

Original Article

Chroma Resilience, Luster Dynamics, Texture Nuances, and Wetting Behavior of Material Jetting 3D-Printed Denture Substrates Under Varied Surface Transformations

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ABSTRACT

This research aimed to investigate how surface finishing techniques impact the color stability, gloss, roughness, and wettability of monolithic polychromatic MJT 3D-printed denture resins. A total of 21 color variants of the same denture resin (TrueDent; Stratasys, Eden, MN, USA) were processed under two surface protocols—either polishing alone or polishing followed by glazing—yielding 42 groups and 420 specimens ($n = 10$ per group). Fabrication was performed using a PolyJet MJT 3D printer (J5 DentaJet; Stratasys, Eden, MN, USA). Color measurements were captured with a digital spectrophotometer before and after surface treatments, and ΔE_{00} and ΔC^* values were computed according to the CIE2000 system. For tooth shades, comparisons were made against the 50%:50% perceptibility threshold (PT) of 0.8 and the acceptability threshold (AT) of 1.8, whereas gingival (pink) shades used PT = 1.72 and AT = 4.08. Surface gloss was quantified with a glossmeter, roughness via optical profilometry, and wettability by measuring contact angles using an optical tensiometer. Statistical significance of color changes was assessed using one-sided, one-sample t-tests against AT and PT, while t-tests evaluated the effect of surface treatment on gloss, roughness, contact angle, and ΔC^* for each variant. Pairwise comparisons employed Fisher's Protected Least Significant Differences ($\alpha = 0.05$). In most instances, glazing induced ΔE_{00} changes exceeding PT and AT, although a few exceptions were noted. Glazed specimens generally displayed higher chroma and more vivid colors than polished-only samples. Gloss values were significantly elevated in glazed specimens ($p < 0.0001$), as was surface roughness ($p < 0.0001$ for most). In contrast, polished samples demonstrated higher contact angles ($p < 0.0001$ for most). Surface finishing markedly affects color, gloss, roughness, and wettability of MJT 3D-printed dentures. Glazing enhanced color saturation and gloss and produced more hydrophilic surfaces, but also increased roughness. These outcomes emphasize the critical role of surface treatment choice in achieving optimal clinical performance of MJT-fabricated dentures.

Keywords: MJT, PolyJet, Denture esthetics, Surface treatment

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Introduction

The introduction of digital technologies has transformed complete denture fabrication, particularly through additive manufacturing (3D printing) since

Maeda's pioneering work in 1994 [1]. Although subtractive milling methods provide advantages like dimensional stability, precise tissue adaptation, and superior retention [2–5], they have drawbacks including high material waste, elevated production

costs, limited ability to mill complex shapes, and constrained digital tooth libraries [6].

Among additive techniques, Vat Photopolymerization (VPP) technologies—such as stereolithography (SLA), digital light processing (DLP), and LCD printing—are widely adopted in prosthodontics [7]. Studies have extensively characterized 3D-printed resins in terms of mechanical properties (e.g., flexural strength), surface roughness, solubility, translucency, water sorption, and color stability [8–10]. However, dentures produced by MJT technology remain underexplored.

Material Jetting (MJT) deposits photopolymer droplets in successive layers that are UV-cured to form the final structure [11]. Commercial MJT systems like PolyJet (Stratasys, Eden Prairie, MN, USA) and MultiJet (3DSYSTEMS, Rock Hill, SC, USA) [12] allow creation of monolithic polychromatic dentures with high dimensional accuracy and smooth surfaces, avoiding the extra bonding or characterization steps required for SLA/DLP dentures [6, 13, 14] (**Figure 1**).

