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Original Article

Bond Strength of Acrylic Denture Tooth to a Novel Thermo-Polymerized Denture Base Copolymer Containing Cycloaliphatic Comonomer after Mechanical and Thermal Aging

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ABSTRACT

Background: There are numerous artificial denture tooth materials available of which acrylic resin teeth were used widely. The resin teeth bond chemically to the denture base resin, and this bonding is affected by numerous intrinsic and extrinsic factors. The type of cross-linker in the denture base monomer is one such factor which has a questionable influence on the bond strength. Recently, cycloaliphatic comonomer was added in the methyl methacrylate monomer and the resultant novel copolymer possessed good physico-mechanical and biological properties. **Purpose:** The purpose of this study was to evaluate the shear bond strength (SBS) between acrylic denture tooth and resultant novel copolymer after cyclic loading and thermal aging. **Materials and Methods:** Sixty central incisor denture teeth were bonded to three types of acrylic denture base resin groups (n = 20 per group) categorized based on the presence of the cycloaliphatic comonomer – Control group (G0): denture bases without cycloaliphatic comonomer and trial groups G10 and G20 contain 10 vol.% and 20 vol.% comonomer, respectively, substituted in the denture base monomer component. The specimens were processed and subjected to cyclic loading and thermal aging which was then followed by SBS testing. **Results:** G20 possessed the highest SBS followed by G10. G0 had the least SBS. All the specimens of the control and trial groups exhibited adhesive–cohesive mixed failure at the resin tooth–base resin interface. **Conclusion:** The addition of cycloaliphatic comonomer increased the SBS between the resultant novel copolymer and the resin teeth after cyclic loading and thermal aging.

KEYWORDS: *Bond strength, comonomer, cross-linker, denture base, resin tooth*

INTRODUCTION

Denture base acrylic resins have been employed in the dental profession for the past 60 years. Although materials with surpassing properties available in the market, it still remains the gold standard.[1] However, debonding of acrylic teeth from its base resin is the most frequently encountered unresolved failure.[2-4] Approximately 22%–30% of all denture repairs are attributed to failed bond in the anterior region.[5] Factors affecting this bond include improper wax elimination from the ridge lap area of the teeth, impetuous application of the separating medium, monomer deficiency during processing, polymerization method employed, water sorption, coefficient of thermal expansion mismatch of teeth and base material, and porosity on the junction of denture base and teeth.[6-8] The physical and chemical properties of artificial teeth are effective in strengthening the bond to denture base resins.[1,9] On the other hand, this bond is affected by

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the physical and chemical properties of acrylic base resins,[10-12] polymerization temperature,[9] and the method of artificial tooth preparation.[11]

Another contributing factor for tooth debonding from the base is the formulation of the denture base materials wherein the cross-linking agents added in the methyl methacrylate (MMA) affect the bond strength.[13-15] Some researchers have reported that the addition of ethylene glycol dimethacrylate (EGDMA) produced no significant difference in the transverse bending properties of MMA-based resins,[14] whereas others have demonstrated that EGDMA had significant effects on transverse bending properties of denture base resins.[13] The changes in mechanical properties with increasing amounts of cross-linking agents have been attributed to the chain length and flexibility of the cross-linking agents used.

A recently identified cycloaliphatic cross-linking comonomer, tricyclodecane dimethanol diacrylate (TCDDMDA), has been copolymerized with P(MMA).[16,17] This novel copolymer P(MMA-*Co*-TCDDMDA) exhibited better mechanical properties and biocompatibility than the conventional P(MMA).[18-21] However, there is no literature concerning the bond strength of P(MMA-*Co*-TCDDMDA) copolymeric resin base to artificial teeth. There are different types of artificial teeth, including methacrylate resin, composite resin, and porcelain teeth, each with its advantages and disadvantages. Previous researches have demonstrated different results on the bond strength of artificial teeth to base resins which is influenced by the type of resin, teeth, and test methods.[22-25] However, in the conventional clinical practice, acrylic teeth remain the prime choice. Intraoral temperature fluctuations are the resultant of routine eating, drinking, and breathing, and can change the interface between the acrylic resin teeth and acrylic resin denture base.[26] Laboratory mimicking of *in vivo* service is often executed because clinical trials are costly and time-consuming.[27] Cyclic loading and artificial thermal aging are *in vitro* processes employed to simulate *in vivo* dynamic events. Hence, the present study aims to evaluate the shear bond strength (SBS) between acrylic denture tooth and P(MMA-*Co*-TCDDMDA) copolymer after cyclic loading and thermal aging. The null hypothesis is that the addition of TCDDMDA comonomer at 10% and 20% (vol/vol) concentrations in MMA would have no effect on the SBS of the resin tooth to base resin.

