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RESEARCH AND EDUCATION

Effect of surface treatment on the repair strength of a 3D printed denture base material

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ABSTRACT

Statement of problem. The increasing adoption of 3-dimensional (3D) printing in prosthetic dentistry necessitates a comprehensive understanding of how different surface treatments influence the repair strength of 3D printed denture base materials to enhance clinical outcomes. While 3D printing offers significant advantages in fabrication efficiency and customization, concerns persist regarding the mechanical properties and durability of 3D printed materials. Despite its clinical significance, only limited information regarding the repair strength of 3D printed denture bases is available in the literature.

Purpose. The purpose of this in vitro study was to evaluate the effect of different surface treatments on the flexural strength of a repaired 3D printed denture base material.

Material and methods. Bar-shaped specimens (65×10×3.2 mm) of a 3D printed denture base material (V-Print dentbase) were printed, postpolymerized, and submitted to Fourier transform infrared (FTIR) spectrometry to determine the degree of C═C conversion (DC%). Eighty-one specimens were assigned to 9 test groups. Sectioned specimens with a 4-mm gap were allocated equally based on the repair surface treatment to the following groups: no treatment (NT), monomer (MN), multiprimer (G-MP), triethylene glycol dimethacrylate (TEGDMA), airborne-particle abrasion (APA), 180-grit paper roughening (180 G), 180 G plus silane (180 G+CB), and bonding agent (SB). Specimens were repaired with an autopolymerizing resin and stored in water for 30 days before testing with a 3-point bend test. Flexural strength data (MPa) were analyzed using the Shapiro-Wilk test (α=.05). Failure modes were classified, and surface-treated specimens were examined using scanning electron microscopy (SEM).

Results. The investigated V-Print dentbase material displayed a high DC (89%). The flexural strength of the intact group was significantly higher than that of all repaired groups ($P<.05$). The 180 G+CB group achieved the highest repair flexural strength, significantly surpassing that of the NT group ($P=.008$).

Conclusions. Using 180-grit paper combined with silane significantly improved the repair flexural strength of the investigated 3D printed denture base material, while other treatments showed no significant improvement. (J Prosthet Dent xxxx;xxx:xxx-xxx)

The advancement of digitally assisted denture fabrications through computer-aided design and computer-aided manufacturing (CAD-CAM) has significantly transformed clinical practice.[1] CAD-CAM addressed several key limitations associated with traditionally processed polymethyl methacrylate (PMMA), offering enhanced precision, improved patient comfort, streamlined workflows, and improved data storage options for the straightforward replication and archiving of dental prostheses.[1,2] Additive manufacturing (AM), commonly referred to as 3-dimensional (3D) printing, and subtractive manufacturing (SM) have emerged as the 2 main CAD-CAM techniques. AM builds structures through layer-by-layer deposition of material, thereby enabling

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Clinical Implications

None of the investigated surface treatments restored the original flexural strength of intact specimens or reached clinically acceptable standards for denture base materials. This study highlights the need for developing more effective repair surface treatments and strategies for 3D printed denture base materials to provide better clinical outcomes.

highly customized designs and minimizing material waste. SM precisely mills prostheses from solid blocks, resulting in products with high strength and resistance to distortion. Both techniques aim to produce digitally assisted dentures with optimal retention, stability, support, and adaptation to intraoral tissues.[2,3]

Despite the workflow and customization advantages offered by 3D printing, a critical consideration for widespread clinical adoption lies in the mechanical properties of the printed materials. Current research has indicated that additive manufactured denture bases may exhibit reduced flexural strength, fracture toughness, and color stability when compared with milled or conventionally processed dentures.[4] While most of the investigated 3D printed denture base materials meet the International Organization for Standardization (ISO) 1567 standard[5] for the flexural strength of denture base resins (≥65 MPa),[6–8] some studies[9,10] have reported lower values, with the performance influenced by resin chemistry, printing parameters, and postpolymerizing protocols.[11–13] Also, some 3D printed denture base resins have displayed lower impact strength because of the postpolymerization step.[14,15] For repaired dentures, the flexural strength varies with the repair technique and material used.[16] For instance, Viotto et al[10] reported a repair strength of 15.5 MPa for a 3D printed denture base, while 51.1 MPa was reported by Neshandar Asli et al.[15]

Denture fracture and chipping have been reported to be recurring clinical complications necessitating effective repair techniques that are straightforward to perform, affordable, and able to restore sufficient strength.[15] Autopolymerizing resins have been commonly used as a repair material because of their ease of application.[17–23] However, a significant challenge arises from the weak bonding at the interface between the repair resin and denture base, leading to the high vulnerability of repaired prostheses to refracture.[15,24] To address this, different surface treatment protocols have been developed, broadly categorized into mechanical[24–26] and chemical.[26–29] Mechanical roughening protocols such as bur roughening[30] or airborne-particle abrasion with alumina oxide of various sizes[15,26,28,30,31] or laser application[15] aimed to increase the bonding area for micromechanical interlocking. Chemical treatments such as methyl methacrylate (MMA) monomer,[26,29,32] acetone,[21] and tetrahydrofuran[31] have been also tested.