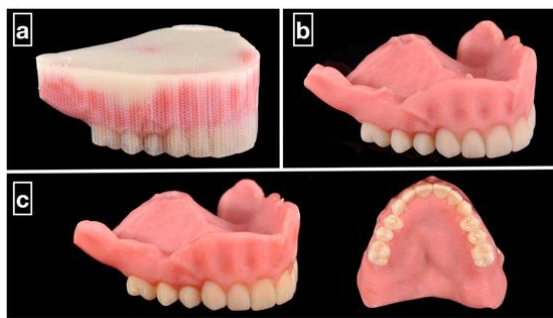


Figure 1. Example of MJT-printed dentures: (a) before support removal, (b) after waterjet removal of supports, (c) after polishing and glazing

Evaluating denture base materials under standardized conditions is essential to understand surface-dependent properties affecting function and durability. Surface roughness, which represents microscopic peaks and valleys, directly influences wettability, adhesion, gloss, and microbial colonization. Ideal denture bases should maintain roughness below $0.2\ \mu\text{m}$ to limit plaque formation, halitosis, staining, and patient discomfort [15–18]. Application of surface coatings can prevent roughness increases caused by mechanical wear, such as brushing [19]. Optiglaze (GC America Inc., Alsip, IL, USA), a light-cured glaze with titanium dioxide nanoparticles, is commonly used to enhance polymeric

dental surfaces [20, 21]. Surface gloss contributes to esthetic perception, which can deteriorate with material aging or color change [22, 23]. Prior studies indicate milled bases have lower roughness, while 3D-printed bases exhibit higher gloss compared with conventional auto-polymerized resins [24]. Despite extensive research on dental prosthesis optics [25], the effects of surface treatments on MJT 3D-printed dentures' color and gloss remain poorly understood.

The goal of this study was to examine the influence of polishing versus polishing plus glazing on color stability, surface gloss, roughness, and wettability of MJT 3D-printed denture materials. The null hypothesis stated that surface finishing would not cause significant changes in any of these properties.

Materials and Methods

The overall experimental workflow is depicted in **Figure 2**. A total of 21 color variants of MJT 3D-printed denture material (TrueDent; Stratasys, Eden, MN, USA) were combined with two surface finishing approaches, resulting in 42 experimental groups (**Figure 3**). 420 specimens were prepared, each with dimensions of $12.0\ \text{mm} \times 12.0\ \text{mm} \times 6.0\ \text{mm}$ ($n = 10$ per group), selected to ensure compatibility with all analytical instruments. All samples were produced by certified personnel at Stratasys using a PolyJet 3D printer (J5 DentaJet; Stratasys, Eden, MN, USA).

Polishing protocol: Each specimen underwent an initial polishing step. One surface was polished using a Stuers Rotopol 31-Rotoforce 3 machine (Spectrographic Limited, Leeds, UK) under continuous water flow at 300 rpm. 2000-grit silicon carbide paper (Stuers LLC, Cleveland, OH, USA) was employed, with a single 30-second cycle per specimen (**Figure 4**).

Glazing protocol: For the glazed groups, specimens were first polished as described above. Subsequently, a nano-filled, light-curable protective glaze (Optiglaze; GC America Inc., Alsip, IL, USA) was applied using disposable, non-absorbent microbrushes (Benda Brush Regular; Centrix Inc., Shelton, CT, USA) to ensure uniform coverage (**Figure 5**). The glaze was cured for 3 minutes at $30\ ^\circ\text{C}$ using an Otoflash G171 light polymerization unit (NK Optik GmbH, Baierbrunn, Germany). One investigator (NT) verified that each surface received complete coverage.

