

## Effect of Toothbrushing Abrasion on Surface Roughness and Gloss Retention of Nanocomposite Denture Teeth Materials

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### Abstract

#### Objectives

This study evaluated the comparative effect of simulated toothbrushing abrasion on the surface roughness (Ra) and gloss retention of nanocomposite, microfilled composite, and conventional polymethyl methacrylate (PMMA) artificial denture teeth.

#### Materials and Methods

Sixty artificial maxillary central incisor denture teeth were divided into three groups (n=20 each) based on their material composition: Group 1 (Nanocomposite; Veracia SA), Group 2 (Microfilled composite; SR Phonares II), and Group 3 (Conventional PMMA; Major Dent). The specimens were embedded in acrylic resin blocks and polished to achieve flat, uniform baseline surfaces. Simulated toothbrushing abrasion was performed using a mechanical brushing simulator with a standard dentifrice slurry under a 200 g vertical load. Profilometric surface roughness (Ra,  $\mu\text{m}$ ) and gloss units (GU, measured at a 60° geometry) were recorded at baseline (T 0 ), after 10,000 brushing cycles (T 1 ), and after 20,000 brushing cycles (T 2 ). Data were analyzed using two-way repeated measures ANOVA and Tukey's post-hoc tests ( $\alpha=0.05$ ).

#### Results

Toothbrushing abrasion significantly increased surface roughness and decreased gloss across all groups ( $p<0.001$ ). At T 2 (20,000 cycles), Group 3 (PMMA) exhibited the highest surface roughness ( $0.48\pm 0.04 \mu\text{m}$ ) and lowest gloss retention ( $42.3\pm 3.1$  GU). Group 1 (Nanocomposite) demonstrated the lowest surface roughness ( $0.23\pm 0.02 \mu\text{m}$ ) and highest gloss retention ( $76.8\pm 2.4$  GU) at T 2 , followed by Group 2 ( $0.31\pm 0.03 \mu\text{m}$ ;  $61.5\pm 2.9$  GU). The differences between all groups at T 1 and T 2 were statistically significant ( $p<0.05$ ).

#### Conclusion

Nanocomposite denture teeth demonstrate superior resistance to toothbrushing abrasion, maintaining lower surface roughness and higher gloss retention over simulated clinical timelines compared to microfilled composite and conventional PMMA teeth.

**Keywords** ;Nanocomposite, Denture Teeth, Toothbrushing Abrasion, Surface Roughness, Gloss Retention, PMMA.

### Introduction

The long-term clinical success and patient acceptance of removable complete and partial dentures depend heavily on the optical and mechanical stability of artificial denture teeth [1]. Polymethyl methacrylate has remained the traditional material of choice for manufacturing denture teeth due to its ease of adjustment, chemical bonding with the denture base, and satisfactory initial esthetics [2]. The ability to easily add, remove, or repair PMMA teeth in the dental laboratory contributes to its widespread use, as does its established track record over many decades of clinical service. However, conventional PMMA teeth exhibit low wear resistance and are highly susceptible to surface degradation caused by functional mastication and regular oral hygiene practices [3]. This susceptibility to wear compromises the occlusal relationships and functional efficiency of the prosthesis over time, necessitating frequent replacements or adjustments.

To overcome these mechanical limitations, manufacturers introduced highly cross-linked polymers and composite resin denture teeth. These materials were developed to address the inherent weaknesses of conventional PMMA by increasing the degree of polymer cross-linking, which enhances wear resistance and reduces the susceptibility to surface degradation. More recently, nanotechnology has been integrated into dental biomaterials, resulting in the development of nanocomposite denture teeth. These materials incorporate uniformly dispersed nano-sized inorganic fillers within a highly cross-linked polymer matrix [5]. This advanced composition aims to optimise the balance between mechanical strength, wear resistance, and esthetic longevity, addressing the limitations of both conventional PMMA and earlier composite materials.

