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RESEARCH AND EDUCATION

Effect of layering gingiva-shade composite resin on the strength of denture base polymers

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ABSTRACT

Statement of problem. Acrylic resin denture base materials, fabricated with either a traditional technique or computer-aided design and computer-aided manufacturing (CAD-CAM) technique, layered with different thicknesses of gingiva-shade composite resin may affect the strength of the definitive prostheses and have not been investigated.

Purpose. The purpose of this in vitro study was to assess the flexural strength of acrylic resin denture base materials modified by layering different thicknesses of gingiva-shade composite resin.

Material and methods. Two denture acrylic resins, heat-polymerized type (Lucitone 199) and CAD-CAM prepolymerized type (AvaDent) polymethyl methacrylate (PMMA) resin, were used as the base materials. Three-millimeter–thick specimens were fabricated and prepared according to the ISO 1567 and ISO 20795-1:2013 and were used as the controls. A proprietary gingiva-shade composite resin (GRADIA gum shades) was used to replace different thicknesses (0.5 mm, 1.0 mm, and 1.5 mm) of the denture base materials, giving 4 groups for each tested material (n=16). A 3-point loading test was conducted by using a universal testing machine and a custom fixture with a crosshead speed of 5 mm/min. The maximum fracture loads were recorded, and ultimate flexural strength values were calculated. The collected data were statistically analyzed with ANOVA and the Tukey honestly significant difference (HSD) tests (α=.05). Representative fractured specimens were examined under a stereomicroscope at ×20 magnification and a scanning electron microscope to determine the interface and fracture patterns.

Results. The mean ±standard deviation of ultimate flexural strengths for the heat-polymerized acrylic resin specimens ranged from 94.79 ±9.89 MPa to 40.34 ±12.79 MPa, and that of the CAD-CAM prepolymerized acrylic resin ranged from 125.98 ±7.96 MPa to 64.16 ±20.77 MPa. Acrylic resin denture base materials after layering with gingiva-shade composite resin had a significantly lower mean fracture load than the controls (P<.05). The Tukey HSD test revealed that the control groups had significantly higher flexural strength values compared with the other tested specimens within each denture acrylic resin group layered with gingiva-shade composite resin (P<.05). The SEM images displayed brittle fracture exhibiting well-defined, flat, compact, and organized surface fractures.

Conclusions. The flexural strengths of CAD-CAM prepolymerized acrylic resins were higher than those of the heat-polymerized denture acrylic resins. The flexural strengths of all 3 thicknesses of the CAD-CAM prepolymerized acrylic resins were greater than 65 MPa. (J Prosthet Dent 2019;122:153.e1-e8)

The soft tissue contour and color are as important to dental esthetics as the shape, color, and overall appearance of the teeth.[1,2] Complete dentures should provide not only masticatory function but also an esthetic dental appearance, including natural gingival contours and shades that harmonize with the surrounding oral soft tissue. Improving denture esthetics includes intrinsic blending of polymethyl methacrylate (PMMA) resins, extrinsic photopolymerized resins, or, more recently, gingival-shade composite resins.[3-6] Also, the excellent mechanical properties of denture resins, especially flexural strength, are essential and mostly depend on the

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Clinical Implications

Layering acrylic denture material with gingiva-shade composite resin to enhance the esthetics of denture base is an option. The addition of gingiva-shade composite resin to enhance the esthetics of denture base resin can be used if applied as thinly as 1.5 mm to the CAD-CAM prepolymerized denture acrylic resin.

type of the material used.[7] Traditional heat-polymerized denture acrylic resin provides favorable working characteristics, acceptable physical and esthetic properties, ease of fabrication, and low cost.[8]

Computer-aided design and computer-aided manufacturing (CAD-CAM) has become popular for complete denture fabrication.[9] The use of prepolymerized PMMA resin blocks, computer software, and 5-axis milling devices allow for CAD-CAM denture bases with fewer microporosities, resulting in improved mechanical properties when compared with traditionally fabricated acrylic resins.[9-14]

Although research has been published comparing the flexural strengths of acrylic resin denture base materials fabricated with either a traditional technique or CAD-CAM,[15] the authors are unaware of research comparing the flexural strengths of homogenous denture base materials with denture bases layered with different thicknesses of gingiva-shade composite resin. The purpose of this in vitro study was to measure the flexural strength of acrylic resin denture base materials, replacing denture base polymers with layers of different thicknesses of gingiva-shade composite resin. The null hypothesis was that no significant differences would be found in the flexural strength values of acrylic resin denture base materials with and without layering with the gingiva-shade composite resin.

MATERIAL AND METHODS

Two different acrylic denture base materials, heat-polymerized type (Lucitone 199; Dentsply Sirona) and prepolymerized denture acrylic resin (AvaDent; Global Dental Science), were evaluated. The sample size was determined by a pilot study and power analysis. (α=.05, β=.80). Sixteen specimens per group were needed for a 20% effect size change to represent a clinically significant difference in flexural strength values.

