Acta Odontologica Scandinavica, 2011; 69: 75–79

Mechanical properties of injection-molded thermoplastic denture base resins

IPPEI HAMANAKA, YUTAKA TAKAHASHI & HIROSHI SHIMIZU

Division of Removable Prosthodontics, Fukuoka Dental College, Fukuoka, Japan

Short title: Mechanical properties of thermoplastic resin

Key Words: Injection-molded thermoplastic denture base resin, mechanical properties, polyamide, polycarbonate polyethylene terephthalate

Abstract

Objective. To investigate the mechanical properties of injection-molded thermoplastic denture base resins. **Material and methods.** Four injection-molded thermoplastic resins (two polyamides, one polyethylene terephthalate, one polycarbonate) and, as a control, a conventional heat-polymerized polymethyl methacrylate (PMMA), were used in this study. The flexural strength at the proportional limit (FS-PL), the elastic modulus, and the Charpy impact strength of the denture base resins were measured according to International Organization for Standardization (ISO) 1567 and ISO 1567:1999/Amd 1:2003. **Results.** The descending order of the FS-PL was: conventional PMMA > polyethylene terephthalate, polycarbonate > two polyamides. The descending order of the elasticmoduli was: conventional PMMA > polycarbonate > polyethylene terephthalate > two polyamides. The descending order of the Charpy impact strength was: polyamide (Nylon PACM12) > polycarbonate > polyamide (Nylon 12), polyethylene terephthalate > conventional PMMA. **Conclusions.** All of the injection-molded thermoplastic resins had significantly lower FS-PL, lower elastic moduli, and higher or similar impact strength compared to the conventional PMMA. The polyamide denture base resins had low FS-PL and low elastic moduli; one of them possessed very high impact strength, and the other had low impact strength. The polyethylene terephthalate denture base resin showed a moderately high FSPL, moderate elastic modulus, and low impact strength. The polycarbonate denture base resin had a moderately high FS-PL, moderately high elastic modulus, and moderate impact strength.

Introduction

A removable partial denture (RPD) without metal clasps has recently been used in dental practice [1,2]. The clinical purpose of such an RPD without metal clasps is that problems relating to the clasps, such as poor esthetics and metal allergies, can be eliminated [3]. Injection-molded thermoplastic resins (polyamides, polyethylene terephthalate, and polycarbonate) are used for denture bases of RPDs without metal clasps because of their advantageous characteristics, such as a higher elasticity than heat-polymerizing base resins, and the fact that they can facilitate denture retention by utilizing the undercuts of abutment teeth in the denture base design [3]. Conventional RPDs are commonly retained at the undercuts of the abutment teeth using metal clasps; the undercut value is 0.25–0.75 mm [4]. Although the retentive clasp arm is deflected during the insertion and removal of an RPD, the denture base material is not deflected. Since a denture base is placed on the soft tissue and underlying hard tissue, it is preferable for the denture base to remain stiff and undergo little deflection during chewing. The flexibility of the retentive clasp arm may be influenced by the length, cross-sectional form, cross-sectional diameter, longitudinal taper, clasp curvature, and metallurgical characteristics of the alloy [5], and the undercut value depends on the metal clasp. However, an RPD without metal clasps is retained at the undercuts of the abutment teeth by means of the denture base. Therefore, the flexibility of the injection-molded thermoplastic resin affects the ease of insertion and removal of the RPD, its retention, and the stress transmitted to the abutment teeth.

Injection-molded thermoplastic resins used for denture base material have previously been investigated [3,6–13]. With regard to polyamide denture base resins, the mechanical properties [6,7,13], dimensional accuracy [10,13], and bonding strength of auto-polymerizing resin [3] were studied. Regarding polycarbonate denture base resin, the mechanical properties [8], dimensional accuracy [9], and bonding strength of the auto-polymerizing resin [3] were examined. Previous studies of a polyethylene terephthalate denture base resin have investigated the residual monomer, water sorption, water solubility [11], and mechanical properties [12]. Despite these earlier studies, little is known about how the mechanical properties compare among polyamide, polyethylene terephthalate, and polycarbonate as denture base material.