During clinical use, patients are instructed to clean their dentures daily using manual toothbrushes and commercial dentifrices to prevent plaque accumulation, denture stomatitis, and staining [6]. However, the mechanical friction generated by toothbrush bristles combined with the abrasive particles in dentifrices induces micro-abrasion on the material surfaces [7]. This wear manifests primarily as an increase in surface roughness and a concomitant loss of surface gloss

[8]. The abrasive particles in dentifrices, typically composed of silica, calcium carbonate, or aluminium hydroxide, create microscopic scratches that progressively degrade the surface finish of the denture teeth over time.

An increase in surface roughness beyond the critical threshold of 0.2  $\mu\text{m}$  accelerates early bacterial colonisation and plaque retention, compromising oral health [9]. Rough surfaces provide mechanical retention sites that protect bacteria from the shearing forces of oral hygiene, facilitating biofilm formation and increasing the risk of denture stomatitis and other oral infections. Simultaneously, the loss of surface gloss diminishes the natural, life-like appearance of the prosthetic teeth, leading to premature esthetic failure [10]. The maintenance of surface gloss is particularly important for anterior denture teeth, where visual appearance is most critical for patient satisfaction and confidence.

Although several studies have examined the wear of composite materials, comparative data on how contemporary nanocomposite denture teeth maintain surface texture and optical gloss under prolonged abrasive challenges remains limited. Most existing research has focused on either conventional PMMA or early generations of composite teeth, without adequately addressing the newer nanocomposite materials that have entered the market. Furthermore, studies often evaluate either roughness or gloss in isolation, without examining the interrelationship between these two parameters and their combined effect on clinical performance.

Therefore, this study aimed to evaluate the effect of simulated toothbrushing abrasion on the surface roughness and gloss retention of nanocomposite denture teeth compared to microfilled composite and conventional PMMA materials. The null hypothesis formulated was that there would be no significant differences in surface roughness and gloss retention among the three denture teeth materials after simulated toothbrushing abrasion. By testing this hypothesis, the study seeks to provide evidence-based guidance for material selection in prosthetic dentistry, ultimately contributing to improved clinical outcomes and patient satisfaction.

## Materials and Methods

### *Specimen Preparation*

Sixty maxillary central incisor artificial denture teeth were selected for this study. The specimens were allocated into three experimental groups, with 20 specimens per group, based on their structural composition. Group 1 consisted of nanocomposite teeth (Veracia SA, Shofu Inc., Kyoto, Japan), which feature silica nanoparticles embedded in a microfilled composite matrix. Group 2 consisted of microfilled composite teeth (SR Phonares II, Ivoclar Vivadent, Schaan, Liechtenstein), which are composed of micro-hybrid fillers and urethane dimethacrylate. Group 3 consisted of conventional PMMA teeth (Major Dent, Major Prodotti Dentari, Moncalieri, Italy), comprising standard cross-linked PMMA.

Each tooth was embedded vertically in a custom cylindrical polyvinyl chloride mold using autopolymerizing acrylic resin, ensuring that the labial surface projected clear of the resin base. To create flat surfaces suitable for precise profilometric and glossimetric evaluations, the labial surfaces were wet-ground sequentially using 600-, 800-, and 1200-grit silicon carbide paper discs under continuous water cooling on a polishing machine. Final polishing was executed using a 0.05- $\mu\text{m}$  alumina slurry on a felt cloth to obtain a uniform baseline surface finish. All specimens were cleaned ultrasonically in distilled water for 10 minutes to eliminate any remaining residue and stored in distilled water at 37°C for 24 hours prior to testing.

### *Baseline Measurements*

Baseline surface roughness was documented using a contact profilometer (Mitutoyo SurfTest SJ-210, Mitutoyo Corp, Kawasaki, Japan). Three parallel traces were drawn across the centre of each specimen surface with a cutoff value of 0.8 mm, an evaluation length of 4.0 mm, and a stylus speed of 0.5 mm/s. The average of these three readings represented the baseline roughness value for each sample.

