



Effects of relining materials on the flexural strength of relined thermoplastic denture base resins

Yunhan Sun¹, So-Yeon Song², Ki-Sun Lee³, Jin-Hong Park³, Jae-Jun Ryu³, Jeong-Yol Lee^{3*}

¹Department of Medicine, Graduate School, Korea University, Seoul, Republic of Korea

²Department of Biomedical Sciences, Graduate School, Korea University, Seoul, Republic of Korea

³Department of Prosthodontics, Korea University Guro Hospital, Seoul, Republic of Korea

PURPOSE. The aim of this study was to evaluate the effects of relining materials on the flexural strength of relined thermoplastic denture base resins (TDBRs). **MATERIALS AND METHODS.** For shear bond strength testing, 120 specimens were fabricated using four TDBRs (EstheShot-Bright, Acrytone, Valplast, Weldenz) that were bonded with three autopolymerizing denture relining resins (ADRRs: Vertex Self-Curing, Tokuyama Rebase, Ufi Gel Hard) with a bond area of 6.0 mm in diameter and were assigned to each group (n=10). For flexural strength testing, 120 specimens measuring 64.0×10.0×3.3 mm (ISO-1567:1999) were fabricated using four TDBRs and three ADRRs and were assigned to each group (n=10). The thickness of the specimens measured 2.0 mm of TDBR and 1.3 mm of ADRR. Forty specimens using four TDBRs and 30 specimens using ADRRs served as the control. All specimens were tested on a universal testing machine. For statistical analysis, Analysis of variance (ANOVA) with Tukey's test as post hoc and Spearman's correlation coefficient analysis ($P=.05$) were performed. **RESULTS.** Acry-Tone showed the highest shear bond strength, while Weldenz demonstrated the lowest bond strength between TDBR and ADRRs compared to other groups. EstheShot-Bright exhibited the highest flexural strength, while Weldenz showed the lowest flexural strength. Relined EstheShot-Bright demonstrated the highest flexural strength and relined Weldenz exhibited the lowest flexural strength ($P<.05$). Flexural strength of TDBRs ($P=.001$) and shear bond strength ($P=.013$) exhibited a positive correlation with the flexural strength of relined TDBRs. **CONCLUSION.** The flexural strength of relined TDBRs was affected by the flexural strength of the original denture base resins and bond strength between denture base resins and relining materials. [*J Adv Prosthodont 2018;10:361-6*]

KEYWORDS: Thermoplastic resin; Denture bases; Denture liners; Bond strength; Flexural strength

INTRODUCTION

Recently, removable partial dentures fabricated without metal clasps using thermoplastic denture base resins (TDBRs)

have become an alternative treatment method due to their superior esthetics.^{1,2}

As early as 1950s in the United States, polyamide was suggested as the material of choice for denture bases.³ Since then, many types of TDBRs have been approved for use as denture bases in Japan, such as polyesters and acrylic resins. All of these TDBRs exhibit more favorable physical properties such as molding precision and elasticity compared to conventional heat polymerizing resins like polymethyl methacrylate (PMMA).^{1,4-6} The main advantage of these materials is their flexibility, which inhibits denture fracture, and their ability to engage tooth undercuts to provide removable partial denture (RPD) retention.⁴ However, previous studies have reported some limitations of the clinical application of TDBRs because some of these TDBRs had a significantly lower flexural strength at the proportional limit and they had issues with repair and relines.^{1,7,8} The flexural strength

Corresponding author:

Jeong-Yol Lee

Department of Prosthodontics, Korea University Guro Hospital

148 Gurodong-ro, Guro-gu, Seoul 08308, Republic of Korea

Tel. +82226261922; e-mail, wddc@korea.ac.kr

Received December 28, 2017 / Last Revision July 5, 2018 / Accepted August 22, 2018

© 2018 The Korean Academy of Prosthodontics

This is an Open Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (<http://creativecommons.org/licenses/by-nc/3.0>) which permits unrestricted non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

This study was supported by the Korea Health Industry Development Institute (2015-2017 Project No. HI15C0620).

of polyamide (Valplast) was reported to be 27 - 42 MPa⁹ and 35 - 41 MPa.¹ Another study reported that the flexural strength of polyamide (Valplast) was 13.7 MPa, that of polyester (EstheShot-Bright) was 24.2 MPa, and that of acrylic resin (Acry-Tone) was 17.3 MPa.¹⁰