Monomer or solvent surface treatment is mainly applied to partially dissolve the surface of the existing resin, allowing for the penetration of monomer from the repair resin and promoting adhesion through a secondary semi-interpenetrating polymer network (semi-IPN) formation between existing and new polymer chains.[33–37] The process of polymer dissolution occurs in 2 stages: initially, solvent molecules penetrate the polymer, causing it to swell into a gel. Subsequently, the gel breaks down, and the molecules diffuse into the solvent-rich areas. Linear amorphous polymers can dissolve completely, while cross-linked polymers only swell without fully dissolving.[33] However, most studies on the repair of 3D printed dentures have been undertaken to simulate the repair of conventional ones. While conventional PMMA-based denture polymers are linear polymers (thermoplastics) that allow surface dissolution and deeper penetration of the repair resin monomer, forming a thicker and homogenous semi-IPN, 3D printed dentures are characterized by tightly cross-linked (thermoset) polymer networks with low residual monomer content, which inherently resist dissolution.[27,33,38]

Despite the growing adoption of 3D printed dentures, optimal repair protocols for these materials remain underexplored. The authors are aware of only 4 studies[10,15,29,38] that investigated the flexural strength of repaired 3D printed denture base materials, with all reporting values being below the baseline performance. Given the inconsistent conclusions regarding optimal repair protocols for enhancing the adhesion between autopolymerizing resin and 3D printed denture base materials, this in vitro study aimed to evaluate the effect of 8 surface treatments on the flexural strength of a repaired 3D printed denture base. The null hypothesis was that surface treatments would have no significant effect on the flexural strength of the repaired 3D printed denture base.

MATERIAL AND METHODS

In this in vitro study, a dimethacrylate-based light polymerizing resin for 3D printing of denture bases (V-Print dentbase; VOCO GmbH) was chosen for its commercial availability and representative cross-linked polymer structure that embodied the inherent challenges associated with repairing additively manufactured resins. V-Print dentbase has a high degree of C=C conversion (DC%) (approximately 90%) and a flexural strength of 89 and 99.6 MPa for intact specimens before and after aging.[39]

Bar-shaped test specimens were designed with dimensions of 65×10×3.2 ±0.02 mm by using a CAD