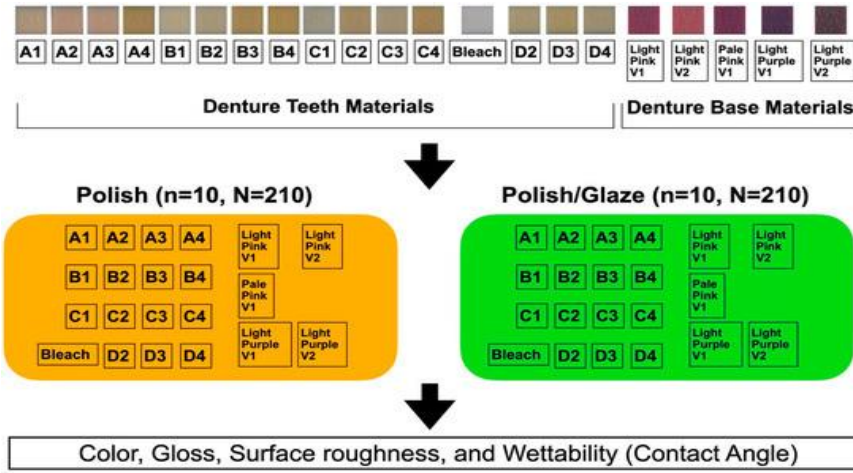


Figure 2. Experimental design overview

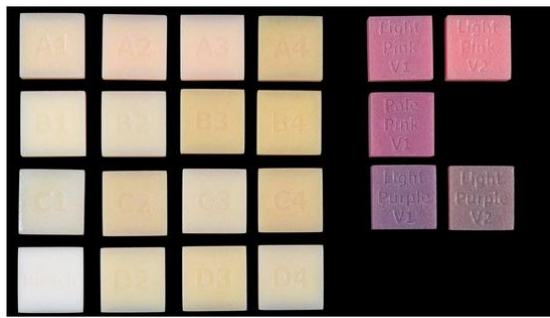


Figure 3. Manufactured specimens.



Figure 4. Polished samples.

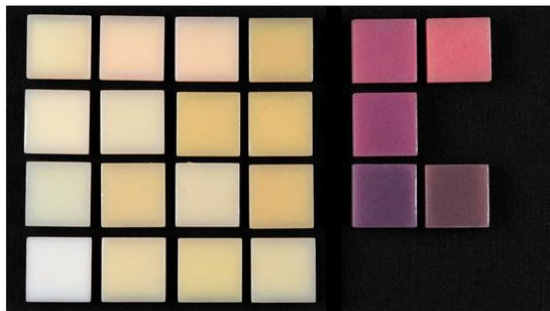


Figure 5. Glazed specimens

Color measurement: A single examiner (TN) assessed color using a contact-type digital spectrophotometer (CM-2600d; Konica Minolta Healthcare Americas Inc., Wayne, NJ, USA). A 3 mm SAV aperture was used, and the device was calibrated with zero (empty) and white (CM-A145 plate) references. Measurements were obtained under UV 100%, D65 illumination,

S/SCI + SCE mask, and a 10° observer angle. Each specimen was measured three times, and the average was used for statistical analysis. To minimize external light interference and ensure consistent contact and angle, specimens were positioned in a custom silicone mold (Exalence putty; GC America Inc., Alsip, IL, USA).

Color difference calculation: ΔE_{00} values between polished and glazed surfaces were computed using the CIEDE2000 formula, accounting for lightness (ΔL^*), chroma (ΔC^*), and hue (ΔH^*) differences:

$$\Delta E_{00} = \sqrt{\left(\frac{\Delta L^*}{k_L S_L}\right)^2 + \left(\frac{\Delta C^*}{k_C S_C}\right)^2 + \left(\frac{\Delta H^*}{k_H S_H}\right)^2 + R_T \left(\frac{\Delta C^*}{k_C S_C}\right) + \left(\frac{\Delta H^*}{k_H S_H}\right)} \quad (1)$$

The perceptibility threshold (PT) and acceptability threshold (AT) for ΔE_{00} were defined as 0.8 and 1.8 for tooth shades, and 1.72 and 4.08 for gingival (pink) shades. The ΔChroma (ΔC^*) was also recorded for subsequent comparisons.

Gloss measurement: Surface gloss was assessed in gloss units (GU) using a Novo-Curve Glossmeter (Rhopoint Americas Inc., Troy, MI, USA). The instrument was calibrated with a standard tile (93.8 GU at 60° incidence). For each specimen, four measurements were taken by rotating the sample 90° clockwise after each reading. The mean of these four values was recorded as the representative gloss for the specimen.

Surface roughness evaluation

Surface texture was quantified using an optical profilometer (Proscan 2000; Scantron, Taunton, UK) across all 420 samples. Measurements employed a spectral sensor (S5/03; Scantron Industrial Products Ltd.) set at a 5 mm working distance, with a range of 300 μm and a resolution of 0.010 μm . Scans were acquired with a step interval of 0.01 mm along both X

and Y axes (100 steps each). The resulting data were processed using Proscan Application Software v.2.0.17, with the auto-leveling feature activated, and roughness values were determined at the center of each specimen (μm).