Materials and Methods

Sixty central incisor denture teeth (Ivostar®; Ivoclar Vivadent Inc., New York, USA) with three multiblended layers made of hardened cross-linked P(MMA) acrylic resin were employed for bonding three types of acrylic denture base resin groups (n = 20 per group): control group (G0) comprises thermo-polymerizable P(MMA) (DPI; Dental Products of India, Mumbai, India) and trial groups G10 and G20 contain 10 vol.% and 20 vol.% TCDDMDA comonomer (Sigma-Aldrich, St. Louis, MO, USA), respectively, substituted in P(MMA) monomer resulting in the formation of new copolymer P(MMA-*Co*-TCDDMDA).

Specimens were fabricated mimicking clinical condition following modified Japanese Industrial Standard (JSA-JIS T 6506, 1989; acrylic resin teeth – Japanese Standard Association). The teeth were embedded onto a surface of customized carving wax block (48 mm × 10 mm × 8 mm) with a 1-mm high cervical area so that the denture base area surrounding the teeth was waxed up circumferentially comprising the neck and the mesiodistal portions. In addition, the long axes of the teeth were adjusted to 45° to the wax block surface mesially and distally using a protractor [Figure 1]. The waxed models were acrylized or processed, finished, and polished by the method described elsewhere.[18] All the specimens were fabricated by a single investigator and stored in distilled water at 37°C for 24 h.

The specimens were subjected to 5000 cycles of load simulating 1 year of average human masticatory function with 5-kg load at a rate of 80 cycles/min in a chewing simulator (SD Mechatronik – CS-4.8; version 5.0e, Germany).[28] This is followed by artificial thermal aging in a weathering chamber (Envirotronics – C1500/-70; Weiss-Voetsch Environmental Testing Instruments [Taicang] Co., Ltd., Jiangsu, China) where the specimens were exposed to the ultraviolet-B light at 80 Wm^{-2} irradiance level. Specimens were aged by switching irradiation for 4 h at 5°C and 4 h at 55°C in 100%

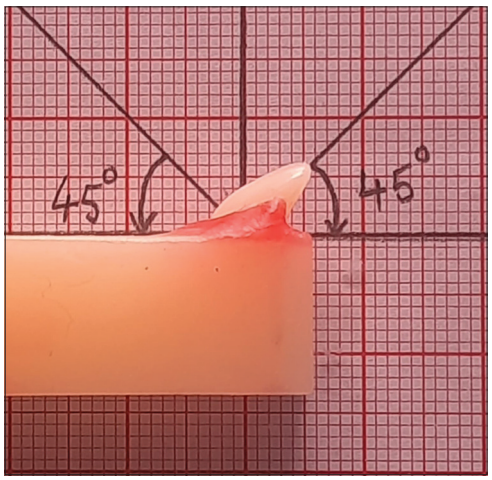


Figure 1: Wax block with resin tooth mounted at 45° inclination

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humidity. The specimens were treated with distilled water for 18 min every 102 min (American Society for Testing and Materials; ASTM test D2565).[29] Then, the SBS test was executed in a dynamic universal testing machine (Instron Electropuls E3000) with load applied to the palatal surface of the teeth at a crosshead speed of 0.5 mm/min [Figure 2].

For statistical analysis, the Statistical Package for the Social Sciences software (SPSS Inc., Chicago, IL, USA, version 21.0) was used. Kolmogorov–Smirnov test indicated that the data were normally distributed and the mean and standard deviation (SD) were calculated. The level of significance was tested with one-way analysis of variance followed by the *post hoc* Tukey's honestly significant multiple comparison tests ($\alpha = 0.05$). $P < 0.05$ was considered for statistical significance.