Removable prostheses often require denture base relining to improve their fit due to gradual changes in residual alveolar ridges.¹¹⁻¹³ Successful denture relining not only relies on the properties of two kinds of materials, but also requires high bond strength between them to achieve a perfectly bonded interface. High bond strength can resist the separation of relined denture bases. On the other hand, weak bond strength will decrease the overall mechanical strength.¹¹⁻¹³ During mastication, relined dentures have to withstand masticatory forces to prevent fracture. Therefore, knowledge of the mechanical properties (bond and flexural strength) of relined resin base is essential in the selection of denture base resins.

Currently, a new type of TDBR, polypropylene, has also been approved for use as a denture base in Japan. However, not enough research has been performed to evaluate its clinical properties. Furthermore, there are still insufficient studies about the effects of relining materials on the flexural strength of relined TDBRs. Therefore, the aim of the present study was to evaluate the effects of relining materials on the flexural strength of relined TDBRs. The null hypothesis of this study was that denture relining materials has no effect on the flexural strength of relined TDBRs.

MATERIALS AND METHODS

The materials involved in this study included four TDBRs: 1. polyester: EstheShot-Bright (ES), I-cast Co. Ltd., Kyoto, Japan; 2. acrylic resin: Acrytone (AC), High Dental Japan, Osaka, Japan; 3. polyamide: Valplast (VA), Valplast International Corp, New York, NY, USA; 4. polypropylene: Weldenz (WE), Weldenz Japan Co. Ltd., Nagoya, Japan). The study also included three Autopolymerizing denture relining resins (ADRRs): 1. Vertex Self-Curing (VE), Vertex-Dental, Zeist, the Netherlands; 2. Tokuyama Rebase II (TO), Tokuyama Dental Corp, Tokyo, Japan; and 3. Ufi Gel Hard (UF), Voco, Cuxhaven, Germany). All materials used are summarized in Table 1 and Table 2.

TDBRs with dimensions of 20.0 × 10.0 × 3.3 mm were fabricated with a stainless steel mold according to the manufacturer's instructions (Table 1) and embedded into autopolymerizing resin using a cylindrical silicone mold with a height of 24.0 mm and a diameter of 23.0 mm. This served as the substrate for shear bond testing. The cylindrical specimens were polished with 600 grit sandpaper to obtain a uniform flat surface. A cylindrical Teflon tube with a height of 3.0 mm and an inner diameter of 6.0 mm was used as a mold to bond the denture relining resins. The ADRRs were mixed accurately with liquid and powder at the ratio according to the manufacturer's instructions (Table 2) then placed into the Teflon tube. The ADRRs were polymerized according to the manufacturer's instructions (Table 2), and the Teflon

Table 1. List of thermoplastic denture base resins

Product	Constituent	Manufacturer	Processing method	Lot No.
EstheShot-Bright (ES)	Polyester	I-cast Co. Ltd., Kyoto, Japan	Heat processed at 270°C for 20 min	4D5760060
Acry-Tone (AC)	Acrylic resin	High Dental Japan, Osaka, Japan	Heat processed at 260°C for 25 min	1211097
Valplast (VA)	Polyamide	Valplast International Corp, New York, USA	Heat processed at 285°C for 20 min	140213
Weldenz (WE)	Polypropylene	Weldenz Japan Co. Ltd., Nagoya, Japan	Heat processed at 235°C for 20 min	111547

Table 2. List of relining materials

Product	Manufacturer	Powder/liquid ratio	Composition	Polymerization cycles	Lot No.
Tokuyama Rebase II (TO)	Tokuyama Dental Corp, Tokyo, Japan	2.1 g/ml	Powder: PEMA Liquid: AAEM and 1.9-nonanediol dimethacrylate	5.5 min at room temperature	Powder: 465 Liquid: 589
Ufi Gel Hard (UF)	Voco, Cuxhaven, Germany	1.8 g/ml	Powder: PEMA Liquid: 1.6-HDMA	8.5 min at room temperature	Powder: 1243338 Liquid: 1242035
Vertex Self-Curing (VE)	Vertex-Dental, Zeist, the Netherlands	2.3 g/ml	Powder: PMMA Liquid: MMA	10 min at 55°C and 2.5 bar	Powder: XW042P02 Liquid: XX3919L02

PEMA, Poly (ethyl methacrylate); AAEM, 2-acetoacetoxy (ethyl) methacrylate; 1,6-HDMA, 1,6-hexanediol dimethacrylate; PMMA, Poly (methyl methacrylate); MMA, Methyl methacrylate

tube and excess material were removed (Fig. 1). Finally, all specimens were placed in a water bath for 48 hours at a temperature of 37°C.

