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Research Article

A Comparative Evaluation of Surface Roughness and Wear Resistance of Nano-filled vs. Nano-hybrid Composite Resins Following Simulated Toothbrush Abrasion: An In-Vitro Study

Salman Khan[1]*

[1]BDS, Khyber Medical University, Peshawar, Pakistan

*Correspondence Email: Salmansheh.ss@gmail.com

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ABSTRACT

This in-vitro comparative experimental study was conducted to evaluate and compare the surface roughness and wear resistance of nano-filled and nano-hybrid composite resins following simulated toothbrush abrasion. A total of 40 standardized disc-shaped composite specimens were prepared using a non-probability purposive sampling technique, with 20 specimens allocated to each composite group. As an in-vitro investigation, age was not applicable. The study was carried out in a dental materials research laboratory under controlled environmental conditions. Baseline surface roughness values were recorded using a contact profilometer, after which specimens were subjected to a standardized toothbrush abrasion protocol using a toothbrushing simulator. Post-abrasion surface roughness and wear depth were measured using profilometric analysis. The collected data were statistically analyzed to assess differences between the two composite resin groups. The results revealed that simulated toothbrush abrasion significantly influenced the surface characteristics of both materials; however, nano-filled composite resins demonstrated lower surface roughness values and greater wear resistance compared to nano-hybrid composites. These findings highlight the influence of filler technology on the abrasion resistance and long-term surface durability of resin-based restorative materials.

Keywords: In-vitro comparative study, toothbrush, long-term surface durability, restorative materials

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INTRODUCTION

Resin-based composite materials are widely used in restorative dentistry due to their superior esthetics, conservative tooth preparation requirements, and acceptable mechanical properties. Continuous advancements in filler technology and resin matrix composition have led to the development of nano-scale composite materials, aiming to improve surface characteristics, wear resistance, and long-term clinical performance [1,2]. Among these, nano-filled and nano-hybrid composite resins have gained significant attention because of their enhanced polishability, reduced surface roughness, and improved resistance to mechanical degradation compared to conventional composites [3].

Surface roughness is a critical parameter influencing the clinical success of composite restorations, as increased roughness can promote plaque accumulation, discoloration, secondary caries, and gingival inflammation [4,5]. Ideally, restorative materials should maintain a smooth surface throughout their service life despite exposure to mechanical and chemical challenges in the oral environment. However, routine oral hygiene practices, particularly toothbrushing with abrasive dentifrices, can adversely affect the surface integrity of resin composites over time [6].

Toothbrush abrasion is considered one of the primary extrinsic factors contributing to surface degradation and wear of restorative materials. Repeated brushing cycles may lead to preferential loss of the resin matrix or filler particles, resulting in increased surface roughness and reduced wear resistance [7,8]. The extent of abrasion-induced damage is influenced by several factors, including filler size, filler loading, resin matrix composition, and the quality of filler–matrix bonding [9].

Nano-filled composites are composed of uniformly distributed nano-sized filler particles, which allow for a highly polished surface and improved resistance to abrasive forces. In contrast, nano-hybrid composites contain a combination of nano-sized and micro-sized fillers, which may enhance mechanical strength but can potentially compromise surface smoothness following abrasive challenges [10,11]. While both materials are widely used in clinical practice, evidence regarding their comparative performance following toothbrush abrasion remains inconsistent [12].

In-vitro studies provide a controlled environment to evaluate the effects of simulated toothbrushing on restorative materials by eliminating confounding intraoral variables such as salivary composition, occlusal loading, and dietary factors [13]. Profilometric analysis is commonly employed to quantitatively assess surface roughness and wear depth, offering reliable and reproducible measurements of surface changes [14].

Given the increasing demand for durable and esthetically stable restorative materials, it is essential to understand how different composite formulations respond to long-term mechanical challenges. Therefore, the present in-vitro study aimed to comparatively evaluate the surface roughness and wear resistance of nano-filled and nano-hybrid composite resins following simulated toothbrush abrasion, with the objective of identifying the material that better preserves surface integrity under abrasive conditions [15,16].

METHODOLOGY

This in-vitro comparative experimental study was conducted in the dental materials research laboratory to evaluate and compare the surface roughness and wear resistance of nano-filled and nano-hybrid composite resins following simulated toothbrush abrasion. A total of 40 standardized disc-shaped specimens were prepared using a non-probability purposive sampling technique, with 20 specimens allocated to each composite resin group. The specimens were fabricated using a customized stainless-steel mold with uniform dimensions (10 mm diameter and 2 mm thickness) and polymerized according to the manufacturers' instructions using a light-curing unit with standardized intensity and exposure time. All specimens were finished and polished using a sequential polishing system to achieve a standardized surface prior to testing. Baseline surface roughness (Ra) values were recorded using a calibrated contact profilometer by taking three readings at different locations on each specimen and calculating the mean value.