The flexural strength of acrylic denture base resins has been evaluated at the fracture load or at the highest load in many studies. Denture base resins exhibit considerable plastic deformation before failure, but the plastic deformation of a material beyond its proportional limit will permanently alter its dimensions. Therefore, plastic deformation is unacceptable for denture base materials, which rely on dimensional stability for their successful use [14]. A denture material should have a proportional limit sufficiently high that permanent deformation does not result from the stress applied during mastication [15]. Thus, measurement of the proportional limit of a denture base material using its resistance to plastic deformation is of significant clinical value. Some studies evaluated the resistance of denture base resins to plastic deformation under a flexural load [14,16–19]; however, the flexural strength at the proportional limit of injection-molded thermoplastic denture base resin has not been quantified.

Some plastics have low resistance to breakage when a load is applied by means of an impact. Such a sudden blow might correspond to the energy of impact resulting from an accident to a person wearing a restoration or from dropping the restoration on the floor [15]. An evaluation of the impact strength of denture base resins is beneficial for clinical purposes but the impact strength of injection-molded thermoplastic denture base resins has not been examined until now.

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

Material and methods

Four injection-molded thermoplastic resins were selected for this study, and a conventional heatpolymerized polymethyl methacrylate (PMMA) was used as a control (Table I).

The flexural properties and Charpy impact strength of the denture base materials were measured according to International Organization for Standardization (ISO) 1567 [20] and ISO 1567:1999/ Amd 1:2003 [21].

Flexural properties

The 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, and the accuracy of the dimensions was verified with a micrometer to within a 0.05-mm tolerance for width and height at three locations for each dimension. Ten specimens were fabricated for each group and stored in water at 37℃ for 50 h before testing. The flexural strength at the proportional limit (FS-PL) and flexural modulus of the specimens were tested. Each specimen was placed on a 50-mm long support for threepoint flexural testing. A vertical load was applied using a load-testing machine (ASG-J; Shimadzu Co. Ltd., Tokyo, Japan) at the midpoint of the specimen at a crosshead speed of 5 mm/min. The FS-PL (MPa) was calculated using the following formula:

$$FS - PL = 3PL/2bd^2$$

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 loaddeflection graph. The elastic modulus (GPa) was calculated according to the following formula:

$$\text{Elastic modulus} = FL^3 / 4bd^3D$$

where F = load at a convenient point in the straightline portion of the load/deflection graph, and D = deflection at load F. Charpy impact test Specimens of each denture base material 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 the dimensions was verified with a micrometer to within a 0.2-mm tolerance for width and height at three locations for each dimension. A notch (type A) was cut in the middle of each specimen, as described in ISO 179 [22]. An edgewise notch was cut to a depth of 1.2 mm, leaving a residual depth beneath the notch of 4.8 mm. Ten specimens were fabricated for each group and stored in a container of water at 37℃ for 7 days before testing; they were conditioned in the container at 23℃ for 60 min prior to testing. A Charpy notched impact strength test was carried out on a pendulum impact tester (DC-C; Toyo Seiki, Tokyo, Japan). After conditioning, the specimen was removed from the water and placed on the specimen supports of the testing apparatus. The test span was 40 mm. The specimen was placed with the notch facing away from the point of impact from the pendulum, and then the pendulum was released in order to fracture the specimen. The Charpy impact strength (kJ/m^2) of the notched specimen was calculated using the formula:

$$\text{Impact strength} = (J_1 - J_2) \times 10^3 / bh$$

where J_1 = energy absorbed by the specimen, J_2 = friction energy of the system, b = depth behind the notch, and h = height of the specimen. All testing was performed under uniform atmospheric conditions of 23.0℃ ± 1℃ and 50% ± 1% relative humidity.

The data were analyzed statistically using a one-way ANOVA (STATISTICA; StatSoft Inc., Tulsa, OK), and Tukey's post-hoc comparison test (STATISTICA) was applied when appropriate (95% confidence level).

Results

One-way ANOVA revealed significant differences among the various denture base materials for the FS-PL, elastic modulus, and Charpy impact strength ($P < 0.05$).

All of the injection-molded thermoplastic resins had a significantly lower FS-PL than the denture base control, Acron (PMMA) ($P < 0.05$). As a group, EstheShot (polyethylene terephthalate) and Reigning (polycarbonate) had the highest FS-PL among the thermoplastic resins ($P < 0.05$). The FS-PL of Lucitone FRS (polyamide) was significantly higher than that of Valplast (polyamide) ($P < 0.05$) (Table II).