The 64 specimens of each denture base material were fabricated and allocated to 4 groups (n=16) (Fig. 1). A proprietary gingiva-shade composite resin (GRADIA GUM shades; GC America) was used to replace different thicknesses (0.5 mm, 1.0 mm, and 1.5 mm) of acrylic resin denture resin materials. The groups evaluated were LUC, heat-processed acrylic resin 3.0-mm control group; LG05, 2.5-mm heat-processed acrylic resin with 0.5-mm gingival resin material; LG10, 2.0-mm heat-processed acrylic resin with 1.0-mm gingival resin material; LG15, 1.5-mm heat-processed acrylic resin with 1.5-mm gingival resin material; CAM, prepolymerized acrylic resin 3.0-mm control group; CG05, 2.5-mm prepolymerized acrylic resin with 0.5-mm gingival resin material; CG10, 2.0-mm prepolymerized acrylic resin with 1.0-mm gingival resin material; CG15, 1.5-mm prepolymerized acrylic resin with 1.5-mm gingival resin material.

Three-millimeter–thick acrylic resin base specimens were fabricated according to the ISO 1567 and ISO 20795-1:2013 and were used as the controls.[16,17] Acrylic resin plates with dimensions of 64×40×3 mm, 64×40×2.5 mm, 64×40×2.0 mm, and 64×40×1.5 mm were fabricated with the compression molding technique.[7] The acrylic resin plates were embedded in a flask with Type III dental stone (Denstone Golden; Kulzer GmbH) and mixed according to the manufacturer's instructions. The liquid-to-powder ratio of the heat-polymerized acrylic resin (Lucitone 199; Dentsply Sirona) was 10 mL of monomer to 21 g of powder. The acrylic resin was mixed according to the manufacturer's recommendations and packed in the flask.

The polymerization cycle for the denture base resin was processing the resin at 74 °C for approximately 2 hours and increasing the temperature of the water bath to 100 °C and processing for 1 hour. After polymerization, the polymerization flask was bench-cooled to room temperature, and the specimens were deflasked. Preparation of the heat-polymerized acrylic resin test specimens in accordance with ISO20795-1:2013[17] required sectioning the heat-polymerized acrylic resin groups to dimensions of 32×10×3 mm, 32×10×2.5 mm, 32×10×2.0 mm, and 32×10×1.5 mm by using a thin diamond-coated disk (987P.104.480; Komet Dental) as measured with digital calipers (Absolute Digimatic; Mitutoyo). The CAD-CAM specimens were milled to 32×10×3 mm, 32×10×2.5 mm, 32×10×2.0 mm, and 32×10×1.5 mm from prepolymerized acrylic resin pucks (AvaDent Digital Dental Solution) by using a 5-axis milling machine (DWX-51D; Roland). All specimen surfaces were smoothed by wet grinding with metallographic grinding papers (320-, 400-, and 600-grit silicon carbide paper).

By using a 3-mm control specimen, a silicone mold (Aquasil Ultra Monophase; Dentsply Sirona) was created to provide a standardized 3-mm thickness for bonding and layering the gingival resin (GRADIA gum shades). The surfaces of the denture base resin specimens were roughened with a tungsten carbide bur (H21LR, Komet USA LLC), and a thin coat of primer (GRADIA Primer) was applied to coat the prepared surfaces and photopolymerized for 1 minute in a