A total of 12 groups consisting of 10 specimens each were fabricated: a) VA + TO, b) VA + UF, c) VA + VE, d) ES + TO, e) ES + UF, f) ES + VE, g) AC + TO, h) AC + UF, i) AC + VE, j) WE + TO, k) WE + UF, l) WE + VE.

A stainless steel mold was used to fabricate TDBRs and ADRRs into bars with dimensions of 64.0 × 10.0 × 3.3 mm (Fig. 2A), which is in accordance with the International Standards Organization (ISO) 1567 (1999) specifications. A total of 160 bars of TDBRs were created and 30 (10 per group) specimens of ADRRs were also fabricated according to the manufacturer's instructions (Table 1, Table 2).

To fabricate relined TDBRs specimens, 120 bars of TDBRs were further trimmed and polished, using a 600 grit sandpaper to obtain a uniform flat surface to achieve a thickness of 2.0 mm (Fig. 2B). TDBRs specimens were placed into the stainless steel mold for relining. The ADRRs were mixed accurately with liquid and powder at the ratio according to the manufacturer's instructions (Table 2) and then placed into the same stainless steel mold on the top of TDBRs specimens. After polymerization, ADRRs and TDBRs have turned into double layer sandwich specimens and then removed from the stainless steel mold. The thickness of the relined ADRR was 1.3 mm. All specimens were placed in a water bath for 48 hours at a temperature of 37°C.

A total of 19 groups consisting of 10 specimens each were created: a) VA + TO, b) VA + UF, c) VA + VE, d) ES + TO, e) ES + UF, f) ES + VE, g) AC + TO, h) AC + UF,

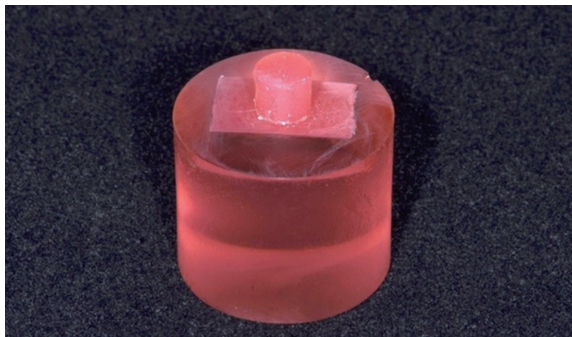


Fig. 1. Specimen for shear bond strength testing.

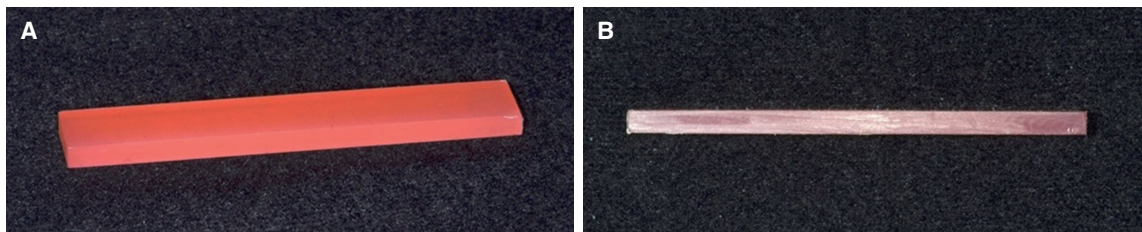


Fig. 2. Specimens for flexural strength testing. (A) Denture base resin with dimensions of 64.0 × 10.0 × 3.3 mm. (B) Trimmed denture base resin with dimensions of 64.0 × 10.0 × 2.0 mm.

l) AC + VE, j) WE + TO, k) WE + UF, l) WE + VE, m) VA, n) ES, o) AC, p) WE, q) TO, r) UF, s) VE.

