Original Article

Effect of Fluoride Mouthrinses on Flexural Strength and Microhardness of 3D-Printed Provisional Resins

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KEY WORDS
3D-printing;
Restoration;
CAD/CAM;
Flexural strength;
Hardness;

ABSTRACT

Background: Three-dimensional (3D)- printing has significantly advanced digital prosthodontics through precise, patient-specific provisional restorations. However, their longevity depends on mechanical properties, such as flexural strength and surface microhardness, which are governed by resin chemistry and processing parameters. Because provisional routinely contact fluoride mouthrinses that may alter these properties, evidence for 3D-printed materials remains limited.

Purpose: This study evaluates the effect of a fluoride-containing mouthrinse on flexural strength and microhardness of 3D-printed provisional resins.

Materials and Method: In this *in vitro* study, rectangular specimens (25×2×2 mm; *n*= 96; 48/resin) from two DLP-printed provisional resins (Detax, Arma) were assigned to three media (*n* = 16/cell): Baseline (no immersion), artificial saliva (AS, 37 °C), and AS with twice-daily 1-minute immersion in alcohol-free fluoride mouthrinse (FE ⁻;225 ppm F). Flexural strength was measured by three-point bending; surface hardness by Vickers microhardness (VHN).

Results: Detax showed higher flexural strength than Arma in all media (all *p* Value< 0.001), with mean differences of 21.9 MPa (Baseline), 24.9 MPa (AS), and 24.4 MPa (FE). For microhardness, Detax exceeded Arma at Baseline (Δ = 0.09 VHN, *p* = 0.014) and FE (Δ = 0.09 VHN, *p*<0.001), but not in AS (*p* = 0.267). Within each resin, one-way ANOVA showed significant medium effects for flexural strength (both *p*<0.001), with Baseline > AS and Baseline > FE; however, no statistically significant difference was observed between AS and FE. Two-way ANOVA indicated significant main effects of Resin and Medium for both endpoints (all *p*<0.001), with no significant interaction terms, indicating additive influences.

Conclusion: This study demonstrated that brief exposure to artificial saliva and fluoride mouthrinse significantly reduces the flexural strength and microhardness of DLP-printed provisional resins. Notably, Detax showed superior stability compared to Arma. The findings suggest that aqueous plasticization and hydrolysis are the primary degradation mechanisms. Therefore, selecting appropriate materials and using neutral-pH, alcohol-free rinses is crucial for enhancing the durability of 3D-printed provisionals.

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Introduction

Three-dimensional (3D) printing, an additive manufacturing process that fabricates objects layer by layer, has become integral to digital prosthodontics. Its application

enables rapid, precise, and patient-specific production of interim and definitive restorations within CAD/CAM workflows [1]. Among additive techniques, stereolithography (SLA) and digital light processing (DLP) are most widely used due to their high resolution, predictable surface quality, and compatibility with dental resin systems, supporting efficient clinical and laboratory integration [2-3].

Provisional restorations are essential in fixed prosthodontics, as they protect the pulp, maintain periodontal health, restore function and esthetics, and serve as functional prototypes for definitive prostheses [4]. According to the glossary of prosthodontic terms, provisional restorations are interim prostheses designed to provide esthetic, functional, and biologic stability for a defined period before placement of the definitive restoration, particularly in complex rehabilitations and implant-supported treatments [5].

Digital manufacturing has transformed provisional workflows. Some comparative studies suggest that 3D-printed provisional restorations can achieve competitive and sometimes superior marginal and internal fit compared with conventional or milled counterparts [6-7]. However, their mechanical performance may be material- and process-dependent, as a systematic review indicate that milled polymers often exhibit higher strength and superior surface finish, whereas 3D-printed resins are rapidly improving and are well suited for interim clinical applications [8].Clinically, the longevity of provisional restorations largely depends on flexural strength [9] and surface microhardness [10], which reflect resistance to occlusal forces and surface wear, respectively. These properties are influenced by printing parameters that affect polymer network formation, including layer orientation and post-processing protocols [11].