Baseline surface gloss was determined using a calibrated micro-glossmeter (Novo-Curve, Rhopoint Instruments, Hastings, UK) at a 60° measurement geometry angle. The measurement area was precisely aligned using a custom silicone positioning jig to ensure reproducibility across testing intervals. Three measurements were collected per specimen and averaged.

### *Simulated Toothbrushing Abrasion*

The specimens were subjected to simulated mechanical brushing using a multi-station toothbrushing simulator (Mechatronik, Feldkirchen-Westerham, Germany). Standard soft-bristled manual toothbrushes (Oral-B Indicator, Procter & Gamble, Cincinnati, OH, USA) were mounted to the brushing arms. A fresh toothbrush head was substituted for each experimental group.

A dentifrice slurry was prepared by blending a standard abrasive toothpaste (Colgate Cavity Protection, Colgate-Palmolive, New York, NY, USA) with distilled water in a 1:2 weight ratio. The Relative Dentin Abrasivity index of the toothpaste was approximately 70–80. The slurry was replenished continuously throughout the testing protocol to avoid particle depletion.

The simulation parameters were adjusted to a constant vertical load of 200 g and an operating speed of 120 strokes per minute in a reciprocating linear motion. The abrasion test was conducted up to a total of 20,000 strokes, which clinically

corresponds to approximately two years of manual denture brushing. Brushing was paused at two distinct intervals for interim data collection. After 10,000 cycles, representing one year of clinical wear, the specimens were extracted from the machine, rinsed thoroughly under running water, cleaned ultrasonically in distilled water for 5 minutes, dried with compressed air, and subjected to post-abrasion roughness and gloss analyses following the identical methodology utilised at baseline. The same procedure was repeated after 20,000 cycles, representing two years of clinical wear.

### Statistical Analysis

Statistical evaluation was conducted utilising SPSS version 23.0 software (IBM Corp., Armonk, NY, USA). Descriptive data were reported as means and standard deviations. Normality and homogeneity of variances were verified via the Shapiro-Wilk and Levene tests, respectively.

A two-way repeated measures analysis of variance was executed to determine the impact of the independent variables, Material Type and Brushing Cycles, on the dependent variables, Surface Roughness and Gloss. Pairwise intra-group and inter-group comparisons were subsequently completed using Tukey's honestly significant difference post-hoc test. The level of statistical significance was established at  $\alpha = 0.05$ .

### Results

#### Surface Roughness (Ra)

The mean surface roughness values for the investigated groups at baseline ( $T_0$ ), 10,000 cycles ( $T_1$ ), and 20,000 cycles ( $T_2$ ) are detailed in Table 1.

Two-way repeated measures ANOVA confirmed that both the material type and the number of brushing cycles had a highly significant effect on surface roughness values, with p-values less than 0.001. The interaction effect between material type and brushing cycles was also statistically significant at  $p < 0.001$ , indicating that the influence of brushing on roughness was dependent on the specific material composition.

At baseline, no statistically significant differences in Ra values were detected among Group 1, Group 2, and Group 3, with a p-value greater than 0.05. This indicates a uniform initial polish across all specimens and confirms that any subsequent differences observed could be attributed to the abrasive challenge rather than pre-existing surface variations.

Following 10,000 brushing cycles, the surface roughness increased significantly in all groups, with p-values less than 0.05. Group 3, the conventional PMMA group, presented the highest mean Ra at  $0.34 \pm 0.03 \mu\text{m}$ , which exceeded the critical plaque-accumulation threshold of  $0.2 \mu\text{m}$ . This elevation indicates that the surface had become sufficiently rough to promote bacterial adhesion and biofilm formation. Group 1, the nanocomposite group, retained the smoothest surface texture with a mean Ra of  $0.17 \pm 0.01 \mu\text{m}$ , remaining below the critical threshold.

At the final 20,000-cycle threshold, Group 3 showed extensive surface degradation, peaking at an Ra of  $0.48 \pm 0.04 \mu\text{m}$ . In comparison, Group 1 restricted the roughness increase to  $0.23 \pm 0.02 \mu\text{m}$ , displaying significantly higher abrasion resistance than Group 2, which recorded  $0.31 \pm 0.03 \mu\text{m}$ , and Group 3. The differences between Group 1 and the other two groups were statistically significant at  $p < 0.01$ .