The shear bond strength tests were performed in a universal testing machine (AG-10KNX, Shimadzu Co., Kyoto, Japan) at a cross-head speed of 1 mm/min until failure occurred. Shear bond strength was expressed as follows: $F = N/A$ where N = maximum force (in N) exerted at the specimen and A = area of bonding (in mm²).

For flexural strength test, all the specimens were placed in a universal testing machine (AG-10KNX, Shimadzu Co., Kyoto, Japan) for three-point bending test at a cross-head speed of 5.0 mm/min and a distance of 50.0 mm between jig wedges. Flexural strength was computed from the equation: $FS = 3Fl / 2bb^2$ where: F = maximum load (in N); l = distance (in mm) between the supports; b = width of the specimen (in mm); and b = thickness of the specimen (in mm).

Data was analyzed by ANOVA with Tukey's test as post hoc analysis ($P = .05$) and Spearman's correlation coefficient analysis ($P = .05$) using SPSS software (SPSS ver. 20.0, IBM, Chicago, IL, USA).

RESULTS

AC groups demonstrated significantly higher bond strength and WE groups showed the lowest shear bond strength compared to other groups ($P < .05$). Groups where ES was bonded with VE resin showed higher bond strength compared to other groups ($P < .05$, Table 3).

Between the TDBRs groups, ES exhibited significantly higher flexural strength compared to all the other groups ($P < .05$). WE demonstrated showed lower flexural strength than all the other groups ($P < .05$, Table 4).

Among the ADRRs groups, the VE group showed significantly higher flexural strength than the TO and UF groups ($P < .05$, Table 4).

Between the relined TDBRs groups, TDBRs relined with VE resin exhibited significantly higher flexural strength compared to the other groups ($P < .05$). The relined ES groups showed significantly higher flexural strength and relined WE groups exhibited lower flexural strength compared to the other groups ($P < .05$, Table 4).

The flexural strength of relined TDBRs exhibited a positive correlation with the flexural strength of TDBRs ($P = .001$) and shear bond strength ($P = .013$, Fig. 3).

Table 3. Mean shear bond strength (± SD) of each group (in MPa)

	EstheShot-Bright	Acry-Tone	Valplast	Weldenz
Vertex Self-Curing	4.20 ± 0.52 ^{A; a}	8.06 ± 0.90 ^{B; a}	1.05 ± 0.13 ^{C; a}	0.82 ± 0.11 ^{C; a}
Ufi Gel Hard	2.58 ± 0.73 ^{A; b}	6.94 ± 0.56 ^{B; b}	2.71 ± 0.51 ^{A; b}	0.86 ± 0.18 ^{C; a}
Tokuyama Rebase II	1.90 ± 0.19 ^{A; b}	3.69 ± 0.53 ^{B; c}	1.44 ± 0.28 ^{A; c; a}	1.03 ± 0.24 ^{C; a}

Different letters show a significant (capital letter: in the same row, small letter: in the same column, *P* < .05)

Table 4. Mean flexural strength (± SD) of each group (in MPa)

	No denture base	EstheShot-Bright	Acry-Tone	Valplast	Weldenz
No relining	-	69.81 ± 0.35 ^A	58.70 ± 1.03 ^B	54.04 ± 0.91 ^B	35.68 ± 0.42 ^C
Tokuyama Rebase II	42.14 ± 8.14 ^a	59.00 ± 1.28 ^{A; a}	52.60 ± 2.68 ^{A; B; a}	50.36 ± 1.02 ^{B; a}	39.75 ± 1.90 ^{C; a}
Ufi Gel Hard	34.40 ± 7.92 ^a	64.83 ± 2.19 ^{A; a}	58.49 ± 3.59 ^{A; B; a; b}	56.54 ± 2.12 ^{B; a; b}	44.55 ± 1.56 ^{C; b}
Vertex Self-Curing	80.05 ± 2.51 ^b	74.34 ± 1.87 ^{A; b}	64.89 ± 3.69 ^{B; b; c}	59.68 ± 1.38 ^{B; b; c}	48.87 ± 1.78 ^{C; b}

Different letters show a significant (capital letter: in the same row, small letter: in the same column, *P* < .05)