All of the injection-molded thermoplastic resins had a significantly lower elastic modulus than Acron ($P < 0.05$) and were significantly different from each other ($P < 0.05$). The elastic moduli of all the thermoplastic resins arranged in descending order were: Reigning, EstheShot, LucitoneFRS, and Valplast (Table II).

LucitoneFRS had the highest impact strength among the denture base materials ($P < 0.05$). The impact strength of Reigning was significantly higher than that of Valplast, EstheShot, and Acron as a group ($P < 0.05$) (Table II).

Discussion

The null hypothesis of this study was rejected, and the mechanical properties of the injection-molded thermoplastic denture base resins were different from each other.

A graph showing the load-deflection values for the various denture base materials is shown in Figure 1. The results of the FS-PL test showed that the polyethylene terephthalate denture base resin (EstheShot) and the polycarbonate denture base resin (Reigning) exhibited a higher FS-PL than the polyamide denture base resins (LucitoneFRS and Valplast). Compared with previous studies of the flexural strength estimated by means of maximum load, the flexural strength of the polyamide denture base resin was lower than that of the conventional PMMA [13], and that of the polyethylene terephthalate denture base resin was similar to that of the conventional PMMA [12]. In the present study, the flexural strength was evaluated using the proportional limit; therefore, the results did not correlate well with those of previous studies. There are few other studies of the flexural strength of the polycarbonate denture base resin. In the present study, the FS-PL of the polyamide denture base resins was »40–60% that of the conventional PMMA (Acron). The findings indicate that a denture base fabricated from a polyamide denture base resin tends to undergo permanent deformation during mastication. In this case, the cancellous bone under the denture base will be absorbed if vertical stress occurs from the deformation. Therefore, it is recommended that a denture base fabricated from a polyamide denture base resin should be reinforced.

The results of the elastic modulus test showed that the polyethylene terephthalate and polycarbonate denture base resins exhibited a higher elastic modulus compared to the polyamide denture base resins. Yunus et al. [13] reported that the flexural modulus of polyamide denture base resin was lower than that of conventional PMMA, which was similar to the results of the present study. However, Pfeiffer et al. [12] found that the flexural modulus of a polyethylene terephthalate denture base resin was higher than that of a conventional PMMA, which differed from the present results. Studies on the flexural strength of polycarbonate denture base resin are scarce. This study found that the flexural moduli of the polyamide denture base resins were »40–50% that of the conventional PMMA, which meant that the polyamide denture base resin was flexible. The findings confirm that dentures made of polyamide denture base resins are easy to place and remove and can be used with deep undercuts of the abutment teeth. Conversely, dentures made of polyethylene terephthalate and polycarbonate denture base resins had high elastic moduli, similar to that of conventional PMMA; in other words, they were stiff. The polyethylene terephthalate and polycarbonate denture base resins tended to cause stress to the abutment teeth during insertion and removal of the denture. Thus, it is recommended that the choice of thermoplastic denture base resin for RPDs without metal clasps should be considered on a case-by-case basis, depending on the retentive areas and the useable undercut potential of the abutment teeth.

None of the injection-molded thermoplastic denture base resins fractured during the flexural testing; these resins were ductile. However, in the impact test, one of the polyamide denture base resins (Lucitone FRS) and the polycarbonate denture base resin had higher impact strength than one of the polyamide denture base resins (Valplast), the polyethylene terephthalate denture base resin, and the conventional PMMA. A widely used textbook [23] indicates that the polyamide and polycarbonate denture base resins had good impact strength, which is similar to the results of the present study, although one of the polyamide denture base resins did not have high impact strength. The first dental use of polyamide was unsuccessful because of excessive water absorption [23]. Since then, however, polyamide has been improved, and many types are now used in industry. Hence, it seems that differences in the composition of the polyamide produced differences in impact strength in the present study.