Assessment of wettability

Contact angle measurements were performed via the sessile drop technique using an optical tensiometer (Theta Lite; Biolin Scientific, Gothenburg, Sweden) under controlled laboratory conditions ($23 \pm 2^\circ\text{C}$, 45% humidity). Each specimen received a 5 μL droplet of Millipore water, and the angle was recorded for 5 seconds using live image capture. The mean contact angle was calculated from two measurements aligned along a reference line across the specimen notches. Surfaces were classified as hydrophilic ($0^\circ \leq \theta \leq 45^\circ$) or hydrophobic ($90^\circ \leq \theta \leq 180^\circ$) [29].

FESEM imaging

Selected specimens (A1P, A1G, Light Pink V2P, Light Pink V2G) were prepared for field-emission scanning electron microscopy by immersion in hexamethyldisilazane (Electron Microscopy Sciences, Hatfield, PA, USA), followed by gold sputtering, and imaged at $2000\times$ magnification.

Statistical considerations

With 10 specimens per group, the study had 80% power to detect effect sizes of 1.32 between any two groups. Color changes (ΔE_{00}) were assessed against 50:50% perceptibility (PT) and acceptability thresholds (AT): for tooth shades, PT = 0.8 and AT = 1.8; for gingival shades, PT = 1.72 and AT = 4.08, using one-sided, one-sample t-tests. The influence of surface treatment (polished vs. glazed) on gloss, roughness, contact angles, and ΔC^* was analyzed with t-tests, and Fisher's Protected Least Significant Differences were applied for multiple comparisons. Significance was set at $\alpha = 0.05$, with all analyses conducted in SAS 9.4 (SAS Institute Inc., Cary, NC, USA).

Results

Color change (ΔE_{00})

The ΔE_{00} values for polished versus glazed specimens are presented in **Figure 6**. Glazing generally produced color shifts exceeding both PT and AT, except for A3, which remained within the PT, and A1, A2, A3, B1, B2, C2, and Bleach, which remained within the AT. ΔC^* values, reflecting chroma differences, are shown in **Figure 7**. Most glazed samples exhibited higher chroma, indicating a more vivid and saturated appearance, whereas A3, B1, Bleach, C1, and C3 did not show statistically significant changes between polished and glazed surfaces.

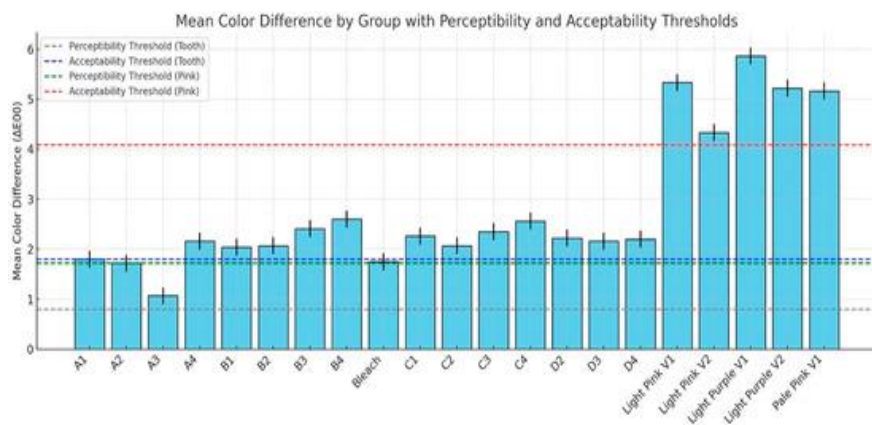


Figure 6. ΔE_{00} between polished (P) and polished + glazed (PG) samples relative to PT and AT for tooth and gingival shades