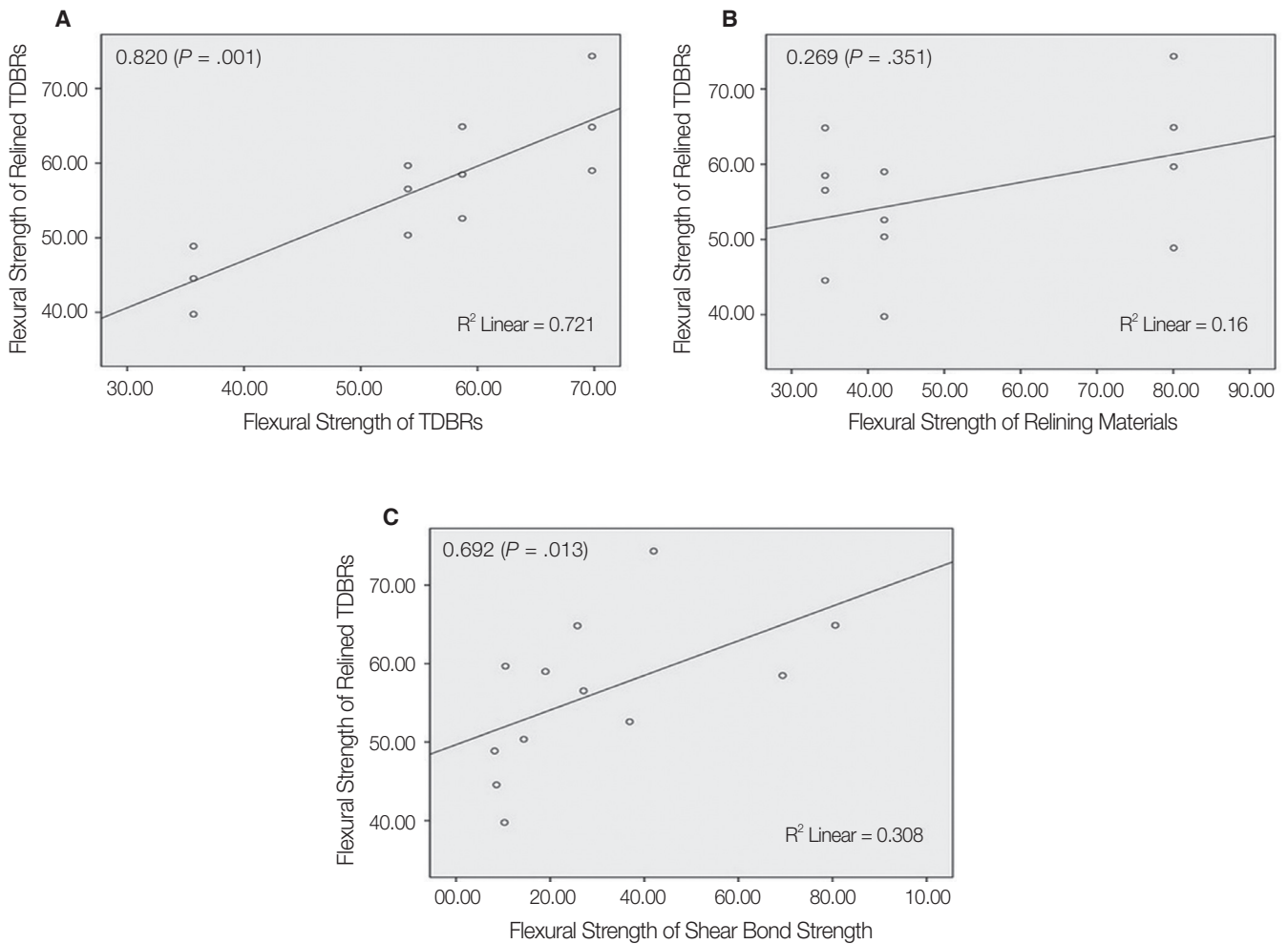


Fig. 3. Correlation coefficient. (A) Flexural strength of the denture base (X) / Relined denture base resins (Y). (B) Flexural strength of the relining materials (X) / Relined denture base resins (Y). (C) Bond strength (X) / Relined denture base resins (Y).