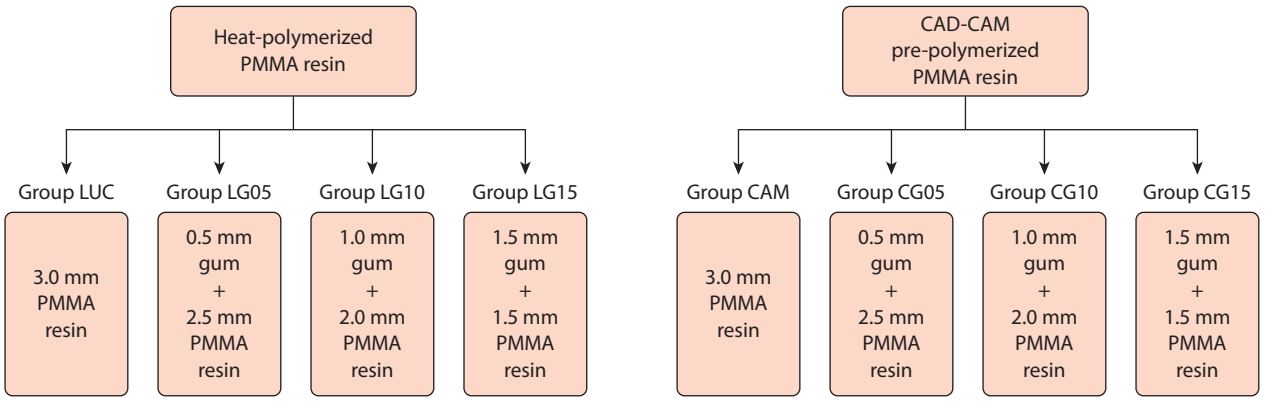

Figure 1. Chart of experimental design protocol (n=16) of 2 different acrylic resin denture base fabrication methods, heat-polymerized, and computer-aided design and computer-aided manufacturing, with and without addition of GRADIA GUM gingival resin. CAD-CAM, computer-aided design and computer-aided manufacturing; CAM, prepolymerized acrylic resin 3.0-mm control group; CG05, 2.5-mm prepolymerized acrylic resin with 0.5-mm gingival resin material; CG10, 2.0-mm prepolymerized acrylic resin with 1.0-mm gingival resin material; CG15, 1.5-mm prepolymerized acrylic resin with 1.5-mm gingival resin material; LG05, 2.5-mm heat-processed acrylic resin with 0.5-mm gingival resin material; LG10, 2.0-mm heat-processed acrylic resin with 1.0-mm gingival resin material; LG15, 1.5-mm heat-processed acrylic resin with 1.5-mm gingival resin material; LUC, heat-processed acrylic resin 3.0-mm control group; PMMA, polymethyl methacrylate.

photopolymerizing unit (Triad 2000; Dentsply Sirona). By using the silicone mold, the gingiva-shade composite resin (Shade G24) replaced the different thicknesses in increments of 0.5 mm, 1.0 mm, and 1.5 mm on the denture acrylic resin specimens by using a silicone point applicator until the overall specimen thickness of approximately 3 mm was reestablished. The specimens were then photopolymerized for 3 minutes in a photopolymerizing unit (Triad 2000; Dentsply Sirona). Metallographic grinding papers (320-, 400-, and 600-grit silicon carbide papers) were used to smooth and flatten all specimens to the required dimensions (32×10×3 mm) in accordance with the ISO 20795-1:2013.[17] The specimen plates were stored in a water bath at a temperature of 37 ±1 °C for 50 ±2 hours before the 3-point loading test, which was conducted by using a universal testing machine and a custom fixture with a crosshead speed of 5 mm/min according to the ISO 20795-1:2013.[17] Each specimen was oriented with the denture acrylic resin facing towards the custom fixture and the gingival resin veneer facing downwards. The maximum loads at fracture were recorded, and the ultimate flexural strength was calculated from the following equation:

Ultimate Flexural Strength = $3FL/2BH^2$, where F is the maximum load applied on the specimen, L is the distance between the supports, B is the width at the center of the specimen, and H is the height at the center of the specimen.

Representative fractured specimens were examined under a stereomicroscope (SZH-10; Olympus Corp) at ×20 magnification and a scanning electron microscope (SEM) (JSM-6010PLUS/LA; JEOL) to determine the interface and fracture patterns. The failure modes were classified as cohesive, adhesive, or mixed. A cohesive type was when fracture of the specimen occurred in either the acrylic resin base or gingival resin veneer while the 2 materials maintained their adhesive bonding. An adhesive type failure occurred at the adhesive interface of the acrylic resin base and gingival resin veneer while neither material fractured. A mixed failure was a mixed cohesive and adhesive failure in which a combination of failures occurred.

The data were statistically analyzed with software (IBM SPSS Statistics, v20; IBM Corp). After assessing normality and homoscedasticity with the Shapiro-Wilk and Levene tests (α=.05), flexural strength values were submitted to a 2-way ANOVA model. Nonparametric Kruskal-Wallis and Mann-Whitney U tests were used to analyze the failure mode data (α=.05).

RESULTS

The results are shown in Figure 2. The mean ±standard deviations (SDs) of ultimate flexural strengths for the heat-polymerized acrylic resin specimens ranged from 40.34 ±12.79 MPa for the group LG15 to 94.79 ±9.89 MPa for the group LUC. The mean ±SD of ultimate flexural strengths for the prepolymerized acrylic resin specimens ranged from 64.16 ±20.77 MPa for the group CG15 to 125.98 ±7.96 MPa for the group CAM. Acrylic resin denture base materials after layering with gingival resin had a significantly lower mean fracture load than the controls (P<.05).