Provisional restorations are exposed to various chemical agents in the oral environment, including fluoride-containing mouthrinses such as NaF and SnF_2, which are routinely recommended for caries prevention [12-13]. However, some *in vitro* studies indicate that certain formulations, particularly those with lower pH or oxidative components, may increase surface roughness or reduce the microhardness of resin-based materials [14-15]. Despite extensive research on composites, evidence regarding the effects of fluoride mouthrinses on 3D-printed provisional resins remains limited, indicating a clinically relevant knowledge gap [16]. Accordingly, the present study was conducted to examine the influence of fluoride-containing mouthrinses on the flexural strength and surface microhardness of two commercially available 3D-printed provisional resins. By concurrently evaluating bulk load-bearing performance and surface integrity following controlled chemical exposure, this investigation aimed to inform evidence-based material selection and oral-hygiene recommendations during the provisional phase of prosthodontic treatment.

Materials and Method

Experimental Design and Ethical Statement

This *in vitro* study was conducted at the Department of Prosthodontics, Hamadan Dental School, Iran, in 2024. The study evaluated the effect of a fluoride-containing mouthrinse on the mechanical performance of 3D-printed CAD/CAM provisional resins. As a bench research study involving only synthetic materials, it was exempt from human or animal subject involvement and adhered to the principles of the *Declaration of Helsinki*.

A sample size estimation was conducted a priori using G*Power software (v3.1.9.7). Based on an anticipated medium-to-large effect size ($f = 0.35$), a significance level (α) of 0.05, and a statistical power ($1 - \beta$) of 0.80 for two-way ANOVA, a minimum sample size of 14 specimens per subgroup was determined. To account for potential fabrication flaws, 16 specimens per group ($n = 16$, total $N = 96$) were fabricated, ensuring sufficient statistical power.

Materials and Specimen Fabrication

Two vat-photopolymerizable provisional resins were utilized: Detax (Germany) and Arma (Germany). A total of 96 rectangular specimens ($n = 48$ per resin) were fabricated with dimensions of $25 \times 2 \times 2$ mm, adhering to standard bar geometry for three-point bending tests. The fabrication workflow included CAD design in Solid-Works, mesh refinement in Meshmixer, and nesting/support generation via Asiga Composer. Specimens were printed using an Asiga Freeform 2 printer (Asiga, Alexandria, NSW, Australia) via Digital Light Processing (DLP).

Post-printing, specimens were rinsed in 98% isopropyl alcohol for two minutes (twice), rested for 30 minutes and UV-cured for 30 minutes; the total exposure was

2 minutes per day over the 30-day immersion period, simulating approximately 6 months of daily clinical mouthrinse use. Dimensional accuracy was verified using a calibrated digital caliper (Fowler/Sylvac Ultra-Cal Mark IV). All specimens were subsequently wet-finished using silicon-carbide papers (#200, #400 and #800) [14].

Conditioning and Treatment Protocols

Specimens from each resin brand were randomly assigned to three groups ($n = 16$ per group) including (1) Baseline: no immersion; served as the control, (2) Artificial saliva: full immersion in artificial saliva at 37 °C, and (3) Artificial saliva + Fluoride: immersion in artificial saliva at 37°C, with twice-daily 1-minute exposures to an alcohol-free fluoride mouthrinse (Oral-B, Germany; 225 ppm F^-).

Artificial saliva was prepared by dissolving 0.34 gmonopotassium phosphate (KH_2PO_4), 1.50 gpotassium chloride (KCl), 0.58 gsodium chloride (NaCl), and 0.03 gmagnesium chloride hexahydrate ($MgCl_2 \cdot 6H_2O$) in distilled water, with subsequent additions of 6 mLof 0.5% (w/v) citric acid and 10 mLof 0.22% (w/v) calcium chloride ($CaCl_2$). The final pH was adjusted to 6.0–7.3. To prevent evaporation, all containers were sealed with paraffin wax, and the mouthrinse was replaced daily. Following the 30-day conditioning period, specimens were rinsed with deionized water, air-dried, and immediately subjected to mechanical testing.

Mechanical Testing

Flexural strength was determined using a universal testing machine (Instron, Canton, MA, USA) at a crosshead speed of 1 mm/min. A three-point bending test was performed with a support span (L) of 20 mm, in accordance with ISO 4049. Flexural strength (σ, in MPa) was calculated as follows:

- $\sigma = \frac{3FL}{2bd^2}$

where $F =$ load at fracture (N) , $L =$ support span (mm) , $b =$ specimen width (mm) ,$d =$ specimen thickness (mm).

Surface microhardness was measured using a micro-Vickers hardness tester (HMV-G20, Shimadzu, Tokyo, Japan) with a 25gf (0.245 N) load and a 10 sdwell time.

Three non-overlapping indentations were performed per specimen, and the mean Vickers hardness number (VHN) was recorded.

Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics (v26). Data are presented as mean ± standard deviation (SD). Normality and homogeneity of variances were verified via Shapiro–Wilk and Levene's tests, respectively. Comparisons between resins within each medium were conducted using independent-samples t-tests, while within-resin comparisons across media were analyzed via one-way ANOVA. To evaluate the interaction between resin type and treatment medium, a two-way ANOVA was employed. Post hoc pairwise comparisons were performed using Tukey's Honestly Significant Difference (HSD) test. Effect sizes were reported using Cohen's d(for t-tests) and partial eta squared (η_p^2) for ANOVA. A p-value $< 0.05$was considered statistically significant.

Table 1: Flexural strength (MPa) of the two resins within each medium

Medium	Resin	Mean ± SD(MPa)	*p* Value
Artificial Saliva	Arma	54.32±3.72	<0.001
	Detax	79.19±5.90	
Baseline (Control)	Arma	73.11±7.11	<0.001
	Detax	94.99±6.96	
Fluoride Exposure	Arma	52.92±3.74	<0.001
	Detax	77.29±5.80	

Results

Comparison between Resins

Detax consistently outperformed Arma across all media ($p < 0.001$). The mean differences in flexural strength were 21.9 MPa at baseline, 24.9 MPa in artificial saliva, and 24.4 MPa after fluoride exposure (Table 1). Regarding microhardness, Detax showed significantly higher Vickers values than Arma at baseline ($\Delta = 0.09$, 95% CI: 0.02–0.16, $p = 0.014$) and after fluoride exposure ($\Delta = 0.09$, 95% CI: 0.05–0.13, $p < 0.001$). However, the difference in artificial saliva was not statistically significant ($p = 0.267$) (Table 2).

Effect of Conditioning Media

A clear pattern was observed in both resins regarding the conditioning media. The baseline condition yielded the highest values, while fluoride exposure produced the lowest, with artificial saliva resulting in intermediate

Table 2: Vickers microhardness (VHN) of the two resins within each medium

Medium	Resin	Mean± SD	*p* Value
Artificial Saliva	Arma	0.37±0.09	0.267
	Detax	0.41±0.09	
Baseline	Arma	0.40±0.12	0.014
	Detax	0.49±0.09	

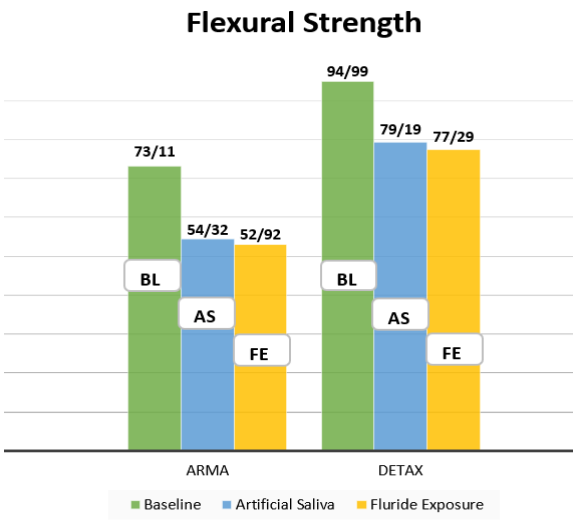


Figure 1: Comparison of flexural strength across groups within each resin

values (Figures 1-2). One-way ANOVA demonstrated significant between-group differences in flexural strength for both resins ($p < 0.001$) (Figure 1). Microhardness followed this same directional pattern, where baseline values were consistently higher than fluoride exposure values for each resin (Figure 2).

Interaction and Main Effects (Two-Way ANOVA)

Both resin and medium exhibited significant, independent effects on flexural strength. However, the resin × medium interaction was not significant. This indicates that the magnitude of the resin effect remained consistent across different media (Table 3). Similarly, a two-way ANOVA on rank-transformed microhardness showed significant main effects for both resin and medium. No statistically significant interaction was observed, mirroring the pattern found in the flexural strength results (Table 4).