DISCUSSION

The results obtained in the present study demonstrated a positive correlation between the flexural strength of relined TDBRs and shear bond strength. Therefore, the null hypothesis that the denture relining materials has no effect on flexural strength of relined TDBRs was rejected.

This study explored the effects of relining materials on the shear bond strength and flexural strength of relined TDBRs. Bond strength between denture base resins and relining resins can be affected by the chemical structures of the two different materials.¹⁴ In our study, AC bonded with VE exhibited the highest bond strength because the chemical structure of AC and VE are the same as PMMA. Polyesters were reported to bond well with ADRRs, while polyamides showed low bond strength with ADRRs.^{9,15,16} In our study, the results were similar to those in the previous studies. Polyesters are polycondensates of polyfunctional carboxylic acid and polyalcohol. Because they adhere strongly to ADRRs, dentures made of these materials are also easy to repair.⁸ Polyamide are linear polymers composed of repeated amide bonds ($-\text{CONH}-$). Insolubility of nylon materials in methyl methacrylate (MMA) means that they do not adhere directly to ADRRs due to the hydrogen bonds between amide groups ($-\text{CONH}_2-$), making denture fractures difficult to repair.¹⁵ If the bond strength is weak, delamination of the interface can occur.¹⁷ In this study, delamination occurred in the WE groups during flexural strength test of relined TDBRs. This may have been caused by the low bond strength, since the WE groups showed the lowest bond strength, which was around 1 MPa.

According to the ISO 1567 (1999), the flexural strength of TDBRs should be more than 65 MPa. In this study, our results indicated that only ES met the standard value requirements and mostly exhibited low flexural strength, especially in the WE groups. Hamanaka *et al.* demonstrated that four types of TDBRs had significantly lower flexural strength at the proportional limit compared to the conventional PMMA.¹⁰ In another study, six thermoplastic resins and a conventional acrylic resin were examined and the results exhibited that they had lower flexural strengths than conventional PMMA.¹ Polyamide was reported to have low flexural strength,¹ while polyester has moderately high flexural strength.¹⁰ Similar results were found in our study. Therefore, caution is needed when using TDBRs in clinical settings because there is a possibility of permanent deformation or fracture of the removable prosthesis after loading. In the flexural strength test of relined TDBRs, the relined ES groups showed significantly higher flexural strength and the relined WE groups exhibited significantly lower flexural strength. This indicates that the flexural strength of relined TDBRs can be affected by the flexural strength of the original material.

Although most studies showed that the flexural strength of relining materials has an effect on the flexural strength of relined denture bases,¹⁸⁻²¹ a previous study evaluated the resistance to plastic deformation of a relined denture base

with different relining materials and reported that relined denture bases exhibited a significant decrease in flexural strength.¹⁸ In addition, a recent study investigated the ability of the relining materials to strengthen denture base resins and found that the strength of relined denture bases is related to the strength of the original two materials.¹¹ Different results were found in the current study compared to previous studies.

According to the Spearman's correlation coefficient, only the flexural strength of TDBRs has a positive effect on the flexural strength of relined TDBRs (Fig. 3A). The flexural strength of relining materials had no statistical effect on the flexural strength of relined TDBRs (Fig. 3B). This may be caused by the varying thickness of the resins (TDBR = 2 mm, relining materials = 1.3 mm). Bond strength can also affect the flexural strength of relined thermoplastic denture base resins (Fig. 3C).

This *in vitro* study had some limitations such as difficulty in the simulation of the oral environment and a need for long-term study. Further studies should be done on how different surface treatment on TDBRs may affect the shear bond strength.

In summary, the results for shear bond strength and flexural strength, from the three-point bending test, suggested that ES has the most suitable mechanical properties for use in clinical practice.

CONCLUSION

Within the limitations in this study, it can be concluded that flexural strength of relined TDBRs was affected by the flexural strength of the original denture base resins and the bond strength between denture base resins and relining materials. Also, EstheShot-Bright was concluded to have the most suitable mechanical properties that could be used in the clinical practice.