The 2-way ANOVA results for the flexural strength test are presented in Table 1. Significantly lower flexural strength values were found for each tested denture base group after layering with gingival resin (P<.001) when compared with their controls. The Tukey HSD test

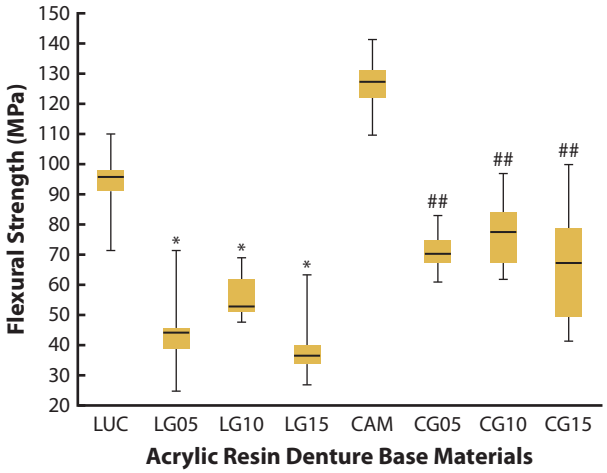

Figure 2. Boxplots of flexural strength values (MPa). *Significant differences ($P<.05$) with respect to control group LUC. ##Significant differences ($P<.05$) with respect to control group CAM. CAM, prepolymerized acrylic resin 3.0-mm control group; CG05, 2.5-mm prepolymerized acrylic resin with 0.5-mm gingival resin material; CG10, 2.0-mm prepolymerized acrylic resin with 1.0-mm gingival resin material; CG15, 1.5-mm prepolymerized acrylic resin with 1.5-mm gingival resin material; LG05, 2.5-mm heat-processed acrylic resin with 0.5-mm gingival resin material; LG10, 2.0-mm heat-processed acrylic resin with 1.0-mm gingival resin material; LG15, 1.5-mm heat-processed acrylic resin with 1.5-mm gingival resin material; LUC, heat-processed acrylic resin 3.0-mm control group.

revealed that the control groups, group LUC and group CAM, had significantly higher flexural strength values compared with the other tested specimens in each denture base group layered with gingival resin ($P<.05$). No statistically significant interactions were found between acrylic resin denture materials and different thicknesses of layered gingiva-shade composite resin ($F=1.68$, $P=.17$).

The occurrence of the type of fracture and the percentage of failure modes for heat-polymerized acrylic resin, the prepolymerized acrylic resin specimens, and the gingival resin-layered specimens are shown in Table 2. No adhesive failures were found in any of the test groups. Optical microscopic observation revealed that most fractures were cohesive for both the heat-polymerized and prepolymerized acrylic resin specimens of the controls. The fractures were classified as brittle because all the fracture fragments presented a smooth fracture surface and could be completely repositioned at the fracture line.

The SEM images showed that the heat-polymerized and prepolymerized acrylic resin materials displayed brittle fractures with well-defined, flat, compact, and organized surface fractures (Figs. 3-7), whereas the gingival resin exhibited disorganized and jagged surfaces. In addition, the SEM micrographs revealed spherical PMMA microspheres (Fig. 3) and air bubble voids, existing mostly in the gingival resin material (Figs. 5-7).

Table 1. Two-way ANOVA

Source	SS	df	MS	F	P
Base material	1776.97	1	1776.97	113.78	<.001
Design	67634.51	3	22544.84	144.3	<.001
Base material×design	786.46	3	262.15	1.68	.175
Error	18748.54	120	156.24	—	—

Table 2. Percentage of failure modes for heat-polymerized acrylate resin and prepolymerized acrylate resin test groups

Group	Cohesive (%)	Adhesive (%)	Mixed (%)
LUC	100	None	None
LG05	87.5	0	12.5
LG10	87.5	0	12.5
LG15	0	0	100
CAM	100	None	None
CG05	62.5	0	37.5
CG10	43.8	0	56.2
CG15	62.5	0	37.5

CAM, prepolymerized acrylic resin 3.0-mm control group; CG05, 2.5-mm prepolymerized acrylic resin with 0.5-mm gingival resin material; CG10, 2.0-mm prepolymerized acrylic resin with 1.0-mm gingival resin material; CG15, 1.5-mm prepolymerized acrylic resin with 1.5-mm gingival resin material; LG05, 2.5-mm heat-processed acrylic resin with 0.5-mm gingival resin material; LG10, 2.0-mm heat-processed acrylic resin with 1.0-mm gingival resin material; LG15, 1.5-mm heat-processed acrylic resin with 1.5-mm gingival resin material; LUC, heat-processed acrylic resin 3.0-mm control group.

DISCUSSION

The flexural strength of a material reflects its potential to resist catastrophic failure under a transverse load and is considered one of the most important mechanical properties of acrylic denture base materials.[7] The 3-point loading test determines both the strength of the material indicated and the amount of distortion expected and is the most common technique of measuring the flexural properties of denture bases.[18-20] The flexural strength of Type 1 denture base polymers, processed and polymerized with any method, should be no less than 65 MPa.[17] The results of this in vitro study indicated that the addition of composite resin while reducing the thickness of acrylic resin significantly decreases the overall flexural strength values. Therefore, the null hypothesis that no significant differences would be found in the flexural strength values of acrylic resin denture base materials before and after replacing and layering with the gingival resin material was rejected.

