mm/min on a load testing machine (ASG-J, Shimadzu Co. Ltd., Tokyo, Japan). The FS-PL (MPa) was calculated according to the following formula:

$$\mathrm{FS-PL} = 3\mathrm{PL} / 2\mathrm{bd}^2 \tag{1}$$

where P = load at the proportional limit, L = span distance (50 mm), b = width of the specimen and d = thickness of the specimen. The load at the proportional limit was determined from each load-deflection graph.

The elastic modulus (GPa) was calculated using the following formula:

$$\text{Elastic modulus} = FL^3 / 4bd^3D \qquad (2)$$

where F = the load at a convenient point in the straight line portion of the load/deflection graph and D = the deflection at load F.

Charpy impact test

The Charpy notched impact strength test was carried out on a pendulum impact tester (DC-C; Toyo Seiki, Tokyo, Japan) with a test span of 40 mm. The specimens were conditioned in a container at 23°C for 60 min prior to testing. After conditioning, each specimen was removed from the water and placed on the specimen supports of the testing apparatus with the notch facing away from the point of impact of the pendulum; then the pendulum was released in order to fracture the specimen. The Charpy impact strength (kJ/m^2) was calculated using the formula:

$$\text{Impact strength} = (J1 - J2) \times 10^3 / bh \qquad (3)$$

where J1 = the value of energy absorbed by the specimen, J2 = the friction energy of the system, b = the depth behind the notch and h = the height of the specimen.

Shear bond strength

Two injection-molded thermoplastic polyester denture base resins were used for the shear bond strength and a conventional heat-polymerized polymethyl methacrylate denture base resin was used as a control (Table I).

Specimens

The specimens of each denture base material were fabricated according to the manufacturers' instructions in gypsum molds with cavities (10 mm long × 10 mm wide × 3 mm high). Each specimen was embedded in an autopolymerizing resin material with an acryl ring and the surfaces of the resins were polished with 400-grit SiC paper.

To define the bonding area, sticky tape with a 6-mm diameter hole and a Teflon ring (1 mm thick) with a circular hole (5.0-mm inner diameter, 6.0-mm outer diameter) were placed on the surface to be bonded on each specimen. The powder and liquid of an autopolymerizing repair resin (Unifast III live pink, GC, Tokyo Japan, Lot numbers: powder 1005173, liquid 1006281) were mixed and applied inside the Teflon ring. The mixing ratio of powder to liquid was 2:1(w/w). After polymerization, the sticky tape and Teflon ring were gently removed and all the specimens were immersed in distilled water at 37°C for 24 h. Half of the specimens were then thermocycled between 5–55°C water for 10 000 1-min cycles. Ten specimens were fabricated per group for each denture base material–thermocycling combination.

Measurement of shear bond strength

The shear bond strengths were determined using a load testing machine (ASG-J, Shimadzu Co. Ltd., Tokyo, Japan) at a crosshead speed of 0.5 mm/min.

All the tests were performed under uniform atmospheric conditions of 23.0 ± 1°C and 50 ± 1% relative humidity.

A two-way analysis of variance (ANOVA) (STATISTICA, StatSoft Inc., Tulsa, OK) was used to study the differences among the denture base materials and the effect of thermocycling. A one-way ANOVA (STATISTICA) was used if there was a significant difference resulting from an interaction between these two variables ($p = 0.05$). The Newman-Keuls post-hoc comparison ($p = 0.05$) (STATISTICA) was applied when appropriate.

Results

The two-way ANOVA revealed that there were significant differences in the FS-PL caused by the variables of denture base material and the effect of thermocycling and their interaction ($p < 0.05$). The one-way ANOVA showed that there were significant differences in FS-PL ($p < 0.05$). The FS-PL of the EstheShot was significantly higher than that of the EstheShot Bright. The thermocycled specimens of EstheShot Bright possessed significantly higher FS-PL compared to the non-thermocycled specimens (Table II).