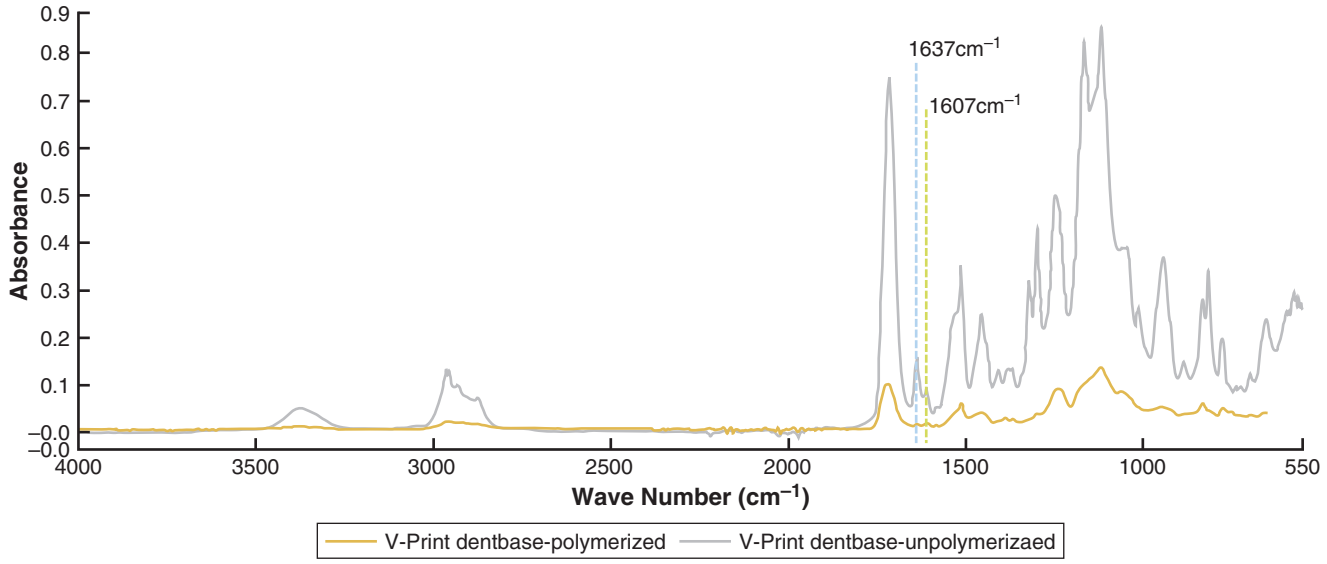

Figure 1. FTIR spectrum of V-Print dentbase material before (black) and after (yellow) 3D printing and postpolymerization. Blue and green lines refer to peaks used for calculation of DC%. DC, degree of conversion; 3D, 3-dimensional.

software program (Autodesk Fusion 360; Autodesk). The design was saved in standard tessellation language (STL) format. Specimens were printed by using a digital light processing printer (Asiga MAX; Asiga) with a 385-nm wavelength light source for cross-linking the resin. The specimens were printed with 50-μm layer thickness and at a 90-degree orientation. After printing, the specimens were immersed twice in isopropanol alcohol (2-Propanol; Fisher Scientific) (≥99.5%) for 2 minutes each to remove unpolymerized resin, air dried, and then postpolymerized in a light chamber (Otoflash G171; NK Optik) under a protecting nitrogen atmosphere (2000 flashes, twice) according to the manufacturer's recommendations.

The DC% of 6 specimens was quantified with Fourier transform infrared (FTIR) spectroscopy using an attenuated total reflectance (ATR) accessory (Spectrum One; Perkin-Elmer). The spectrum of unpolymerized resin was measured initially, followed by measurements for the printed, postpolymerized specimens. DC% was calculated from the aliphatic C═C peak at 1637 cm^{-1} normalized against the reference peak at 1607 cm^{-1} (Fig. 1) according to the formula: $DC(\%) = (1 - \frac{C_{aliphatic} / C_{reference}}{U_{aliphatic} / U_{reference}}) \times 100$, where $C_{aliphatic}$ represented the absorption peak observed at 1637 cm^{-1} in the polymerized specimen, and $C_{reference}$ represented the reference peak of the polymerized specimen observed at 1607 cm^{-1}. Similarly, $U_{aliphatic}$ corresponded to the absorption peak at 1637 cm^{-1} in the unpolymerized resin, and $U_{reference}$ corresponded to the reference peak of the unpolymerized specimen at 1607 cm^{-1}.

Eighty one specimens were equally assigned to 9 groups according to the applied surface treatment as follows: intact specimens (intact) group, specimens repaired without surface treatment (NT group) as the negative control, Palapress resin monomer (MN group), G-Multi PRIMER (G-MP group), triethyleneglycol dimethacrylate (TEGDMA group), airborne-particle abrasion (APA group), 180-grit paper roughening (180 G group), 180-grit paper roughening plus Ceramic Bond silane (180 G+CB group), and 3M ScotchBond Universal Adhesive (SB group). The materials used in the study are listed in Table 1.

All specimens, excluding the intact group, were sectioned into 2 equal halves with a high-precision saw (Secotom-50; Struers). Each half was polished under water-cooling using 800-grit Federation of European Procedures of Abrasives (FEPA) silicon carbide (SiC) paper (grit 800; Struers) to widen the repair space by 2 mm from each side, creating a 4-mm-wide repair space with repair surfaces parallel to each other (Fig. 2); for the 180 G and 180 G+CB groups, the repair space was made by grinding with a 180-grit FEPA SiC paper (grit 180; Struers). The process was carried out by the same operator (M.G) for each specimen.

In the APA group, cleaned repair surfaces were treated with 50-mm aluminum oxide particles using an airborne-particle abrasion device (CoJet Prep; Solventum) at a pressure of 0.25 MPa from approximately 10 mm for 10 seconds on each surface. Other chemical surface treatments (MN, G-MP, TEGDMA) were applied for 60 seconds with a microbrush before air drying. For the SB group, a layer of the bonding agent (3M ScotchBond Universal Adhesive; Solventum) was applied followed by active rubbing for 20 seconds and air drying for 5 seconds before light polymerization (Elipar S10; Solventum) for 10 seconds.