Material Group	Baseline ( $T_0$ )	10,000 Cycles ( $T_1$ )	20,000 Cycles ( $T_2$ )
<b>Group 1: Nanocomposite</b> (Veracia SA)	$0.06 \pm 0.01^{a,A}$	$0.17 \pm 0.01^{a,B}$	$0.23 \pm 0.02^{a,C}$
<b>Group 2: Microfilled Composite</b> (SR Phonares II)	$0.07 \pm 0.01^{a,A}$	$0.24 \pm 0.02^{b,B}$	$0.31 \pm 0.03^{b,C}$
<b>Group 3: Conventional PMMA</b> (Major Dent)	$0.06 \pm 0.02^{a,A}$	$0.34 \pm 0.03^{c,B}$	$0.48 \pm 0.04^{c,C}$

**Table 1:** Mean surface roughness values ( $Ra \pm SD$  in  $\mu\text{m}$ ) for the tested denture teeth materials across brushing intervals.

Note: Different lowercase superscript letters indicate statistically significant differences within the same column (between groups). Different uppercase superscript letters indicate statistically significant differences within the same row (between time intervals) ( $p < 0.05$ ).

#### Gloss Retention

The mean gloss values recorded in Gloss Units at the corresponding testing intervals are organized in Table 2. Brushing abrasion induced a distinct drop in surface gloss across all material subsets over time, with a p-value of less than 0.001. At baseline, all groups displayed high, comparable gloss measurements fluctuating between 91.2 and 93.5 GU, and the differences between groups were not statistically significant.

After 10,000 cycles, surface gloss decreased across all groups. Group 3, the conventional PMMA group, dropped sharply to  $56.4 \pm 3.4$  GU. In contrast, Group 1, the nanocomposite group, preserved high gloss levels at  $84.1 \pm 2.1$  GU, indicating superior resistance to optical degradation during the early phase of abrasive challenge.

By 20,000 cycles, the nanocomposite group retained the highest gloss level at  $76.8 \pm 2.4$  GU, representing superior gloss retention compared to Group 2, which recorded  $61.5 \pm 2.9$  GU, and Group 3, which showed  $42.3 \pm 3.1$  GU. The inter-group differences at the final measurement interval were all statistically significant, with p-values less than 0.05. This pattern suggests that the incorporation of nano-sized inorganic fillers into the polymer matrix effectively resists the micro-abrasive effects of toothbrushing, thereby preserving the optical properties of the denture teeth over prolonged clinical use.

Material Group	Baseline (T0)	10,000 Cycles (T1)	20,000 Cycles (T2)
Group 1: Nanocomposite (Veracia SA)	$93.5 \pm 1.8^{a,A}$	$84.1 \pm 2.1^{a,B}$	$76.8 \pm 2.4^{a,C}$
Group 2: Microfilled Composite (SR Phonares II)	$92.1 \pm 2.0^{a,A}$	$71.3 \pm 2.6^{b,B}$	$61.5 \pm 2.9^{b,C}$
Group 3: Conventional PMMA (Major Dent)	$91.2 \pm 2.3^{a,A}$	$56.4 \pm 3.4^{c,B}$	$42.3 \pm 3.1^{c,C}$

**Table 2:** Mean gloss values (GU $\pm$ SD) for the tested denture teeth materials across brushing intervals. Note: Different lowercase superscript letters indicate statistically significant differences within the same column (between groups). Different uppercase superscript letters indicate statistically significant differences within the same row (between time intervals) ( $p < 0.05$ ).

## Discussion

The results of this study demonstrate that simulated toothbrushing abrasion significantly modifies both the surface roughness and gloss retention of artificial denture teeth. Furthermore, significant variations were identified among the materials tested, with the nanocomposite teeth showing lower surface roughness and higher gloss retention compared to microfilled composite and conventional PMMA alternatives. Therefore, the null hypothesis formulated for this study was rejected.