The two-way ANOVA indicated that there were significant differences in the elastic modulus caused by the variables of denture base material and the effect of thermocycling, and their interaction ($p < 0.05$). The one-way ANOVA revealed that there were significant differences in the elastic modulus ($p < 0.05$). The elastic modulus of the EstheShot was significantly higher than that of the EstheShot Bright. The thermocycled specimens showed a significantly higher elastic modulus compared to the non-thermocycled specimens (Table II).

Significant differences in the impact strength caused by the variables of denture base material and the effect of thermocycling and their interaction ($p < 0.05$) were found using the two-way ANOVA. The one-way ANOVA revealed significant differences in the impact strength ($p < 0.05$). The impact strength of the EstheShot Bright

Table II. Mean and standard deviation (SD) of the mechanical properties of the polyester denture base resins (n = 10).

Denture base material	Thermo-cycling	Flexural strength at proportional limit (FS-PL) (MPa)	Elastic modulus (GPa)	Charpy impact strength (kJ/m^2)
EstheShot (PET)	No	32.6 (2.7)^a	2.11 (0.04)	4.32 (0.49)^a
EstheShot (PET)	Yes	33.4 (3.3)^a	2.42 (0.08)	1.36 (0.39)^a
EstheShot Bright (PCAT)	No	24.2 (0.7)	1.59 (0.02)	67.96 (4.78)
EstheShot Bright (PCAT)	Yes	27.1 (3.0)	1.79 (0.03)	41.95 (23.42)

^{a}Groups that were not significantly different from each other (p > 0.05).

Table III. Mean and standard deviation (SD) of the shear bond strength (MPa) of an auto-polymerizing repair resin to the denture base resins and their failure mode (n = 10).

Denture base material	Thermo-cycling	Shear bond strength (MPa)	Failure mode C/M/A
EstheShot (PET)	No	15.9 (1.3)^a	10/0/0
EstheShot (PET)	Yes	16.2 (1.6)^a	10/0/0
EstheShot Bright (PCAT)	No	11.7 (1.5)^b	5/4/1
EstheShot Bright (PCAT)	Yes	10.0 (1.2)^c	1/5/4
Acron (PMMA)	No	11.7 (1.5)^b	0/0/10
Acron (PMMA)	Yes	9.4 (0.6)^c	0/0/10

$^{a, b, c}$Groups that were not significantly different from each other (p > 0.05). Failure mode: C, cohesive; M, mixture of cohesive and adhesive; A, adhesive.

specimens was significantly higher than that of the EstheShot specimens, while the thermocycled EstheShot Bright specimens were significantly lower than the non-thermocycled EstheShot specimens (Table II).

The variables of denture base material and effect of thermocycling and their interaction (p < 0.05) were tested using the two-way ANOVA, which showed significant differences in the shear bond strength. The one-way ANOVA revealed significant differences in the shear bond strength (p < 0.05). For the EstheShot specimens, the shear bond strength was significantly higher than that of the other specimens. There were no significant differences between EstheShot Bright and Acron for either the non-thermocycled specimens or the thermocycled specimens. The thermocycled EstheShot Bright and Acron specimens showed significantly lower shear bond strength compared to the non-thermocycled specimens (Table III).

Discussion

The null hypothesis of this study was rejected and the properties of the two injection-molded thermoplastic polyester denture base resins tested, polyethylene terephthalate copolymer (PET) and polycycloalkylene terephthalate copolymer (PCAT), were different from each other.