Although significant differences in mean flexural strengths were found when comparing control groups LUC (94.46 MPa) and CAM (125.98 MPa) with groups CG05 (70.77 MPa), CG10 (76.59 MPa), and CG15 (67.71 MPa), the mean flexural strengths for groups CG05, CG10, and CG15 still met the minimum flexural property requirement of 65 MPa. However, the mean flexural strengths for groups

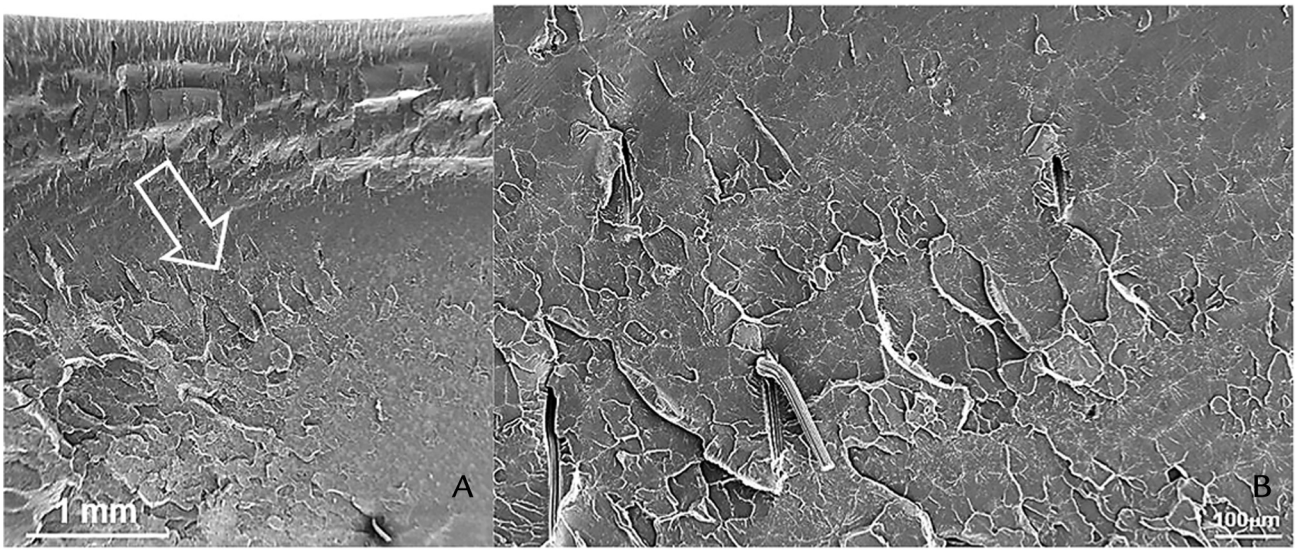

Figure 3. Scanning electron microscope images of representative fracture surface of AvaDent CAD-CAM prepolymerized denture base resin specimen. A, *White arrow* indicates plane, compact, and organized surface, original magnification ×20. B, Acrylic resin failure by transgranular or transcrystalline fractures, original magnification ×100.