All specimens were repaired by using autopolymerizing resin (Palapress; Kulzer GmbH), selected as repair

Table 1. Composition of materials used according to manufacturer declaration

Material	Manufacturer	Composition	Description and Indications	Lot Number
V-Print dentbase	VOCO GmbH	Aliphatic urethane dimethacrylate 50–100%, ethoxylated bisphenol A dimethacrylate 25–50%, triethylene glycol dimethacrylate 5–10%, diphenyl (2,4,6-trimethylbenzoyl) phosphinoxid ≤2.5%[40]	3D printing material (light-polymerizing resin) for the generative production of denture bases for removable dentures[40] Available in gingival (pink) shade	2206085
Palapress	Kulzer GmbH	Liquid: methylmethacrylate >90%, tetramethylene dimethacrylate ≥1-≤5%, maleic acid <0.1%, 2-Hydroxy–4-methoxy benzophenone <0.25%, mequinol <1%, quaternary ammonium compounds, tri-C8–10-alkylmethyl, chlorides ≥0.025-<0.25% Powder (based on methacrylate copolymers): dibenzoyl peroxide 1-<2.5%, methyl methacrylate ≥1-≤5%, 1-Benzyl–5-phenylbarbituric acid ≥0-≤5%[41]	Autopolymerizing repair resin indicated for partial dentures, completing partial dentures, edge designs, repairs, indirect relines, and extensions[41] Available in pink and clear shades	M010068
G-Multi PRIMER	GC Corp.	Ethyl alcohol (90–100%), phosphoric acid ester monomer (1–5%), dimethacrylate (1–5%)[42]	Primer for glass ceramics, hybrid ceramics, zirconia, Alumina, composite and metal bonding[42]	000149
Triethylene glycol dimethacrylate	Sigma-Aldrich	Triethylene glycol dimethacrylate ~95%	-	74196KMV
Aluminum oxide particles (Korox)	Bego	Particles of Al_2O_3, 50 µm in size	Airborne-particle abrasion	14957410713
Ceramic Bond	VOCO GmbH	50–100% acetone[43]	Silane coupling agent for porcelain or ceramic (incl. zirconium dioxide) and composite[43]	1941644
180-grit abrasive paper	Struers	Silicon carbide grinding paper, grain size 82 µm	Grinding paper for wet grinding of materials	40400058
3M Scotchbond Universal Adhesive	Solventum	2. Hydroxy ethyl methacrylate 15–25%, bisphenol a digylcidyl ether1 dimethacrylate (BisGMA) 15–25%, (2-propenoic acid, 2-methyl-, reaction products with 1,10-decandiol and Phosphorous oxide (P2O5)) 10–20%, ethanol 10–15%, water 10–15%, 2-propenoic acid, 2-methyl, 3- (trimethoxysil) propyl ester, reaction products with vitreous silica 7–13%, copolymer of acrylic and itaconic acid 1–5%, camprhoquinone <2%, dimethyl aminobenzoate (–4) <2%, dimethylamino ethyl methacrylate <1%, 2,6-di-tert-butyl-p-cresol <0.5%[44]	Universal adhesive used for bonding light-polymerized composite or compomer for all classes of direct restoration, bonding of dual-polymerizing cements and core build-up materials, bonding of self-cure composites, repair of composite or compomer restorations, and bonding veneers in combination with 3 M RelyX Veneer Cement[44]	7988488

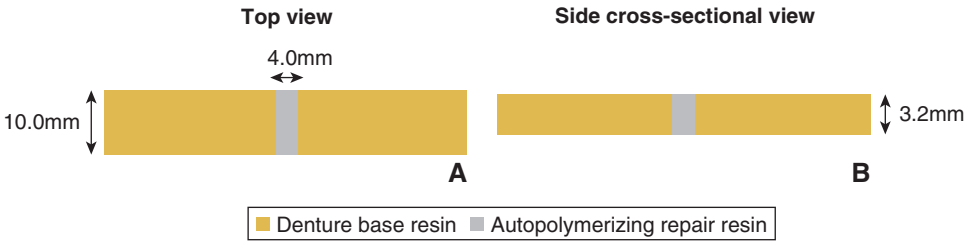

Figure 2. Schematic illustration of repaired specimens.

material because of its widespread use, convenience, and good mechanical properties.[3] The 2 halves of each specimen were placed into a matching polyvinyl siloxane mold (Lab-Putty; Coltène) previously obtained from an intact specimen. Repair resin powder and liquid were mixed in accordance with the manufacturer's instructions and poured into the mold, slightly overfilling the gaps to compensate for polymerization shrinkage and allow for finishing. The specimens were polymerized in a pressurized unit (Ivomat IP2; Ivoclar AG) filled with water at 55 °C for 15 minutes under a pressure of 0.2 MPa. After polymerization and cooling, the specimens were finished and polished using a grinding machine (LaboPol-21; Struers) with FEPA abrasive SiC papers (grits 500, 800, 1200; Struers) under water-cooling. The width and diameter of each specimen was verified by using digital calipers (Digital Caliper; Harley Benton Tools). All specimens were stored in distilled water for 30 days at 37.0 ±0.5 °C before testing.