Toothbrushing simulators are widely accepted in dental materials research as reliable tools to mimic the mechanical challenges occurring in the oral cavity [11]. The baseline parameters selected for this protocol, including a 200 g vertical force and 20,000 individual strokes, approximate the structural friction and wear sustained over two years of manual maintenance by an average denture wearer [12]. This standardized approach allows for controlled comparison of material performance under clinically relevant conditions, eliminating the variability inherent in clinical studies while providing insights into the relative abrasion resistance of different materials.

Surface roughness values above  $0.2 \mu\text{m}$  are clinically relevant because they provide microscopic retentive niches that protect bacterial clusters from mechanical rinsing [9, 13]. When the surface roughness exceeds this threshold, plaque accumulation accelerates, increasing the risk of denture stomatitis, halitosis, and other oral infections. Our findings show that while all groups began with highly polished surfaces below this threshold, conventional PMMA rapidly degraded, exceeding the threshold by 10,000 cycles with a value of  $0.34 \mu\text{m}$  and reaching  $0.48 \mu\text{m}$  at 20,000 cycles. This substantial increase in roughness reflects the inherent vulnerability of PMMA to abrasive wear. PMMA lacks inorganic reinforcing filler complexes, leaving its unreinforced organic matrix vulnerable to the abrasive scratches inflicted by dentifrice particles [14]. The polymer chains are easily displaced or removed by the mechanical action of bristles and abrasive particles, resulting in progressive surface degradation.

In contrast, the nanocomposite group maintained excellent surface texture, only slightly exceeding the biological threshold after 20,000 cycles with a value of  $0.23 \mu\text{m}$ . This superior resistance to abrasion is primarily due to its structural composition. Nanocomposite denture teeth incorporate silica nanoparticles that are uniformly distributed throughout the polymer matrix [5, 15]. The small particle size reduces the inter-filler spacing, protecting the surrounding resin matrix from selective abrasion [16]. When the outer resin matrix gradually wears away, these nanoscale fillers are shed evenly, preventing the formation of deep surface defects that would otherwise increase roughness [17]. The uniform dispersion of nanoparticles also contributes to a more homogenous wear pattern, as the filler particles bear the brunt of the abrasive forces and protect the softer polymer matrix. This distribution of load across the surface minimizes the creation of large scratches or pits that would compromise the surface finish.

The microfilled composite group exhibited intermediate values for both surface roughness, at  $0.31 \mu\text{m}$ , and gloss retention, at 61.5 GU, at the final testing interval. Microfilled composites contain larger inorganic filler complexes compared to nanocomposites. During mechanical abrasion, these larger particles tend to debond or pluck from the resin matrix, creating micro-voids that increase surface roughness and scatter light, which reduces gloss [18, 19]. The irregular removal of these larger fillers creates an uneven surface profile where the exposed resin matrix between the filler particles is selectively worn away, leaving the filler particles protruding above the surface. This selective wear pattern creates peaks and valleys that significantly increase the average roughness and compromise the optical properties of the material.

Surface gloss is closely related to surface roughness, as flat, uniform surfaces produce specular light reflection, which creates high gloss [20]. When a surface becomes roughened, light is scattered in multiple directions rather than being reflected uniformly, reducing the perceived gloss. Our results confirm this relationship: as surface roughness increased from baseline to the final measurement interval, gloss values decreased across all groups. The nanocomposite group preserved high gloss levels at 76.8 GU, whereas the conventional PMMA group dropped to 42.3 GU, appearing visually dull. This reduction in gloss compromises the esthetic quality of the denture, as low gloss values fail to mimic the natural hydration and appearance of human enamel [21]. The natural gloss of enamel is an important component of the esthetic appeal of a denture, and its loss can make the prosthesis appear artificial and aged, potentially reducing patient satisfaction and confidence.