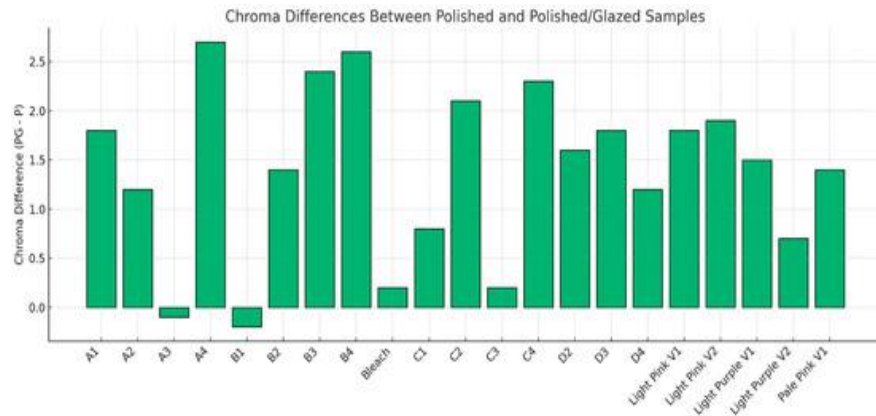


Figure 7. ΔC^* changes between polished-only and polished + glazed samples; positive values (PG-P) indicate higher chroma in glazed surfaces

Surface roughness, wettability, and gloss

Figure 8 summarizes statistical outcomes for roughness, wettability, and gloss. All glazed specimens, except B3 ($p = 0.4514$), had significantly higher surface roughness than polished samples ($p < 0.0001$). Representative profilometry scans are shown

in **Figure 9a,b**, and SEM images of polished versus glazed surfaces appear in **Figure 9c,d**. Contact angle images are presented in **Figure 10**. Across all materials, polished specimens displayed higher contact angles ($p < 0.0001$), indicating more hydrophobic behavior, while glazed samples consistently exhibited greater gloss units ($p < 0.0001$).

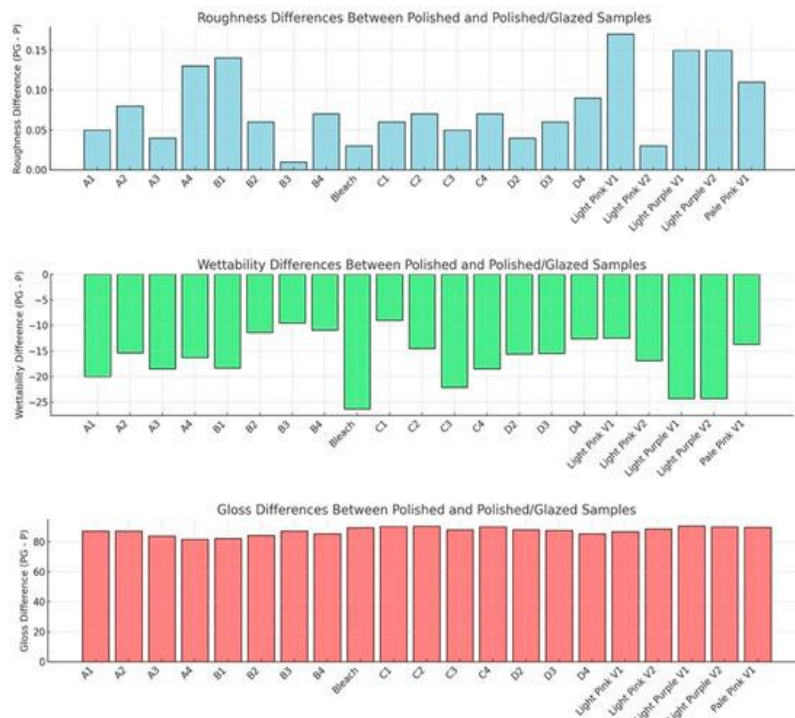


Figure 8. Data depicting surface roughness (μm , mean $\pm$ SD), wettability (contact angle, degrees, mean $\pm$ SD), and gloss (GU, mean $\pm$ SD). “P” denotes the polished-only groups, whereas “PG” indicates polished and glazed groups. A positive roughness difference (PG-P) reflects that glazed samples were rougher than polished ones. A negative wettability difference (PG-P) shows that glazed samples were less wettable (i.e., exhibited higher contact angles). A positive gloss difference (PG-P) signifies that glazed samples displayed higher gloss than polished specimens