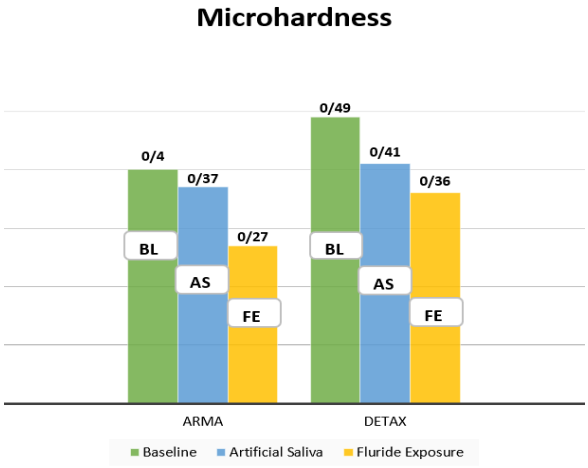


Figure 2: Comparison of Vickers microhardness across groups within each resin

Table 3: Two-way ANOVA for flexural strength (MPa)

Source	Type III Sum of Squares	Mean Square	F	*p* Value
Resin	13,490.04	13,490.04	414.64	<0.001
Medium (Group)	7,048.10	3,524.05	108.30	<0.001
Resin× Medium	41.08	20.54	0.63	0.53

Discussion

This *in vitro* study compared the effects of a fluoride-containing mouthrinse and artificial saliva on flexural strength and surface microhardness of two DLP-printed provisional resins (Arma and Detax). Across all conditions (baseline, artificial saliva, fluoride), Detax consistently exhibited higher values than Arma for both properties. Immersion in either medium significantly reduced flexural strength and microhardness relative to baseline. In Detax, reductions after fluoride were indistinguishable from those after artificial saliva for both outcomes, whereas in Arma microhardness though not flexural strength decreased more after fluoride than after saliva. Taken together, these findings implicate water sorption and hydrolytic plasticization as the dominant degradation pathways, with additional, formulation-dependent surface softening likely related to the mouthrinse chemistry (e.g., lower pH). Thus, deterioration cannot be attributed to fluoride alone under present protocol; performance is material-specific, with Detax providing a wider safety margin than Arma.

Flexural strength, which is critical for resisting occlusal forces was consistently higher in Detax than Arma at baseline and after exposure. The highest values occurred before exposure, and the lowest followed immersion in the fluoride mouthrinse for both materials.

Our findings showed significant decreases from baseline after both artificial saliva and fluoride in each resin, with no difference between saliva and fluoride for flexural strength in either material. Detax maintained a clear absolute advantage over Arma across all conditions, yet both resins exhibited significant post-immersion declines relative to baseline.

Table 4: Two-way ANOVA on rank-transformed microhardness (VHN)

Source	Type III Sum of Squares	Mean Square	F	*p* value
Resin	0.128	0.128	16.40	<0.001
Medium (Group)	0.263	0.132	16.90	<0.001
Resin×Medium	0.015	0.008	0.97	0.38

Previous studies have shown similar results [17-19]. Wang *et al*. [17] showed that additional fluoride release or exposure to specific solution chemicals reduced the flexural strength of resin materials, primarily through matrix softening and disruption of the filler-matrix interface. Similarly, Lambert *et al*. [18] reported that in additively produced polymers (e.g., FREEPRINT® splint 2.0), post-rinse solutions left the surface roughness unchanged but significantly reduced flexural strength, indicating chemical interactions rather than topographic damage. These effects of the fluoride mouthwash could be due to its acidic pH, which has detrimental effects on the mechanical properties of these two resins [19].

Microhardness reflects resistance to localized deformation, wear, and chemical softening; its decline may presage surface degradation and earlier restoration failure [3]. In our study, Detax showed consistently higher microhardness than Arma at baseline and after exposure. Both materials exhibited significant reductions after immersion in artificial saliva and a fluoride mouthrinse versus baseline. The decrement was material-dependent: in Detax, losses were similar in saliva and fluoride (no differential fluoride effect), whereas in Arma, fluoride produced a greater drop than saliva, indicating greater near-surface susceptibility to rinse chemistry.

These findings align with the previous literature. Gurgan *et al*. [20] likewise found significant hardness reduction across restorative materials following simulated daily mouthrinse exposure. Jyothi *et al*. [21] observed Vickers microhardness declines with five commercial rinses, with the largest loss in Listerine, implicating solvent/alcohol effects. Extending this, Hamdy *et al*. [22] showed the greatest reduction with a whitening rinse (Colgate Optic White) versus chlorohexidine or green-tea rinses, arguing that rinse composition, beyond pH alone, governs softening. In CAD/CAM polymers, Hazar *et al*. [14] demonstrated significant microhardness and color changes after 30-day immersion in povidone-iodine (PVP-I) and hydrogen peroxide (H□O□) (but not increased roughness). The decrease in microhardness after exposure to mouthwash is likely due to the low pH of the mouthwash. Previous research has shown that low pH environments promote the chemical erosion of temporary restorative materials and reduce their microhardness by etching the surface with acid and leaching the main cations composing the matrix [19].