A universal testing machine (LR30K plus; Lloyd Instruments) was used to assess the flexural strength of each specimen by performing a 3-point bend test with a 50-mm-span length. The load was applied perpendicularly to the center of the repaired area at a crosshead speed of 5 mm/minute until fracture occurred. Flexural strength values were calculated in MPa by the PC software program (Nexygen 4.0; Lloyd Instruments) by using the following formula: $S= 3WL/2bd^2$, where S is the flexural strength or fracture strength in N/mm^2, W is the load applied for fracture in N, L is the distance between the 2 vertical rods (50.0 mm), b is the width of the specimen (10.0 mm), and d is the thickness of the specimen (3.2 ±0.2 mm).

Fracture patterns were examined with a stereomicroscope (Olympus SZ40; Olympus) to identify failure modes of the fractured specimens, which were assigned to the following 3 categories: cohesive failures (within the denture base resin or repair resin), adhesive failures (at interface between the denture base resin and repair resin), or mixed failures. Additional representative specimens for each surface treatment were examined using a scanning electron microscope (SEM) (Apreo S field-emission SEM; Thermo Scientific) with the microscope set at low vacuum mode to evaluate the impact of surface treatments on the morphological features of the denture base material. Specimens with the applied surface treatments were mounted and sputter coated with gold (SCD 050; BAL-TEC) at 40 mA for 60 seconds. Images were captured at a magnification of ×500 at 1 kV. Surfaces treated with 3M Scotchbond Universal Adhesive were polymerized with light according to the manufacturer's instructions before SEM analysis. Statistical analysis was performed using Statistics software program (IPM SPSS Statistics, v26.0; IBM Corp). Normal distribution was evaluated with the Shapiro-Wilk test, which indicated that flexural strength data were not normally distributed. Consequently, flexural strength was compared among groups by using the Kruskal-Wallis test, while pairwise comparisons were made by using the Mann-Whitney test with Bonferroni adjustment (α=.05). The median and interquartile range (IQR) were used for nonnormally distributed variables (flexural strength).

RESULTS

The mean DC% of the V-Print dentbase material was 89 ±2%. For flexural strength, mean ±standard deviation (SD) and median ±IQR values are presented in Figure 3 and Table 2, respectively. The Kruskal-Wallis test detected a significant difference among the study groups in terms of repair flexural strength (P<.001). The median flexural strength of the intact group was significantly higher than that of all other repaired groups (97.6 MPa, P<.05). The 180 G+CB group had the highest repair flexural strength (35 MPa), being significantly higher than that of the NT (17.5 MPa) (P=.008). Other groups, including 180 G, MN, APA, G-MP, TEGDMA, and SB showed no significant improvement compared with the NT group (P≥.05).

Representative SEM micrographs of the NT, MN, G-MP, TEGDMA, APA, 180 G, 180 G+CB, and SB groups are presented in Figure 4. The NT, MN, and TEGDMA specimens displayed transverse grooves caused by polishing with the 800-grit polishing paper. The APA group had several depressions and projections, consistent with the particle impact. Irregular deeper grooves were observed in the 180 G and 180 G+CB groups, reflecting the mechanical roughening caused by the 180-grit polishing