Ideally, it is preferable for an RPD denture base without metal clasps to have a high FS-PL, low elastic modulus, and high impact strength because a high FS-PL can prevent permanent deformation of the denture, and a low elastic modulus offers ease of insertion and removal of a denture. There are currently various kinds of injection-molded thermoplastic resins used clinically for RPDs without metal clasps, and the present study demonstrated that the mechanical properties of the injection-molded thermoplastic denture base resins differ from each other. Nevertheless, there is currently insufficient information about injection-molded thermoplastic denture base resins and RPDs without metal clasps. Clinicians should be well aware of the properties of injectionmolded thermoplastic denture base resins in order to choose one for an RPD without metal clasps that is suitable for each patient.

Conclusions

This experiment evaluated some clinically relevant mechanical properties of injection-molded thermoplastic denture base materials. Based on the experimental conditions tested, the following conclusions may be drawn:

(1) All of the injection-molded thermoplastic resins had significantly lower FS-PL, lower elastic modulus, and higher or similar impact strength than the conventional heat-polymerized acrylic resin.

(2) The polyamide thermoplastic resins had low FS-PL and low elastic modulus; one of them possessed very high impact strength and the other had low impact strength.

(3) The thermoplastic resin composed of polyethylene terephthalate had moderately high FS-PL, moderate elastic modulus, and low impact strength.

(4) The thermoplastic resin composed of polycarbonate had moderately high FS-PL, moderately high elastic modulus, and moderate impact strength.

Acknowledgements

The authors thank Aishi Dental Laboratory Co., Ltd. for supplying some of the specimens used in this project.

Declaration of interest: The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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] Carr AB, McGivney GP, Brown DT. McCracken's removable partial prosthodontics, 11th ed. St. Louis, MO: Mosby Elsevier; 2005. p. 179–80.

[5] Phoenix RD, Cagna DR, DeFreest CF. Stewart's clinical removable partial prosthodontics, 3rd ed. Chicago, IL: Quintessence Publishing Co, Inc; 2003. p. 64.

[6] Hargreaves AS. Nylon as a denture-base material. Dent Pract Dent Rec 1971;22:122–8.

[7] Stafford GD, Huggett R, MacGregor AR, Graham J. The use of nylon as a denture-base material. J Dent 1986;14:18–22.

[8] Hiromori K, Fujii K, Inoue K. Viscoelastic properties of denture base resins obtained by underwater test. J Oral Rehabil 2000;27:522–31.

[9] 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.

[10] Parvizi A, Lindquist T, Schneider R, Williamson D, Boyer D, Dawson DV. Comparison of the dimensional accuracy of injection-molded denture basematerials to that of conventional pressure-pack acrylic resin. J Prosthodont 2004;13:83–9.

[11] 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.

[12] Pfeiffer P, Rolleke C, Sherif L. Flexural strength and moduli of hypoallergenic denture base materials. J Prosthet Dent 2005;93:372–7.

[13] 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.

[14] 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.

[15] Powers JM, Sakaguchi RL. Craig's restorative dental materials, 12th ed. St. Louis, MO: Mosby Elsevier; 2006. p. 77, 519.

[16] 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.

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

[18] Takahashi Y, Chai J, Kawaguchi M. Equilibrium strengths of denture polymers subjected to long-termwater immersion. Int J Prosthodont 1999;12:348–52.
[19] 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.
[20] International Standard. ISO 1567 for Dentistry—Denture base polymers. Geneva, Switzerland: International Organization for Standardization; 1999.
[21] International Standard. ISO 1567 AMENDMENT 1 for Dentistry—Denture base polymers AMENDMENT 1. Geneva, Switzerland: International Organization for Standardization; 2003.
[22] International Standard. ISO 179-1 for Plastics—Determination of Charpy impact properties. Part 1: Non-instrumented impact test. Geneva, Switzerland: International Organization for Standardization; 2000.
[23] O’Brien WL. Dental materials and their selection, 4th ed. Chicago, IL: Quintessence Publishing Co, Inc; 2008. p. 79–83.

Table I. Denture base materials tested.