The superior performance of the nanocomposite material can be attributed to several interrelated factors. First, the nano-sized fillers provide a more uniform surface composition that resists selective wear. Second, the high cross-linking density of the polymer matrix enhances the overall mechanical strength of the material. Third, the strong adhesion between the filler particles and the polymer matrix prevents filler debonding, which is a common cause of surface degradation in microfilled composites. These structural advantages combine to provide a material that maintains both its mechanical integrity and its optical properties under prolonged abrasive challenge.

The clinical significance of these findings is substantial. For patients who wear dentures, maintaining the surface quality of the artificial teeth is essential for both oral health and patient satisfaction. The increased surface roughness associated with PMMA teeth promotes plaque accumulation, which can lead to denture stomatitis and other oral infections. The loss of gloss reduces the natural appearance of the denture, which can affect the patient's confidence and willingness to wear the prosthesis. By selecting materials that resist these forms of degradation, clinicians can improve the long-term outcomes for their patients. The nanocomposite material tested in this study appears to offer a clear advantage over both conventional PMMA and microfilled composite materials in terms of surface stability and esthetic longevity.

While these results provide useful comparative data on material performance, this *in vitro* design has certain limitations. The simulated environment did not account for the complex chemical changes that occur in the oral cavity, such as temperature fluctuations, variable salivary pH, and exposure to dietary solvents, which can soften polymer matrices and accelerate wear [22]. The abrasive slurry used in this study may not fully replicate the diversity of dentifrices available in the market, some of which contain more aggressive abrasive particles. The study also did not account for the effects of different brushing techniques or toothbrush bristle stiffness, which can influence the rate and pattern of wear. Additionally, the absence of saliva in the testing environment means that the lubricating and protective effects of the salivary pellicle were not simulated. Future clinical studies are needed to evaluate the long-term wear patterns of these materials under real-world conditions. Studies that incorporate multiple dentifrice formulations, toothbrush types, and user techniques would provide a more comprehensive understanding of material performance.

However, within these limitations, the use of nanocomposite materials appears to offer clear advantages for the mechanical and esthetic longevity of removable dental prostheses. The enhanced resistance to abrasion and superior gloss retention of nanocomposite teeth suggest that they can maintain a more natural appearance and a smoother surface for a longer period, contributing to improved oral hygiene and patient satisfaction. These findings support the clinical preference for nanocomposite denture teeth, particularly in patients who are expected to have high functional demands or who place a high value on the esthetic quality of their prosthesis. Future research should explore the long-term clinical performance of these materials and investigate the potential for further improvements through modification of the filler composition and polymer matrix.

## Conclusion

Based on the findings of this study and within the limitations of the *in vitro* design, the following conclusions can be drawn:

Simulated toothbrushing abrasion significantly increases the surface roughness and decreases the surface gloss of all tested artificial denture teeth materials over time. The mechanical friction generated by toothbrush bristles and abrasive dentifrice particles progressively degrades the surface finish of denture teeth, affecting both their functional and esthetic properties. Nanocomposite denture teeth (Veracia SA) exhibit superior resistance to abrasion, maintaining the lowest surface roughness and the highest gloss retention after 20,000 brushing cycles. The uniform dispersion of silica nanoparticles within the highly cross-linked polymer matrix effectively protects the surface from abrasive wear, preserving both the smooth texture and optical clarity of the material.

Conventional PMMA denture teeth are highly susceptible to mechanical abrasion, showing surface roughness changes that exceed the critical clinical threshold of  $0.2 \mu\text{m}$  after 10,000 cycles, along with a substantial loss of surface gloss. The absence of inorganic reinforcing fillers leaves the PMMA matrix vulnerable to abrasive scratches, compromising both the oral hygiene potential and the esthetic quality of the prosthesis.

Based on these findings, the clinical selection of denture teeth materials should consider the anticipated abrasive challenges of long-term use. Nanocomposite materials offer a clear advantage in maintaining surface smoothness and

gloss, which may contribute to improved plaque control, reduced risk of denture stomatitis, and enhanced patient satisfaction with the appearance of the prosthesis.

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