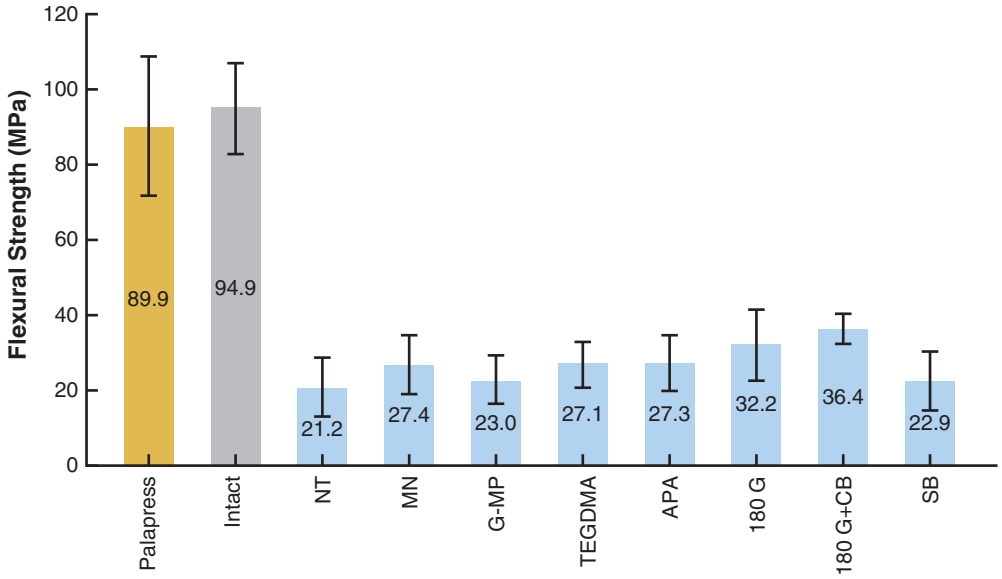

Figure 3. Flexural strength (mean values) of tested groups of repaired V-Print denture base material. Error bars represent standard deviation. Same letter above columns indicates no statistically significant difference ($P \geq .05$). Palapress values from Perea-Lowerly et al.[3].

paper. None of the tested chemical treatments displayed any signs of surface resin dissolution. The SB treatment resulted in a smoother surface than the mechanical treatments and the nontreated surface.

Failure modes are presented in Figure 5. Cohesive failure within the repair resin was noted in 100% of the specimens of APA and 180 G +CB groups. A similar failure mode was also noticed in 78% of the 180 G group, 44% of the NT and MN groups, 22% of the TEGDMA group, and 33% of the SB group.

DISCUSSION

This in vitro study evaluated the efficacy of 8 different surface treatments on the flexural strength of a repaired 3D printed denture base. The null hypothesis that surface treatments would have no significant effect on the flexural strength of the repaired 3D printed denture base was partially rejected, as the 180 G+CB group demonstrated significantly higher repair flexural strength than that of the NT group (P=.008), whereas the other surface treatments yielded no significant improvement.

Achieving adequate adhesion between the denture base and repair material is critical for a durable repair. Previous studies[29,30,38,45] have reported that milled and conventional PMMA-based denture base materials exhibited higher bond strength with reline or repair materials than their 3D printed counterparts. Therefore, the main challenge in 3D printed prosthesis repair arises from a weak bond at the interface of the original and repair resin.[29] The limited effectiveness of monomer or solvent surface treatments, as observed in the present study, can be attributed to the high resistance of 3D printed resins to dissolution because of their inherent highly cross-linked structure and low residual monomer, adversely affecting the secondary IPN formation.[27,38] Wemken et al[38] reported that the AM denture base material used in the current study exhibited minimal solubility even with long-term immersion for 60 minutes in acetone or MMA monomer compared with conventional PMMA.

Table 2. Median and interquartile range (IQR) of flexural strength of test groups

Group Abbreviations	Descriptions	Flexural Strength (MPa)
		Median ±IQR
Intact	Positive control	97.6 ±14.6^{a}
NT	No surface treatment	17.5 ±11.6^{b}
MN	Repair resin (Palapress) monomer	28.3 ±9.5^{b}
G-MP	G-Multi PRIMER	23.1 ±10.1^{b}
TEGDMA	Triethyleneglycol dimethacrylate	29.0 ±12.5^{bc}
APA	Airborne-particle abrasion with 50-μm Aluminum oxide particles	26.07 ±8.3^{bc}
180 G	180-grit paper roughening	28.1 ±9.9^{bcd}
180 G+CB	180-grit paper roughening + Ceramic Bond silane	35.4 ±5.5^{d}
SB	3M ScotchBond Universal Adhesive	22.9 ±10.8^{b}

Same superscript lowercase letters indicate statistical similarity ($P \geq .05$)