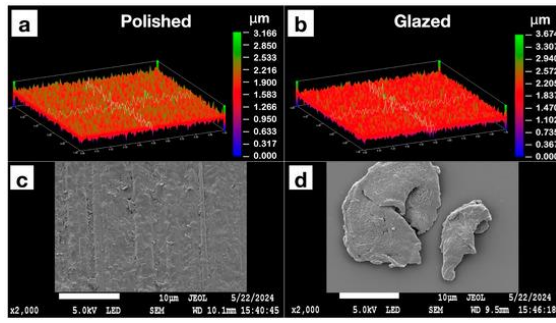


Figure 9. Optical profilometer images showing surface roughness for Light Pink V2 specimens with polished and glazed treatments are displayed in (a,b). Corresponding SEM images are shown in (c,d)(a) Polished profilometer; (b) Glazed profilometer; (c) Polished SEM; (d) Glazed SEM

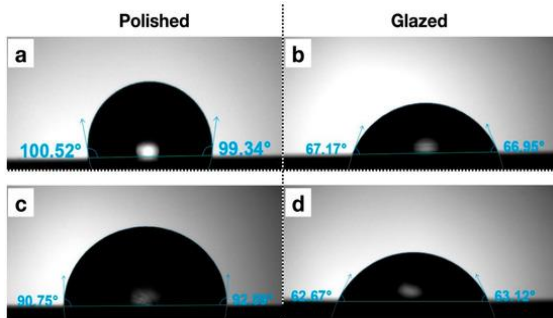


Figure 10. Representative contact angle images for different surface treatments (a) A1 polished; (b) A1 glazed; (c) Light Pink V2 polished; (d) Light Pink V2 glazed

Discussion

The study results refuted the null hypothesis, confirming that surface treatments influenced color, gloss, roughness, and wettability of MJT 3D-printed denture materials. Specifically, ΔE_{00} values between polished and glazed surfaces were significantly affected, with glazing typically exceeding both the perceptibility (PT) and acceptability thresholds (AT) (**Figure 6**). While prior studies have shown that both polishing and glazing improve color stability [27, 30, 31], none have specifically quantified ΔE_{00} changes for MJT-printed denture materials. Past research largely focused on fit and adaptation accuracy [32]. Previous investigations into SLA- or DLP-printed resins have evaluated roughness and color stability under aging simulations, including brushing and thermocycling, but MJT materials have not been examined. For example, Çakmak *et al.* reported that DLP-printed, milled, and heat-cured resins experienced significant roughness alterations and $\Delta E_{00} > 1.72$ after brushing and thermal aging, yet these remained within acceptable limits ($\Delta E_{00} < 4.08$) [33].

These findings cannot be directly applied to MJT materials, emphasizing the novelty of this work.

The glazing process applied a nano-filled, light-cured coating (Optiglaze), which reduced surface porosity by filling microdefects [34]. Literature shows this coating can minimize color change [27, 35, 36]. In the present study, only A3 remained within the PT, and A1, A2, A3, B1, B2, C2, Bleach, and Light Pink V2 were within the AT, with no significant differences, possibly due to material composition or slight variations in manual application, despite standardized manufacturing.

For ΔC^* , most materials showed higher values after glazing, resulting in more vivid and saturated colors (**Figure 7**). This effect may be linked to the sorption and solubility characteristics of MJT materials [37], as they could absorb the glaze, increasing chroma [38]. To date, no studies have examined the effect of surface treatment on color, solubility, and sorption in MJT-printed denture materials. These findings suggest that a glazed shade guide might be necessary during shade selection to ensure accurate color matching for MJT dentures intended for glazing.

The traditional CIELab system has limitations in reliably quantifying color differences. To address this, the CIEDE2000 formula was introduced in 2000, providing corrections for non-uniform color spacing, more accurate hue and chroma calculations, and accounting for the non-uniformity of human color perception [38–43]. Thus, ΔE_{00} was calculated using CIEDE2000 in this study and compared to PT and AT values. The 50:50% PT represents the threshold at which 50% of observers detect a color difference, while the 50:50% AT indicates the threshold considered acceptable by 50% of observers [38]. In this study, PT = 0.8 and AT = 1.8 were applied for tooth shades, and PT = 1.72 and AT = 4.08 for gingival (pink) shades [26–43].