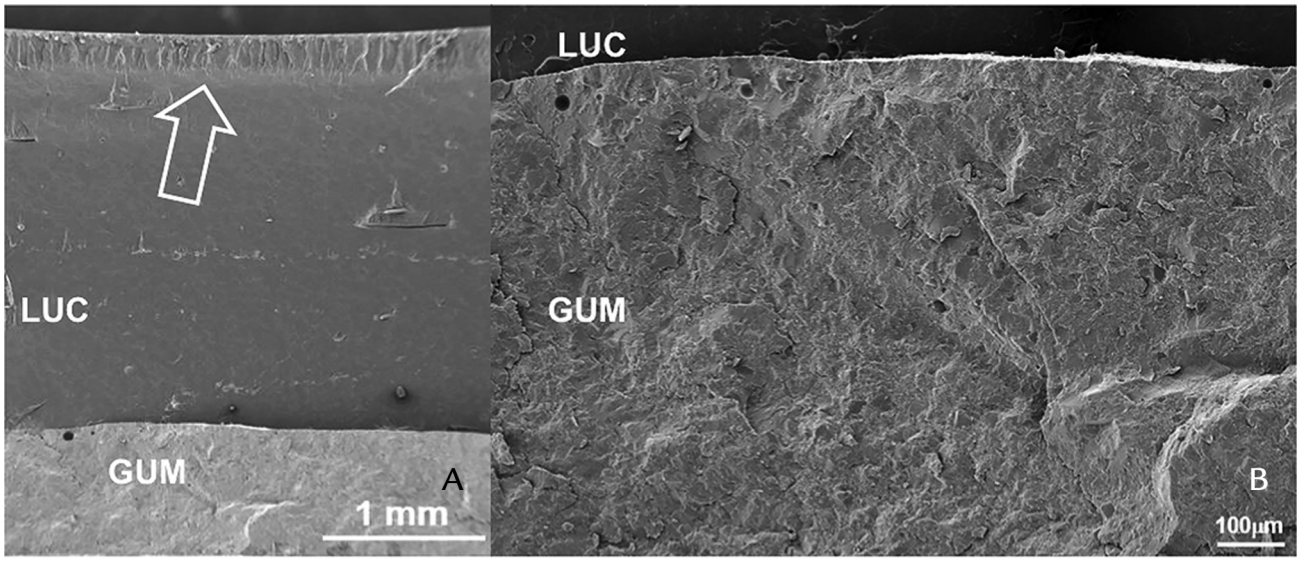

Figure 4. Scanning electron microscope images of representative fracture surface of LG10 specimen. A, *White arrow* indicates propagation of small cracks along compressed acrylic resin base, original magnification ×20. B, Jagged surface in gingival resin material. Original magnification ×100. GUM, gingival resin material, 1.0 mm in thickness; LUC, Lucitone 199 heat-polymerized denture base resin, 2.0 mm in thickness.

LG05 (47.02 MPa), LG10 (55.56 MPa), and LG15 (38.66 MPa) all failed to meet the minimum flexural property requirements for Type 1 denture base polymers. The maximum molar and premolar occlusal forces in complete denture wearers approximate 55 N,[21] decreasing to 40 N in complete denture wearers with severe mandibular resorption.[21] In the current study, in group LG15 with 1.5-mm–thick gingival resin layering on 1.5-mm–thick heat-polymerized denture resin, the mean fracture load was 84.4 N. This value still exceeds the occlusal force of complete denture wearers. Clinically, an acrylic resin denture base material with a higher flexural strength may be less inclined to fracture during function. Therefore, denture success depends on selecting the appropriate material for the clinical situation.

The results of this study indicate that the flexural strength values of the prepolymerized CAD-CAM acrylic resin groups are higher than those of the heat-polymerized resin groups and agree with the findings reported by Alp et al.[15] The higher degree of polymerization with low residual monomer content, higher

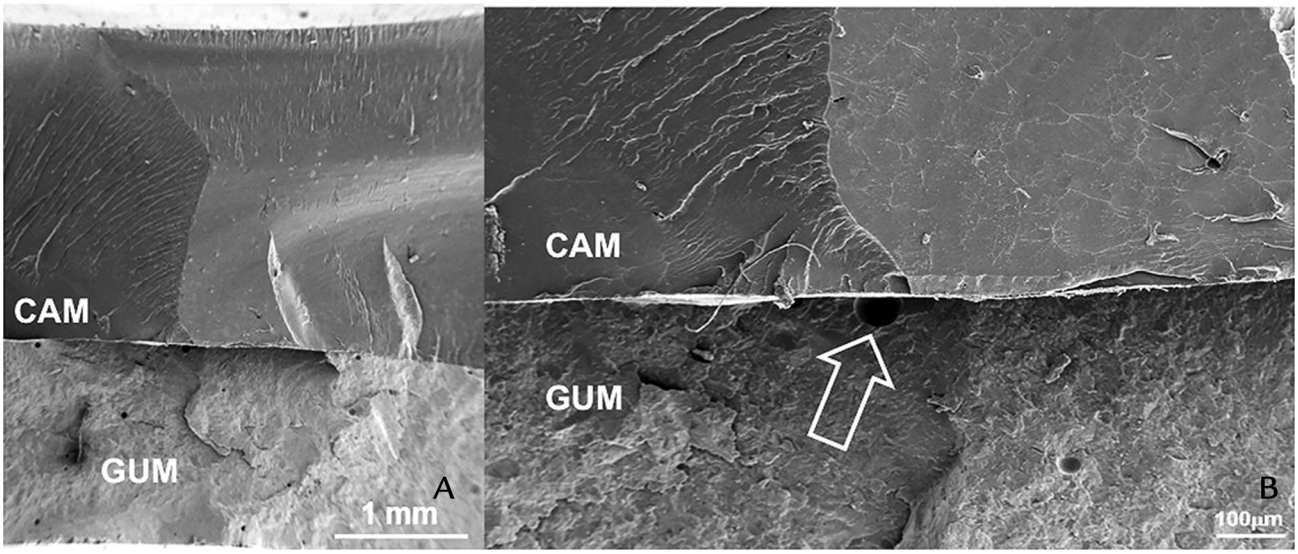

Figure 5. Scanning electron microscope images of representative fracture surface of CG10 specimen. A, Fracture line propagating from acrylic resin through composite resin interface, original magnification ×20. B, *White arrow* indicates air bubble along acrylic resin and composite resin interface, presenting near crack propagation, original magnification ×100. CAM, AvaDent CAD-CAM prepolymerized denture base resin specimen, 2.0 mm in thickness; GUM, gingival resin material, 1.0 mm in thickness.