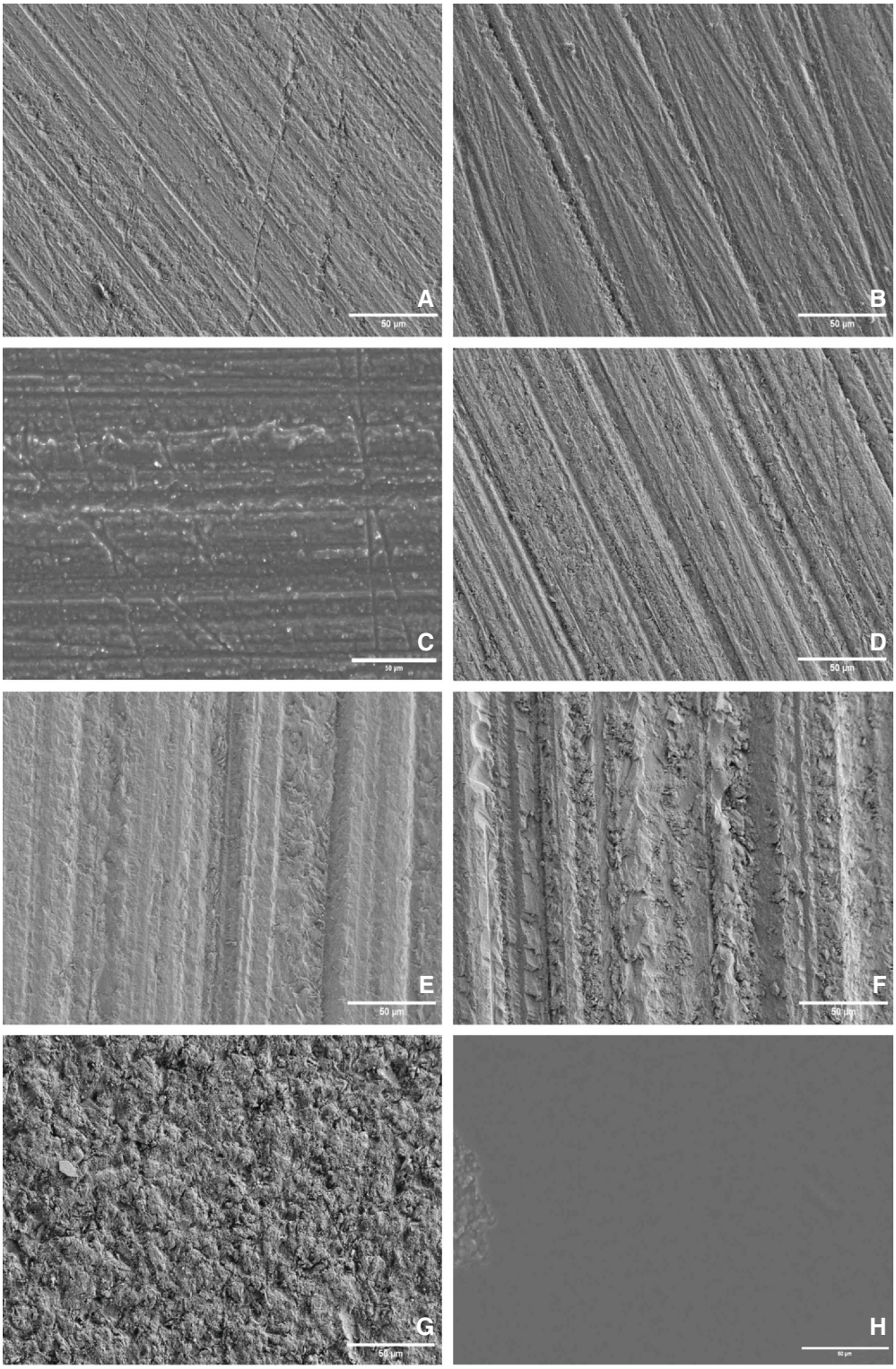

Figure 4. Scanning electron microscopic images of V-Print dentbase material surface after surface treatments. A, NT (control). B, MN. C, G-MP. D, TEGDMA. E, 180 G. F, 180 G+CB silane. G, APA. H, SB surface treatment after light polymerization. Original magnification ×500. A, B, C, D polished with 800-grit silicon carbide paper before surface treatments, while E, F were polished with 180-grit silicon carbide paper. Scale bar 50 µm.

According to the ISO 1567 standard,[5] intact conventional denture base polymers must exhibit a minimum flexural strength of 65 MPa. In case of repair, the flexural strength of these resins varies according to the repair technique, used materials, and other parameters.[10,17,24] The repair flexural strength values