With regard to mechanical properties, the present study showed that the flexural strength at the proportional limit (FS-PL) of PET was higher than that of PCAT, the elastic modulus of PET was higher than that of PCAT and the impact strength of PCAT was higher than that of PET. Compared with a previous study [4], the results for PET in the present study were similar to those found for PET in the previous study. However, the results of the FS-PL and elastic modulus of PCAT in the present study were different from those of PET but they were similar to those of polyamide (Nylon PACM12, Lucitone FRS, DENTSPLY International Inc., York, PA) in the previous study. The impact strength of PCAT in the present study was twice that of polyamide (Nylon PACM12), which was the highest of all the injection-molded thermoplastic denture base resins in the previous study. Based on these results, it seems that the mechanical properties of PCAT are completely different from those of PET but are similar to those of polyamide (Nylon PACM12). In the polymer science field, PCAT materials generally provide softness, which is inherent in their molecular composition, compared to PET materials [24]. Therefore, this property may explain how the mechanical properties of polyester denture base materials affect its characteristics.

In this study, the elastic moduli of PET and PCAT significantly increased after thermocycling, probably because static fatigue caused by thermal stress affected the elastic moduli of these resins [14]. Likewise, the impact strength of PCAT significantly decreased, causing brittleness after thermocycling, again likely due to static fatigue caused by thermal stress [14]. Moreover, PET remained brittle after thermocycling. For these reasons, it seems that the two injection-molded thermoplastic polyester denture base resins stiffened after thermocycling. However, their FS-PL did not weaken. Therefore, these resins will generally strengthen after stiffening. These findings were similar to those for PET in the previous study [14].

Regarding the bonding strength of the auto-polymerizing resin in this study, the shear bond strength of PET was significantly higher than that of PCAT and polymethyl methacrylate (PMMA). The examination of the failure mode showed that all of the PET specimens fractured cohesively, while that of the PCAT specimens underwent cohesive or a mixture of cohesive and adhesive fracture. All the PMMA specimens displayed adhesive fracture. The shear bond strength of PET in this study was similar to that of PET in the previous study [15]. In the polymer science field, PCAT materials generally have better chemical resistance than PET materials [24], which means that PCAT denture base material has weaker bonding to auto-polymerizing resin compared to PET denture base material. Therefore, it seems the nature of polyesters tends to affect the bonding of the two polyester denture base materials. However, the shear bond strength of PCAT was not significantly different from that of PMMA, which may explain why the bonding of auto-polymerizing resin to PCAT is equal to that of a conventional heat-polymerized PMMA. Thus, it seems that the bonding of auto-polymerizing resin to PCAT will not be affected during clinical use.

In this study, the mechanical properties and bonding strength of auto-polymerizing resin to two injection-molded thermoplastic polyester denture base resins were compared. Although the compositions of these polyester denture base resins are similar, their properties are different. As mentioned earlier, investigations of the flexibility of the injection-molded thermoplastic resin are important for dental practice. There are currently several kinds of injection-molded thermoplastic denture base resins used clinically for RPDs without metal clasps, but the information about their properties is insufficient. Therefore, more testing of the properties of the various types of injection-molded thermoplastic denture base resins should be performed.

Conclusions

This study evaluated some clinically relevant properties of two injection-molded thermoplastic polyester denture base resins. Based on the experimental conditions tested, the following conclusions may be drawn:

(1) The properties of the injection-molded thermoplastic denture base resins composed of polyethylene terephthalate copolymer and polycycloalkylene terephthalate copolymer were different from each other.
(2) The polycycloalkylene terephthalate copolymer denture base resin had significantly lower flexural strength at the proportional limit, lower elastic modulus, higher impact strength and lower shear bond strength compared to the polyethylene terephthalate copolymer denture base resin.