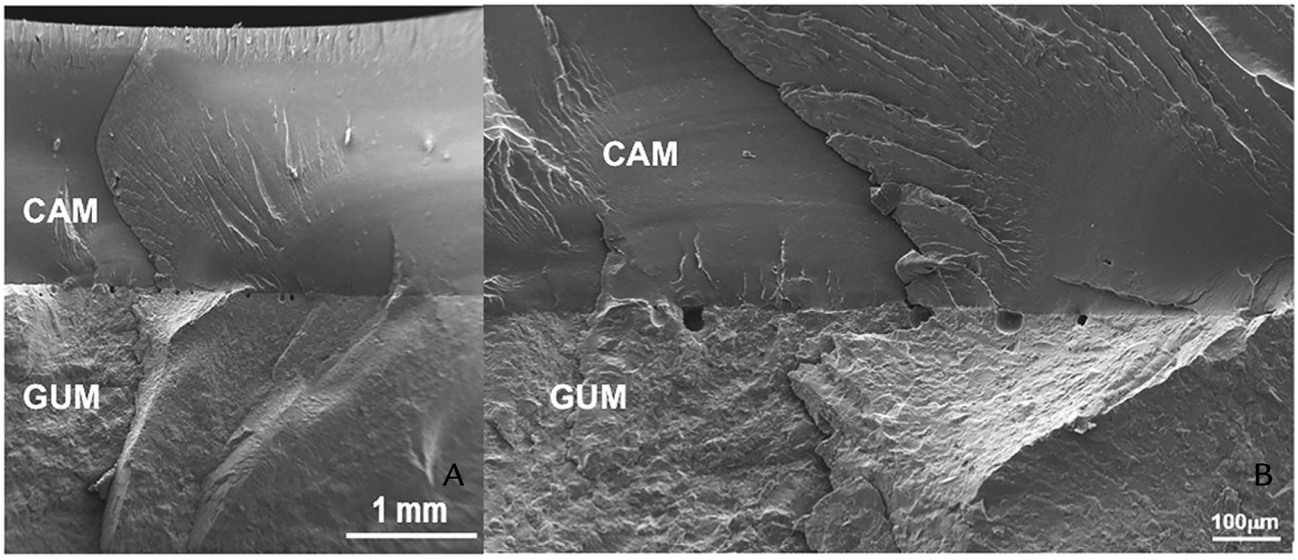

Figure 6. Scanning electron microscope images of representative fracture surface of CG15 specimen. A, Brittle fracture surface of prepolymerized resin shows plane, compact, and organized surface, original magnification ×20. B, Crack propagation near air bubble along acrylic resin and composite resin interface, original magnification ×100. CAM, AvaDent CAD-CAM prepolymerized denture base resin specimen, 1.5 mm in thickness; GUM, gingival resin material, 1.5 mm in thickness.

condensation, and reduced porosity of the prepolymerized acrylic resin may explain these findings.[15,22,23] Ayman[23] reported that CAD-CAM manufactured denture base resin had a significantly higher flexural modulus than heat-polymerized PMMA. The residual monomer content in denture base resins after processing was measured with gas chromatography, and the residual monomer content in prepolymerized CAD-CAM PMMA resin was found to be significantly lower than in heat-polymerized denture base resin. The author suggested that the lower concentration of residual MMA monomer in the CAD-CAM denture resin explains the higher flexural modulus of CAD-CAM compared with heat-polymerized denture acrylic resin.[23]

Denture bases are loaded under compression or impact and fracture when the maximum mechanical capacity of the material is exceeded.[24] In the flexural strength test, the specimens are oriented with the acrylic