ORCID

So-Yeon Song <https://orcid.org/0000-0002-7738-5370>

Jin-Hong Park <https://orcid.org/0000-0002-3220-9912>

Jaе-Jun Ryu <https://orcid.org/0000-0001-6903-5955>

Jeong-Yol Lee <https://orcid.org/0000-0003-3079-0376>

REFERENCES

1. Takabayashi Y. Characteristics of denture thermoplastic resins for non-metal clasp dentures. *Dent Mater J* 2010;29:353-61.
2. Goiato MC, Santos DM, Haddad MF, Pesqueira AA. Effect of accelerated aging on the microhardness and color stability of flexible resins for dentures. *Braz Oral Res* 2010;24:114-9.
3. 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.
4. Katsumata Y, Hojo S, Hamano N, Watanabe T, Yamaguchi H, Okada S, Teranaka T, Ino S. Bonding strength of autopoly-

- merizing resin to nylon denture base polymer. *Dent Mater J* 2009;28:409-18.
5. Kasumata Y, Hojo S, Ino S, Hamano N, Watanabe T, Suzuki Y, Ikeya H, Morino T, Toyoda M. Mechanical characterization of a flexible nylon denture base material. *Bull Kanagawa Dent Coll* 2007;35:177-82.
 6. 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.
 7. Fueki K, Ohkubo C, Yatabe M, Arakawa I, Arita M, Ino S, Kanamori T, Kawai Y, Kawara M, Komiyama O, Suzuki T, Nagata K, Hosoki M, Masumi S, Yamauchi M, Aita H, Ono T, Kondo H, Tamaki K, Matsuka Y, Tsukasaki H, Fujisawa M, Baba K, Koyano K, Yatani H. Clinical application of removable partial dentures using thermoplastic resin-part I: definition and indication of non-metal clasp dentures. *J Prosthodont Res* 2014;58:3-10.
 8. Fueki K, Ohkubo C, Yatabe M, Arakawa I, Arita M, Ino S, Kanamori T, Kawai Y, Kawara M, Komiyama O, Suzuki T, Nagata K, Hosoki M, Masumi S, Yamauchi M, Aita H, Ono T, Kondo H, Tamaki K, Matsuka Y, Tsukasaki H, Fujisawa M, Baba K, Koyano K, Yatani H. Clinical application of removable partial dentures using thermoplastic resin. Part II: Material properties and clinical features of non-metal clasp dentures. *J Prosthodont Res* 2014;58:71-84.
 9. Takahashi H, Kawada E, Tamaki Y, Teraoka F, Hosoi T, Yoshida T. Basic properties of thermoplastic resins for denture base material referred to non-clasp denture. *J Jpn Dent Mater* 2009;28:161-7.
 10. Hamanaka I, Takahashi Y, Shimizu H. Mechanical properties of injection-molded thermoplastic denture base resins. *Acta Odontol Scand* 2011;69:75-9.
 11. Arena CA, Evans DB, Hilton TJ. A comparison of bond strengths among chairside hard reline materials. *J Prosthet Dent* 1993;70:126-31.
 12. Takahashi Y, Chai J. Shear bond strength of denture reline polymers to denture base polymers. *Int J Prosthodont* 2001; 14:271-5.
 13. 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.
 14. Arima T, Murata H, Hamada T. Analysis of composition and structure of hard autopolymerizing reline resins. *J Oral Rehabil* 1996;23:346-52.
 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;71: 1250-4.
 16. Hamanaka I, Shimizu H, Takahashi Y. Bond strength of a chairside autopolymerizing reline resin to injection-molded thermoplastic denture base resins. *J Prosthodont Res* 2017;61: 67-72.
 17. da Cruz Perez LE, Machado AL, Canevarolo SV, Vergani CE, Giampaolo ET, Pavarina AC. Effect of reline material and denture base surface treatment on the impact strength of a denture base acrylic resin. *Gerodontology* 2010;27:62-9.
 18. 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.
 19. Archadian N, Kawano F, Ohguri T, Ichikawa T, Matsumoto N. Flexural strength of rebased denture polymers. *J Oral Rehabil* 2000;27:690-6.
 20. Seo RS, Murata H, Hong G, Vergani CE, Hamada T. Influence of thermal and mechanical stresses on the strength of intact and relined denture bases. *J Prosthet Dent* 2006;96: 59-67.
 21. Reis JM, Vergani CE, Pavarina AC, Giampaolo ET, Machado AL. Effect of relining, water storage and cyclic loading on the flexural strength of a denture base acrylic resin. *J Dent* 2006; 34:420-6.