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References

[1] Goiato MC, Panzarini SR, Tomiko C, Luvizuto ER. Temporary flexible immediately removable partial denture: a case report. Dent Today 2008;27:114, 116.
[2] Kaplan P. Flexible removable partial dentures: design and clasp concepts. Dent Today 2008;27:120, 122–3.
[3] Katsumata Y, Hojo S, Hamano N, Watanabe T, Yamaguchi H, Okada S, et al. Bonding strength of autopolymerizing resin to nylon denture base polymer. Dent Mater J 2009;28:409–18.
[4] Hamanaka I, Takahashi Y, Shimizu H. Mechanical properties of injection-molded thermoplastic denture base resins. Acta Odontol Scand 2011;69:75–9.
[5] Hargreaves AS. Nylon as a denture-base material. Dent Pract Dent Rec 1971;22:122–8.
[6] Stafford GD, Huggett R, MacGregor AR, Graham J. The use of nylon as a denture-base material. J Dent 1986;14:18–22.
[7] Hiromori K, Fujii K, Inoue K. Viscoelastic properties of denture base resins obtained by underwater test. J Oral Rehabil 2000;27:522–31.
[8] Pronych GJ, Sutow EJ, Sykora O. Dimensional stability and dehydration of a thermoplastic polycarbonate-based and two PMMA-based denture resins. J Oral Rehabil 2003;30: 1157–61.
[9] Parvizi A, Lindquist T, Schneider R, Williamson D, Boyer D, Dawson DV. Comparison of the dimensional accuracy of injection-molded denture base materials to that of conventional pressure-pack acrylic resin. J Prosthodont 2004;13:83–9.
[10] Pfeiffer P, Rosenbauer EU. Residual methyl methacrylate monomer, water sorption, and water solubility of hypoallergenic denture base materials. J Prosthet Dent 2004;92:72–8.
[11] Pfeiffer P, Rolleke C, Sherif L. Flexural strength and moduli of hypoallergenic denture base materials. J Prosthet Dent 2005;93:372–7.
[12] Yunus N, Rashid AA, Azmi LL, Abu-Hassan MI. Some flexural properties of a nylon denture base polymer. J Oral Rehabil 2005;32:65–71.
[13] Takabayashi Y. Characteristics of denture thermoplastic resins for non-metal clasp dentures. Dent Mater J 2010;29:353–61.
[14] Takahashi Y, Hamanaka I, Shimizu H. Effect of thermal shock on mechanical properties of injection-molded thermoplastic denture base resins. Acta Odontol Scand 2012;70:297–302.
[15] Hamanaka I, Shimizu H, Takahashi Y. Shear bond strength of an autopolymerizing repair resin to injection-molded thermoplastic denture base resins. Acta Odontol Scand 2013;[Epub ahead of print].
[16] International Standard. ISO 1567 for Dentistry. Denture base polymers. Genève, Switzerland: International Organization for Standardization; 1999.

[17] International Standard. ISO 1567 AMENDMENT 1 for Dentistry. Denture base polymers Amendment 1. Genève, Switzerland: International Organization for Standardization; 2003.

[18] International Standard. ISO 179-1 for Plastics. Determination of Charpy impact properties – Part 1: non-instrumented impact test. Genève, Switzerland: International Organization for Standardization; 2000.

[19] Takahashi Y, Kawaguchi M, Chai J. Flexural strength at the proportional limit of a denture base material relined with four different denture reline materials. Int J Prosthodont 1997;10: 508–12.

[20] Takahashi Y, Chai J, Kawaguchi M. Effect of water sorption on the resistance to plastic deformation of a denture base material relined with four different denture reline materials. Int J Prosthodont 1998;11:49–54.

[21] Chai J, Takahashi Y, Kawaguchi M. The flexural strengths of denture base acrylic resins after relining with a visible-light-activated material. Int J Prosthodont 1998;11:121–4.

[22] Takahashi Y, Chai J, Kawaguchi M. Equilibrium strengths of denture polymers subjected to long-term water immersion. Int J Prosthodont 1999;12:348–52.

[23] Takahashi Y, Chai J, Kawaguchi M. Strength of relined denture base polymers subjected to long-term water immersion. Int J Prosthodont 2000;13:205–8.

[24] Mark HF. Encyclopedia of polymer science and technology. Volume 2 3rd ed. Hoboken, NJ: John Wiley & Sons, Inc; 2003. p 127–34.