Results

The mean SBS and SD of the groups are tabulated in Table 1. There exists a statistically significant difference among the groups ($P = 0.000$). Table 2 describes the *post hoc* multiple comparisons where statistically significant difference existed between the compared groups (G0 vs. G10, G0 vs. G20, and G10 vs. G20) ($P = .000$). G20 possessed the highest SBS followed by G10. G0 had the least SBS. Therefore, the new copolymer *P*(MMA-*Co*-TCDDMDA) exhibited greater SBS than the conventional *P*(MMA). The failure interface was examined visually. All the specimens of the control and trial groups exhibited adhesive–cohesive mixed failure [Figure 3]. However, the cohered ridge lap portion of the teeth in the base acrylic differed among the groups. The cohered portion of the teeth was high for G20 specimens, followed by G10 and low for G0 specimens.

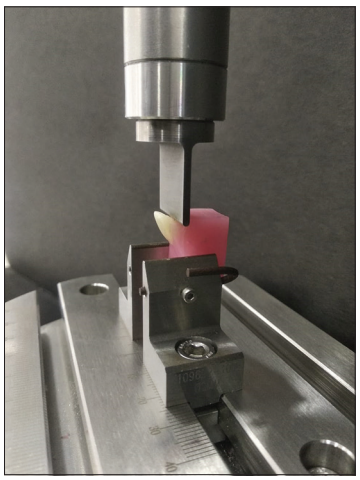


Figure 2: Resin tooth subjected to shear loading

Discussion

The results of this present research suggest that difference in the composition of denture base influenced the SBS to the denture teeth. The new P(MMA-*Co*-TCDDMDA) copolymer of the G20 group showed the highest SBS which is higher than the American National Standards/American Dental Association Specification (ANSI/ADA 15), International Organization for Standardization for synthetic resin teeth (ISO 3336), British Standard (BS 3990), South African Standard (SABS 1342), and finally, Japanese Standard for acrylic resin teeth (JIS T 6506).[2] Despite cyclic loading and artificial thermal aging, P(MMA-*Co*-TCDDMDA) copolymer of the G20 group exhibited the highest SBS with acrylic teeth, and thus, the null hypothesis was rejected. Although the SBS of G10 specimens was <G20, this reduction is attributed to the cyclic loading and thermal aging.

Higher the cross-linking, stronger the denture teeth, but weaker the bond strength.[30] The acrylic monomers in the

Table 1: One-way analysis of variance test for shear bond strength

Group	Mean (MPa)±SD	*P*
G0	23.93±0.06	0.000
G10	28.86±0.12	
G20	36.55±0.09	

SD: Standard deviation

Table 2: *Post hoc* Tukey's honestly significant difference test

Group	Compared group	Mean difference	Significant
G0	G10	−4.92650*	0.000
	G20	−12.61550*	0.000
G10	G20	−7.68900*	0.000