However, the literature presents conflicting findings. Gurdal *et al*. [23] reported no significant microhardness change under their protocol, and Kwon *et al*. [24] found no effect of bleaching agents on nanofilled composite hardness over three weeks differences likely attributable to material chemistry, exposure schedules, and solution acidity/solvents. Additional evidence from Cavalcanti *et al*. [25] and Fayed *et al*. [26] supports that prolonged antimicrobial/oxidizing exposures degrade hardness in composites and hybrid CAD/CAM ceramics, while Yap *et al*. [27] linked certain rinses (notably Listerine and chlorohexidine with alcohol) to stronger reductions in microhardness and wear.

Although several previous studies [18, 23] have reported findings consistent with the present results, the available literature is not entirely consistent. Some investigations have reported minimal or non-significant changes in the mechanical properties of restorative materials following exposure to fluoride-containing solutions [14]. Such discrepancies may be attributed to differences in experimental design, including variations in restorative material composition, filler characteristics, resin matrix formulation [28], fluoride concentration, and the pH of the tested solutions [29]. In addition, differences in exposure duration, storage conditions, and artificial aging protocols may substantially influence the degree of material degradation [30]. Therefore, the reductions observed in flexural strength and microhardness in the present study should not be interpreted as a universal effect of fluoride exposure alone, but rather as the result of a complex interaction between the chemical environment and the intrinsic properties of the restorative materials. These factors may partly explain the variability reported across different studies.

In this *in vitro* study, the Arma and Detax resins were evaluated, and both exhibited reductions in surface microhardness and flexural strength following exposure to a fluoride-containing mouthrinse. Detax demonstrated superior mechanical performance relative to Arma, maintaining higher microhardness and flexural strength after exposure. The small sample size and brief assessment interval necessitate larger, longer-term investigations to substantiate these effects. Moreover, because the mouthrinse used in this study had an acidic pH, future work should examine formulations with neutral to near-neutral pH to delineate pH-dependent impacts on the m-

echanical properties of these materials.

From a clinical standpoint, the present findings underscore the importance of careful material selection and appropriate patient guidance when provisional restorations are subjected to routine mouthrinse use. Dental practitioners should recognize that exposure to fluoride-containing mouthrinses may influence the mechanical properties of certain provisional restorative materials, particularly those exhibiting lower baseline resistance. Consequently, when prescribing fluoride mouthrinses for patients with temporary restorations, clinicians should consider the material's susceptibility to chemical degradation and provide clear recommendations regarding the appropriate frequency and duration of mouthrinse use. Within the limitations of this *in vitro* study, the use of neutral-pH, alcohol-free mouthrinses may be preferable, and prolonged immersion of provisional restorations during the temporization period should be avoided, as such conditions may contribute to surface softening and reductions in microhardness.

Conclusion

In conclusion, brief and repeated exposure to artificial saliva and fluoride-containing mouthrinse significantly degrades the mechanical properties of 3D-printed (DLP) provisional resins. Throughout the study, Detax consistently outperformed Arma in terms of maintaining flexural strength and surface microhardness. The comparable flexural strength losses observed in both media suggest that aqueous plasticization and hydrolytic degradation are the dominant pathways, whereas fluoride-induced surface softening was specifically observed in the Arma group. These results underscore that degradation resistance is highly material-dependent and heavily influenced by resin formulation. Future studies should validate these findings across a broader range of resin chemistries and rinse formulations, utilizing more complex thermo-mechanical and pH-cycling protocols to better simulate clinical conditions

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Declaration of AI

During the preparation of this manuscript, the authors utilized generative artificial intelligence (ChatGPT, OpenAI) solely for language editing, grammar improvement, and readability enhancement. After using this tool, the authors thoroughly reviewed, verified, and edited the entire content, and take full responsibility for the integrity and scientific accuracy of the final published work.

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Ethical approval

The present *in vitro* experimental study was conducted at the Faculty of Dentistry, Hamadan University of Medical Sciences, during the 2024-2025 academic year. The study protocol was reviewed and approved by the Research Committee and Ethics Committee of Hamadan University (Ethics Code: IR.UMSHA.RES.1404.252).

Conflict of Interest

The authors claim to have no conflict of interest

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