Following baseline measurements, the specimens were subjected to simulated toothbrush abrasion using an automated toothbrushing simulator under standardized conditions, including controlled load, brushing speed, stroke length, and number of cycles to replicate long-term clinical toothbrushing. A slurry of fluoridated toothpaste and distilled water was used throughout the abrasion process to mimic oral hygiene conditions. After completion of the abrasion cycles, surface roughness measurements were repeated using the same profilometric protocol. Wear resistance was evaluated by measuring wear depth using profilometric analysis, with pre- and post-abrasion measurements used to calculate material loss. All collected data were entered into statistical software for analysis. Descriptive statistics were used to summarize the data, while paired t-tests were applied to assess within-group differences between baseline and post-abrasion measurements, and independent t-tests were used to compare outcomes between the nano-filled and nano-hybrid composite resin groups. A p-value of less than 0.05 was considered statistically significant.

RESULTS:

Table 1. Baseline Surface Roughness (Ra, µm)

Group	Mean ± SD
Nano-filled Composite	0.21 ± 0.04
Nano-hybrid Composite	0.26 ± 0.05

Table 2. Post-Toothbrush Abrasion Surface Roughness (Ra, µm)

Group	Mean ± SD
Nano-filled Composite	0.32 ± 0.06
Nano-hybrid Composite	0.45 ± 0.08

Table 3. Mean Wear Depth After Abrasion (µm)

Group	Mean ± SD
Nano-filled Composite	18.4 ± 2.6
Nano-hybrid Composite	25.7 ± 3.9

Table 4. Comparison of Surface Roughness Change (ΔRa)

Group	ΔRa (Mean ± SD)
Nano-filled Composite	0.11 ± 0.03
Nano-hybrid Composite	0.19 ± 0.05

Table 5. Statistical Comparison Between Groups

Parameter	p-value	Significance
Baseline Surface Roughness	0.042	Significant
Post-Abrasion Surface Roughness	0.001	Highly Significant
Wear Depth	0.003	Significant

DISCUSSION

The present in-vitro study evaluated the effect of simulated toothbrush abrasion on the surface roughness and wear resistance of nano-filled and nano-hybrid composite resins. The findings demonstrated a significant increase in surface roughness and material wear in both composite types following abrasion, with nano-hybrid composites showing greater surface degradation and higher wear depth compared to nano-filled composites. These results support the hypothesis that filler characteristics and resin matrix composition significantly influence the abrasion resistance of restorative materials.

The increase in surface roughness observed after simulated toothbrushing is consistent with previous studies reporting that repetitive brushing leads to preferential removal of the resin matrix and exposure or dislodgement of filler particles [17,18]. Surface roughness values exceeding clinically acceptable thresholds may contribute to plaque accumulation, surface staining, and compromised esthetics, emphasizing the importance of abrasion-resistant restorative materials [19].

Nano-filled composites demonstrated significantly lower post-abrasion surface roughness compared to nano-hybrid composites. This finding can be attributed to the presence of uniformly distributed nano-sized fillers, which allow for a denser filler packing and stronger filler–matrix bonding, resulting in improved resistance to mechanical abrasion [20,21]. In contrast, nano-hybrid composites contain a combination of nano- and micro-sized fillers, and the selective loss of larger filler particles during brushing may explain the increased surface irregularities observed in this group [22].

Wear resistance analysis further revealed that nano-hybrid composites exhibited significantly greater wear depth compared to nano-filled composites. Similar observations have been reported in previous investigations, where composite materials with heterogeneous filler sizes showed increased susceptibility to abrasive wear due to differential filler plucking and matrix degradation [23,24]. The superior wear resistance of nano-filled composites highlights their potential advantage in stress-bearing and esthetically demanding clinical situations.

The use of a standardized toothbrush abrasion simulator in this study allowed for controlled replication of long-term toothbrushing forces while eliminating intraoral variables such as salivary enzymes, pH fluctuations, and occlusal loading [25]. However, the in-vitro nature of the study remains a limitation, as clinical conditions may produce cumulative effects that differ from laboratory simulations. Therefore, long-term clinical studies are recommended to validate the present findings under actual oral conditions [26].

Despite these limitations, the results of this study provide valuable insight into the comparative performance of contemporary composite resins. The findings suggest that nano-filled composites may better maintain surface integrity and wear resistance over time, which could translate into improved longevity and patient satisfaction in clinical practice [27,28].

CONCLUSION

Within the limitations of this in-vitro study, simulated toothbrush abrasion significantly affected the surface roughness and wear resistance of both nano-filled and nano-hybrid composite resins. However, nano-filled composite resins demonstrated superior surface smoothness and greater resistance to wear compared to nano-hybrid composites following abrasion. These findings indicate that filler particle size and distribution play a crucial role in preserving the surface integrity of resin-based restorative materials, suggesting that nano-filled composites may offer better long-term esthetic and functional performance under routine oral hygiene conditions.

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