*The mean difference is significant at the 0.05 level

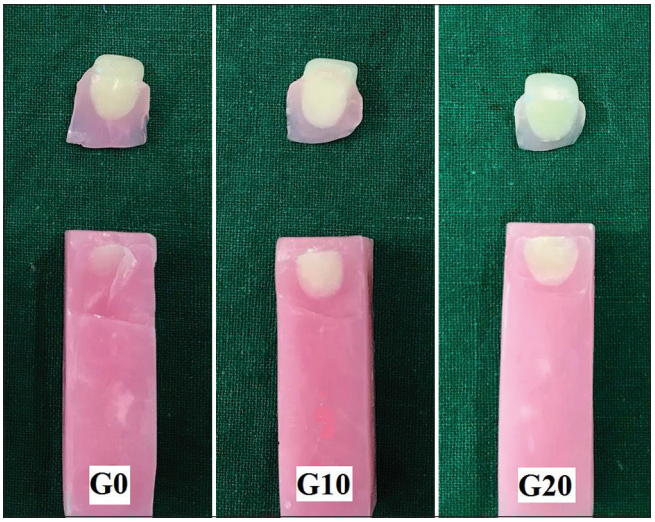


Figure 3: Adhesive–cohesive mixed failure

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dough stage have a pivotal role in establishing bonding between the teeth and the denture base. Therefore, the acrylic monomer ought to be efficacious in swelling the resin teeth's ridge lap region. Cross-linking during the processing of resin teeth lessens this swelling caused by MMA.[6,31] The cross-linked polymer matrix of a resinous tooth is commonly distributed unevenly, with the ridge lap region not as highly cross-linked as the incisal region.[31] The results of the present research can be attributable to two important factors. The first factor is the diffusion rate of MMA from the base resin matrix before thermo-polymerization. This diffusion rate is influenced by the polymerization temperature.[32] Early polymerization of the resinous dough after contacting the resin teeth would jeopardize the bonding.[5,9] The second contributing factor is the cross-linker present in the denture base monomer. The widely used cross-linker is EGDMA which not only diminishes crazing but also enhances the stiffness and hardness of the denture base.[13] Another cross-linker 1,4-butanediol methacrylate decreased the bond strength between the resin teeth and denture base when compared to EGDMA cross-linker which may be attributable to the type and quantity of the cross-linker in the denture base monomer.[15] In this present research, addition of TCDDMDA, a difunctional dual reactive cross-linker, increased the SBS. This is attributed to its unique steric hindrance property exclusively with the central tricyclic ringed group by which it slows the rate of polymerization and increases the dough's contact time with the resinous teeth, thereby permitting the monomer's diffusion. TCDDMDA comonomer not only slows the polymerization rate but also increases the degree of conversion. TCDDMDA complemented the thermo-polymerization by decreasing the residual monomer content.[16,17] The results of the present research unveiled that G0 specimens possessed the least bond strength values. This is attributable to the existence of residual monomer which exhibits a plasticizing effect, thereby deteriorating the mechanical properties of the acrylic resins and jeopardizing the resin tooth–base resin interfacial adhesion.[33]

The other testing standards mentioned elsewhere measure the resin tooth–base resin interfacial bond strength focusing primarily on the denture tooth material's strength and induce cohesive fractures.[34] Previous researches employed either flat and ground tooth surfaces bonded to base denture resin or unmodified ridge lap portion of the resinous teeth without encroaching the proximal, buccal, and lingual surfaces with denture base material.[4,7,12,26,30,35-39] These testing designs are not realistic, and furthermore, the load direction exerted varies completely from clinical scenario.[40] Therefore, resin teeth with compromised mechanical properties pass the test fortunately, however, only if the failure is partly adhesive, a rational measurement can be conjectured. Hence, in the present research, a more pragmatic design yielded a mixed adhesive–cohesive failure mode.

Some of the previous researches have concluded that thermocycling significantly affected the resin teeth–base resin bond strength[26,39] whereas others concluded that thermal aging did not affect the bond strength significantly.[41] Marra *et al*.[42] concluded that the resin tooth/base resin combinations can be adversely affected by thermocycling and the effects varied based on the materials or brands used. Therefore, in this research, all the specimens were subjected to artificial thermal aging. This may be the first probable research to employ cyclic loading in assessing the SBS since mechanical loads also definitely affect the bond strength. However, SBS of the loaded specimens was not compared with the nonloaded specimens which paves a way to future investigations. Additional researches may be executed concerning the various surface treatments of the resinous tooth.

Conclusion

Within the limitations of the present research, it can be concluded that the addition of TCDDMDA comonomer in MMA increased the SBS between the resultant novel P(MMA-*Co*-TCDDMDA) copolymer and the acrylic resin denture teeth after cyclic loading and thermal aging.

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Conflicts of interest

There are no conflicts of interest.