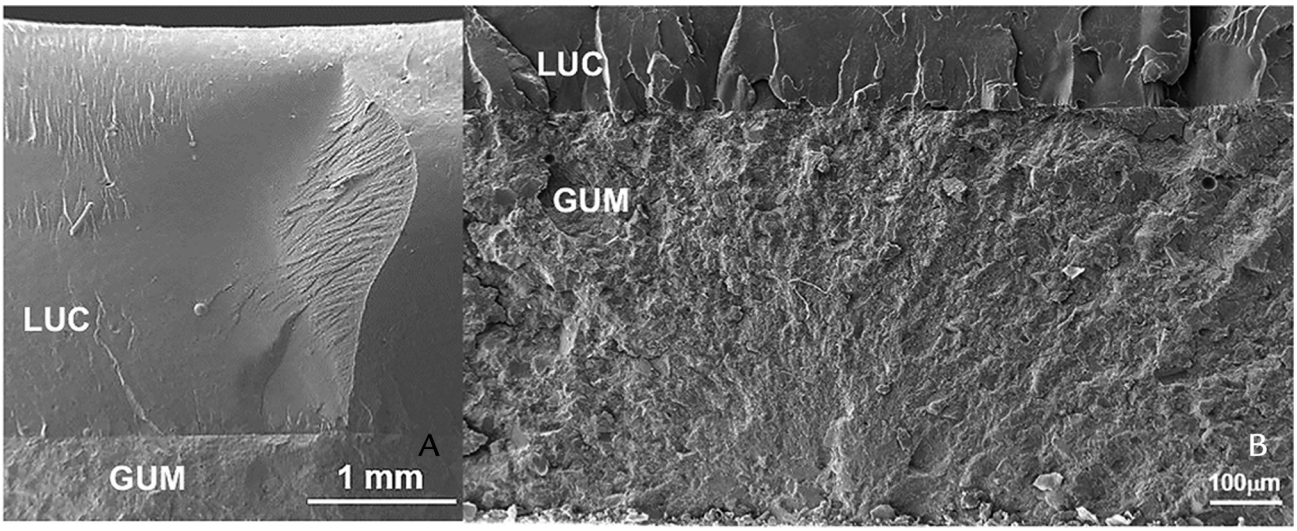

Figure 7. Scanning electron microscope images of representative fracture surface of LG05 specimen. A, Brittle fracture surface of heat-polymerized resin shows plane, compact, and organized surface, original magnification ×20. B, Irregularities of composite resin fracture generated by tensile forces, appearing less brittle compared with surface within acrylic resin fractures, original magnification ×100. GUM, gingival resin material, 0.5 mm in thickness; LUC, Lucitone 199 heat-polymerized denture base resin, 2.5 mm in thickness.

resin subjected to compressive forces. The layered gingival resin was therefore subjected to tensile force during testing. The mode of fracture differed among the groups. All specimens for both control groups had only catastrophic failures because of the uniformity of the denture base resin material. The occurrence of cohesive type fractures was more prevalent for the heat-polymerized acrylic resin groups compared with the prepolymerized groups (Table 2). Although the surface of specimens was standardized before composite resin application, the difference in fracture type could be explained by the homogenous, more condensed, and less porous microstructure of the CAD-CAM prepolymerized acrylic resins. The lower concentration of residual monomer content in the CAD-CAM prepolymerized acrylic resin surface may also contribute to a weaker bonding interface. The LG15 specimens had mixed cohesive and adhesive failure, possibly because the 1.5 mm of heat-processed acrylic resin was too thin and the compressive forces led to debonding and eventual fracture of both materials.

Whether the decrease in denture acrylic resin thickness played the primary role in lowering the flexural strength values for groups layered with gingival resin material is unclear. All data collected from the 3-point loading test were input into the equation to calculate the ultimate flexural strength for different thicknesses. The variables in the equation are as follows: F represents the force on the specimen, B is the width at the center of the specimen, and H is the height at the center of the specimen. If the heights of the acrylic denture resin of each specimen group are changed from the 3 mm of the controls to the 2.5 mm, 2.0 mm, and 1.5 mm of the tested groups, the theoretical ultimate flexural strength values of 100% from the 3-mm baseline value will decrease approximately 30.6%, 55.6%, and 75.4%, respectively. However, in the current study, the results do not support these changes because the addition of the gingival resin to the altered acrylic resin test groups restores the overall thickness of each specimen to 3 mm. Nevertheless, the results of the study indicated that the nonhomogenous specimens (experimental groups) were weaker in ultimate flexural strength compared with the homogenous denture base resin control groups. The application of the gingival resin not only enhances the esthetics of the denture base but also introduces flaws or air bubbles at the denture base resin and composite resin-bonding interface and is the primary cause of weakened specimens.

The heat-polymerized acrylic resin had a microstructure with larger granules compared with the prepolymerized acrylic resin. The microstructure of brittle fractures (Fig. 3) in both the heat-polymerized and prepolymerized acrylic resins were similar, indicating that the acrylic resin failed by transgranular or transcrystalline fracture.[25,26] During the 3-point loading test, the compressive forces were generated at the middle of the upper surfaces of the specimens, and crazing can be seen along the compressed acrylic resin base subsurface (Fig. 4). Air bubbles could be seen along the acrylic resin and composite resin-bonding interface, and cracks were seen near or through these air bubbles for both the acrylic resin and composite resin specimens (Figs. 5, 6). In contrast, tensile forces were generated at the middle of the lower surfaces of the specimens, and the propagation of small cracks could be seen along the composite

resin. Irregularities of the composite resin fractures could be seen, but the fracture pattern appeared less brittle than the acrylic resin fractures. The bonding interface of the composite resin into the acrylic resin appeared to be an intimate integration indicated by the arrow in Figure 7.

The limitations of the current study include the lack of cyclic loading and thermocycling before the loading test, conditions which may better simulate the intraoral situation.[27] Future studies should evaluate other mechanical properties such as the impact strength and fracture toughness of these materials.

CONCLUSIONS

Based on the findings of this in vitro study, the following conclusions were drawn:

1. The flexural strength of the CAD-CAM prepolymerized acrylic resins was higher than that of the conventional heat-polymerized acrylic resins.
2. The addition of gingival resin to enhance esthetics for denture base can be used if applied to a maximum of 1.5 mm to the CAD-CAM prepolymerized denture resin.
3. The flexural strengths of all 3 thicknesses of the CAD-CAM prepolymerized denture resin were greater than 65 MPa.

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