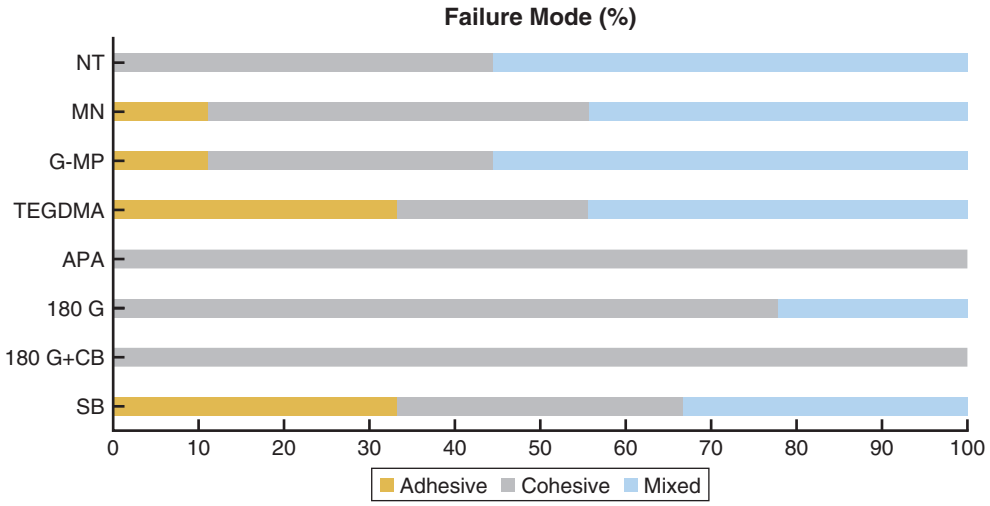

Figure 5. Percentage (%) of failure modes in test groups after flexural strength testing.

observed in the present study were consistent with prior research,[10] as the highest repair flexural strength (35.4 MPa) of the 180 G+CB group was less than 50% of the strength of intact specimens, even though it was statistically higher ($P<.05$) than that of the untreated specimens (17.5 MPa). Furthermore, the present study showed that the repair strength was not significantly increased by using the 50-μm APA, which was consistent with Viotto et al,[10] where the 50-μm APA yielded a maximum strength of 15.5 MPa, or approximately 43% of the original strength of the intact 3D printed denture base material. Conversely, Neshandar Asli et al[15] reported a higher repair flexural strength (51.1 MPa), approximately 66% of intact strength (77.0 MPa) when using 250-μm aluminum oxide APA with a 3D printed PMMA-based denture base material (DentaBase), suggesting that both the particle size and the chemical composition of AM materials across studies can play a role in the efficacy of mechanical roughening.

The superior performance of the 180 G+CB group can be explained by the synergistic effect of both mechanical surface roughness and silane chemical application. While mechanical roughening increased the surface area for bonding, silanization enhances interfacial adhesion between dissimilar materials through improved surface wetting and chemical bonding by OH-groups, mostly on the inorganic bonding site.[46] Silane primers have been successfully used to enhance bond strength in conventional composite resin repair although their long term hydrolytic stability has been questioned.[47,48]

The influence of the repair gap dimensions on flexural strength has been investigated with a repair gap of 1.5 to 10 mm in previous studies.[17,22,49] Despite using a 4-mm repair gap, repair strengths observed in the present study were either comparable to or greater than those reported for smaller gap dimensions. Specifically, APA treatment in the present study yielded a repair strength of 27.33 MPa, which compares favorably with the repair strength (19.27 MPa) reported by Gad et al[16] for a 2.5-mm repair gap, suggesting that surface treatment efficacy may partially compensate for larger defects, though further optimization is still required. While beveling the repair surface could increase the bonding area and influence the stress distribution during loading to be more of the shear stress type, it may also introduce distortion of the repaired denture.[50,51]

While combining mechanical roughening and silane application showed some promise, its clinical utility remains limited to interim solutions. The persistent challenges in achieving durable repairs for 3D printed denture bases likely arise from differences in the chemical composition and polymerization mechanism between 3D printed denture base resins (such as, light-polymerized urethane methacrylate or diacrylate) and conventional autopolymerizing PMMA repair materials.

Limitations of this study included testing only 1 brand of 3D printed denture base material and autopolymerizing repair resin. Furthermore, only a single repair gap width was investigated, and the specimens were evaluated after a relatively short aging period without incorporating fatigue testing. Additionally, the flexural strength test in this study was centered on the repair zone rather than at the interface, which could have influenced the observed failure modes and strength values. Future research should explore other repair resins with monomer systems tailored for 3D printed polymers and other new strategies that diverge from conventional repair protocols. Additionally, reinforcement strategies such as fiber incorporation should be explored as they may offer further improvements.

CONCLUSIONS

Based on the findings of the present study, the following conclusions were drawn:

1. The highest repair flexural strength of the investigated 3D printed denture base material (35.4 MPa) remained below 50% of the strength observed in the control intact specimens (97.6 MPa) and did not meet the levels recommended by the ISO standards.
2. While combining the 180-grit paper roughening with silane application significantly improved the repair flexural strength compared with the non-treated specimens (P=.008), other tested surface treatments achieved no significant improvement.

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