Constituent	Material	Manufacturer	Processing method	Lot number
Polyamide (Nylon 12)	Valplast	Valplast International Corp., Long Island City, NY	Injection molding technique; heat processed at 215º C for 20 min	080632
Polyamide (NylonPACM12)	Lucitone FRS	DENTSPLY International Inc., York, PA	Injection molding technique; heat processed at 300º C for 17 min	090417A
Polyethylene terephthalate	EstheShot	i-Cast Co. Ltd., Kyoto, Japan	Injection molding technique; heat processed at 230º C for 20 min	JBB
Polycarbonate	Reigning	Toushinyoukou Co. Ltd., Niigata, Japan	Injection molding technique; heat processed at 320º C for 30 min	COC28T
PMMA	Acron	GC Corp., Tokyo, Japan	Heat-polymerized, compression molding technique; heat-processed at 70ºC for 90 min, then at 100ºC for 30 min, and bench cooled for 30 min	Powder: 0910232 Liquid: 0910051

Table II. Mean and standard deviation (SD) of the mechanical properties of the denture base materials.

Denture base material	Flexural strength at proportional limit (MPa); mean (SD)	Elastic modulus (GPa); mean (SD)	Charpy impact strength (kJ/m^2); mean (SD)
Polyamide (Valplast)	13.7 (0.8)	1.04 (0.11)	6.86 (0.48)[a]
Polyamide (Lucitone FRS)	22.3 (0.9)	1.45 (0.05)	30.24 (9.82)
Polyethylene terephthalate (EstheShot)	30.4 (2.1)[a]	1.98 (0.08)	4.09 (0.59)[a]
Polycarbonate (Reigning)	29.6 (1.0)[a]	2.19 (0.11)	21.32 (5.50)
PMMA (Acron)	38.2 (4.0)	2.77 (0.12)	1.06 (0.12)[a]

[a]Denotes no significant differences among denture base materials ($P > 0.05$).

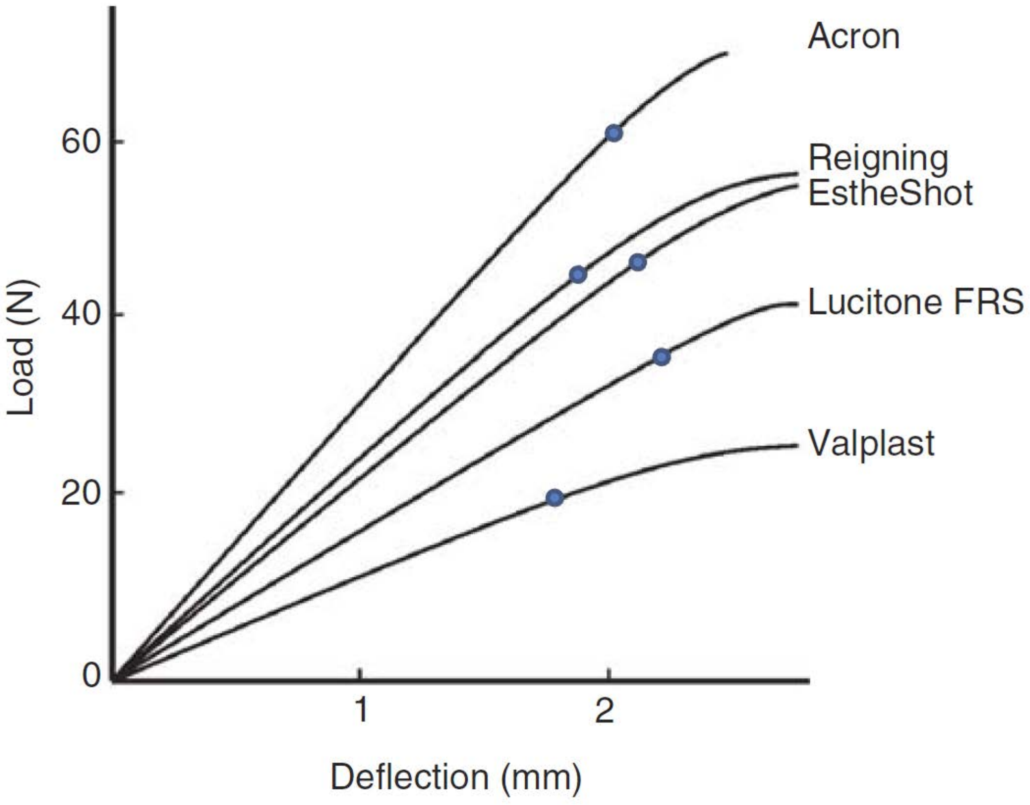

Figure 1. Load-deflection graphs of various denture base materials.
The dots indicate the proportional limit.