The current study demonstrated that glazed surfaces exhibited noticeably higher roughness compared to polished ones across all tested materials, which aligns with some previous findings [44]. However, other reports have shown conflicting results, with glazing either having no significant impact on surface roughness [19] or producing smoother finishes than unglazed surfaces [44, 45]. These differences likely stem from manual variations in the glazing process and the type of denture base resin used, as most prior work focused on PMMA [20] or hybrid resins [46, 47]. Profilometer scans and SEM images of polished versus glazed surfaces (**Figure 10**) indicate that, at a microscopic level, glazing may leave small surface

debris even though it generally appears smoother to the naked eye [45].

In terms of surface wettability, polished specimens consistently showed higher contact angles, making them more hydrophobic than glazed counterparts (**Figure 10**). Wettability, along with surface roughness, topography, and surface charge, is a crucial factor in microbial colonization and biofilm formation on prosthetic bases [48–51]. Biofilm accumulation is a major contributor to denture stomatitis and can reduce the lifespan of dental prostheses. Among surface properties, research suggests that contact angle plays a dominant role in bacterial adhesion, where lower contact angles (more hydrophilic surfaces) correspond to reduced microbial attachment [51–53]. By contrast, surface roughness appears to have a weaker influence on bacterial adherence [51]. Therefore, despite the higher roughness observed after glazing, the lower contact angle indicates that glazed MJT surfaces may improve hygiene and reduce bacterial colonization, supporting their clinical use.

Regarding surface gloss, all glazed samples displayed significantly higher gloss values than polished ones (**Figure 8**), which is consistent with prior studies indicating that glazing enhances surface reflectivity [54, 55]. Comparative data for gloss between milled and 3D-printed denture bases are limited. One study reported that coating 3D-printed denture bases did not alter gloss or roughness [24], likely due to differences in coating composition. Based on these results, clinicians may consider glazing MJT 3D-printed dentures to achieve higher gloss and improved wettability, benefiting both esthetics and patient hygiene. Additionally, since some shades exceeded perceptibility and acceptability thresholds after glazing, using a glazed shade guide during clinical shade selection is recommended to optimize color matching.

This study has several limitations. Being an *in vitro* experiment, it could not replicate the full range of oral conditions, such as aging protocols, immersion liquids, or time periods [41, 56]. While a single investigator (TN) performed all surface treatments consistently, human factors could introduce variability. The study also did not account for operator-dependent differences or subjectivity in manual glazing, which may influence surface results. Measurement limitations exist as well, since gloss and wettability may vary due to sample placement or the use of only one type of spectrophotometer and glossmeter. Only two surface treatments (polishing alone and polishing with a single glaze) were tested, without including untreated or alternative finishes, which limits generalization.

Furthermore, although increased hydrophilicity suggests reduced bacterial adhesion, no microbiological tests were performed to confirm this.

Future investigations should incorporate biofilm formation assays or *in vivo* analyses to validate the hygiene benefits of glazing. Additional studies are needed to assess the mechanical and optical stability of MJT-printed dentures under simulated mechanical or thermal aging. Research should also explore different glaze materials, polymerization methods, and application durations. Comparative studies between MJT dentures and those fabricated using milling, conventional techniques, or other 3D printing technologies are necessary to guide clinical decisions. Long-term clinical studies will be crucial to confirm these *in vitro* findings.

Conclusions

This investigation confirmed that surface treatments markedly influence color, gloss, roughness, and wettability of MJT 3D-printed denture materials. Glazing enhanced chroma, increased gloss, and improved hydrophilicity compared to polishing alone. Although glazing increased surface roughness, the esthetic and potential hygiene advantages support its clinical use for MJT-printed dentures. These findings emphasize the importance of surface treatment choices in evaluating the performance of MJT-fabricated denture materials.

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Conflict of Interest: None

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Ethics Statement: None

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