References

1. Cunningham JL. Shear bond strength of resin teeth to heat-cured and light-cured denture base resin. J Oral Rehabil 2000;27:312-6.
2. Patil SB, Naveen BH, Patil NP. Bonding acrylic teeth to acrylic resin denture bases: A review. Gerodontology 2006;23:131-9.
3. Darbar UR, Huggett R, Harrison A, Williams K. The effect of impurities on the stress distribution at the tooth/denture base resin interface. Asian J Aesthet Dent 1994;2:7-10.
4. Darbar UR, Huggett R, Harrison A. Denture fracture – A survey. Br Dent J 1994;176:342-5.
5. Huggett R, John G, Jagger RG, Bates JF. Strength of the acrylic denture base tooth bond. Br Dent J 1982;153:187-90.
6. Rupp NW, Bowen RL, Paffenberger GC. Bonding cold curing denture base acrylic resin to acrylic resin teeth. J Am Dent Assoc 1971;83:601-6.
7. Cunningham JL, Benington IC. An investigation of the variables which may affect the bond between plastic teeth and denture base resin. J Dent 1999;27:129-35.
8. Gharebagh TG, Hamedirad F, Miruzadeh K. Comparison of bond strength of acrylic, composite, and nanocomposite

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artificial teeth to heat-cure acrylic denture base resin. Front Dent 2019;16:166-72.
9. Büyükyilmaz S, Ruyter IE. The effects of polymerization temperature on the acrylic resin denture base-tooth bond. Int J Prosthodont 1997;10:49-54.
10. Adeyemi AA, Lyons MF, Cameron DA. The acrylic tooth-denture base bond: Effect of mechanical preparation and surface treatment. Eur J Prosthodont Restor Dent 2007;15:108-14.
11. Yanikoglu DN, Duymus DZ, Bayindir DF. Comparative bond strengths of autopolymerizing denture resin and light cured composite resin to denture teeth. Int Dent J 2002;52:20-4.
12. Thean HP, Chew CL, Goh KI. Shear bond strength of denture teeth to base: A comparative study. Quintessence Int 1996;27:425-8.
13. Arima T, Hamada T, McCabe JF. The effects of cross-linking agents on some properties of HEMA-based resins. J Dent Res 1995;74:1597-601.
14. Caycik S, Jagger RG. The effect of cross-linking chain length on mechanical properties of a dough-molded poly (methylmethacrylate) resin. Dent Mater 1992;8:153-7.
15. Korkmaz T, Dogan A, Dogan OM, Demir H. The bond strength of a highly cross-linked denture tooth to denture base polymers: A comparative study. J Adhes Dent 2011;13:85-92.
16. Ajay R, Suma K, JayaKrishnaKumar S, Rajkumar G, Kumar SA, Geethakumari R. Chemical characterization of denture base resin with a novel cycloaliphatic monomer. J Contemp Dent Pract 2019;20:940-6.
17. Ajay R, Suma K, Sasikala R, Sajidabegum S, Vignesh V, Bhuvaneshkumar D. Chemical structure and physical properties of heat-cured poly (methyl methacrylate) resin processed with cycloaliphatic comonomer: An *in vitro* study. J Contemp Dent Pract 2020;21:285-90.
18. Ranganathan A, Karthigeyan S, Chellapillai R, Rajendran V, Balavadivel T, Velayudhan A. Effect of novel cycloaliphatic comonomer on the flexural and impact strength of heat-cure denture base resin. J Oral Sci 2020;63:14-7.
19. Ajay R, Suma K, Rakshagan V, Ambedkar E, Lalithamanohari V, Sreevarun M. Effect of novel cycloaliphatic comonomer on surface roughness and surface hardness of heat-cure denture base resin. J Pharm Bioallied Sci 2020;12:S67-72.
20. Ajay R, Suma K, SreeVarun M, Balu K, Devaki V, Devi N. Evaluation of *In vitro* cytotoxicity of heat-cure denture base resin processed with a dual-reactive cycloaliphatic monomer. J Contemp Dent Pract 2019;20:1279-85.
21. Ajay R, Suma K, Arulkumar S, Mahadevan R, Ambedkar E, Biju KA. Histocompatibility of novel cycloaliphatic comonomer in heat-cured denture base acrylic resin: Histomorphometric analysis in rats. J Pharm Bioallied Sci 2020;12:S453-61.
22. Takahashi Y, Chai J, Takahashi T, Habu T. Bond strength of denture teeth to denture base resins. Int J Prosthodont 2000;13:59-65.
23. Ghahramani L, Shahabi S, Amirjan A, Fazel A. Comparison of bond strength of composite and acrylic teeth to heat-cured and auto-polymerized acrylic denture base. J Dent Med Tehran Univ Med Sci 2010;23:215-26.
24. Chittaranjan B, Taruna M, Sudheer N, Patil NS. Evaluation of shear bond strength of three different types of artificial teeth to heat cure denture base resin: An *in vitro* study. Indian J Dent Res 2013;24:321-5.
25. Papazoglou E, Vasilas AI. Shear bond strengths for composite and autopolymerized acrylic resins bonded to acrylic resin denture teeth. J Prosthet Dent 1999;82:573-8.
26. Barbosa DB, Barao VA, Monteiro DR, Compagnoni MA, Marra J. Bond strength of denture teeth to acrylic resin: Effect of thermocycling and polymerization methods. Gerodontology 2008;25:237-44.
27. Gale MS, Darvell BW. Thermocycling procedures for laboratory testing of dental restorations. J Dent 1999;27:89-99.
28. Ajay R, Suma K, Ali SA, Kumar Sivakumar JS, Rakshagan V, Devaki V, *et al.* Effect of surface modifications on the retention of cement-retained implant crowns under fatigue loads: An *in vitro* study. J Pharm Bioallied Sci 2017;9:S154-60.
29. May KB, Razzoog ME, Koran A 3rd, Robinson E. Denture base resins: Comparison study of color stability. J Prosthet Dent 1992;68:78-82.
30. Barpal D, Curtis DA, Finzen F, Perry J, Gansky SA. Failure load of acrylic resin denture teeth bonded to high impact acrylic resins. J Prosthet Dent 1998;80:666-71.
31. Vallittu PK, Ruyter IE, Nat R. The swelling phenomenon of acrylic resin polymer teeth at the interface with denture base polymers. J Prosthet Dent 1997;78:194-9.
32. Chung KH, Chung CY, Chung CY, Chan DC. Effect of pre-processing surface treatments of acrylic teeth on bonding to the denture base. J Oral Rehabil 2008;35:268-75.
33. Barbosa DB, de Souza RF, Pero AC, Marra J, Compagnoni MA. Flexural strength of acrylic resins polymerized by different cycles. J Appl Oral Sci 2007;15:424-8.
34. Lang R, Kolbeck C, Bergmann R, Handel G, Rosentritt M. Bond of acrylic teeth to different denture base resins after various surface-conditioning methods. Clin Oral Investig 2012;16:319-23.
35. Morrow RM, Matvias FM, Windeler AS, Fuchs RJ. Bonding of plastic teeth to two heat-curing denture base resins. J Prosthet Dent 1978;39:565-8.
36. Clancy JM, Boyer DB. Comparative bond strengths of light-cured, heat-cured, and autopolymerizing denture resins to denture teeth. J Prosthet Dent 1989;61:457-62.
37. Cardash HS, Liberman R, Helft M. The effect of retention grooves in acrylic resin teeth on tooth denture-base bond. J Prosthet Dent 1986;55:526-8.
38. Vallittu PK. Bonding of resin teeth to the polymethyl methacrylate denture base material. Acta Odontol Scand 1995;53:99-104.
39. Saavedra G, Neisser MP, Sinhoreti MA, Machado C. Evaluation of bond strength of denture teeth bonded to heat polymerized acrylic resin denture bases. Braz J Oral Sci 2004;3:458-64.
40. Bragaglia LE, Prates LH, Calvo MC. The role of surface treatments on the bond between acrylic denture base and teeth. Braz Dent J 2009;20:156-61.
41. Andrade de Freitas SL, Brandt WC, Miranda ME, Vitti RP. Effect of thermocycling, teeth, and polymerization methods on bond strength teeth-denture base. Int J Dent 2018;2018:2374327.
42. Marra J, de Souza RF, Barbosa DB, Pero AC, Compagnoni MA. Evaluation of the bond strength of denture base resins to acrylic resin teeth: Effect of thermocycling. J Prosthodont 2009;18:438-43.