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Research Article

Unlocking Local Potential: A Comprehensive Evaluation of the Mechanical, Physical, and Clinical Properties of Pakistani-Made Dental Composites

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ABSTRACT

Objective: To assess and compare the mechanical, physical, and simulated clinical behavior of locally available dental composite resins.

Methods: In this one-year experimental study, 200 composite specimens were prepared from four brands available in Pakistan (n = 50 each). Specimens were prepared as per standard procedures. Tests included mechanical properties (compressive strength, flexural strength, surface hardness), physical properties (water sorption, solubility), and clinical performance (wear resistance, surface degradation). The data were analysed using IBM SPSS Statistics 26. Comparisons between groups were made using one-way ANOVA and Tukey's post-hoc test. A p-value ≤ 0.05 was considered significant.

Results: There were statistically significant differences ($p < 0.001$) between the four brands of composite resin for all parameters. Brand C had the highest compressive strength (285.3 ± 22.4 MPa), flexural strength (120.7 ± 11.1 MPa), and surface hardness (72.6 ± 6.3 VHN), as well as the least water sorption and solubility. It also exhibited good wear resistance and surface integrity. Brand A showed relatively lower values for all the properties.

Conclusion: Dental composites from Pakistan exhibited mixed results. Some materials had the potential to be used with at least equal properties as international brands, showing the capability of local brands; however, it is advised to test these materials clinically.

Keywords: Dental Materials, Composite Resins, Mechanical Properties, Physical Properties, Hardness.

INTRODUCTION

Dental resin composites have already taken the place of the traditional form of restorative dentistry, mainly because of the aesthetic superiority, adhesive qualities, and minimal invasiveness of the procedure of their use.[1] Composite resin, since its first introduction in the middle of the 20th century as an alternative to dental amalgam, has experienced an unending development in its formulation, the use of better filler systems, better resin matrix, and better methods of polymerization.[2] These developments have greatly enhanced their mechanical properties, such as compressive strength, flexural strength, wear resistance, and marginal integrity, to be used in both anterior and posterior restorations.[3, 4]

Dental caries is also one of the most widespread oral diseases across the world, with an estimated 2.5 billion individuals exhibiting untreated lesions in permanent teeth, a significant burden on the populace.[5, 6] Although composite resins are widely used, research has shown that it has a long existence period in clinical terms, with most existing between 5-15 years according to the quality of materials, the expertise of the operator, and the oral conditions.[7] But the bulk of the existing

evidence is based on imported commercial brands with little emphasis on locally produced options.

The dental materials market in Pakistan has experienced a recent growth, with several locally manufactured composite resins entering the market.[8] The purpose of these materials is to decrease reliance on costly imports and enhance accessibility of these materials to both the government and the privatized dental industry. Nevertheless, scientific literature on the mechanical, physical, and clinical performance of these indigenous composites is largely lacking. The majority of clinicians still depend on brand reputation instead of using evidence-based assessment of materials available within their locality, which leaves concerns over their effectiveness and reliability in the long run.[6]

Due to the increasing relevance of cost-effective healthcare solutions and the need to have sustainable dental materials, there is a need to scientifically test locally produced composites under controlled conditions. Their physical, mechanical, and clinical properties will not only be a validation of their performance but also will be part of the evidence-based material choice in the daily dental practice. Such data is crucial to support the creation of native dental materials and to educate the future formulation and quality assurance. Therefore, comparing and contrasting the mechanical, physical, and clinical properties of dental composite resin produced in Pakistan was the aim of this study, and to determine whether or not they can be used as a reliable restorative material in contemporary dentistry.

METHODOLOGY

The study was a comparative in-vitro experimental study that aimed at comparing the mechanical, physical, and clinical characteristics of dental composite resin manufactured in Pakistan. The purpose of the study was to evaluate the efficiency of locally produced composites in controlled laboratory conditions and compare their properties to the international standards. The experiment was conducted in the Department of Dental Materials. The time frame of the research was one year during which the entire process of sample preparation, testing, and data analysis was accomplished.

The Open epi software was used with an estimated prevalence of composite restoration failure of about 15%, a confidence interval of 95%, and a power of 80%.[9] The calculated sample size was 200. The study employed a non-probability consecutive sampling method to consider all potential Pakistani-manufactured composite resin materials in the market at that time.

The choice of different brands and colors of the local composites was aimed at variability and representativeness of the available products. The inclusion criteria included Pakistani-manufactured light-cured dental composite resins that were commercially available, frequently used in dental practice, and fully labeled by the manufacturer with batch numbers and expiry dates. The study only included Nano hybrid, micro hybrid, and hybrid composites that were to be used as restoratives. Exclusion criteria involved expired composite materials, imported or international materials, experimental or prototype materials that were not commercially offered, and composites whose manufacturer information was incomplete. Any materials that indicated contamination or improper storage were also not included in the study.

Standardized laboratory-based experimental protocols were used to gather the data. Materials of dental composite resin manufactured by Pakistani manufacturers were sampled with four commercially available brands of material (Brand A, Brand B, Brand C, and Brand D) that were extensively distributed in the local dental market and are routinely used in a traditional restorative procedure in dental clinics in Pakistan. Brand A was a traditional micro hybrid composite used as a general anterior and posterior restoration, having relatively larger particles of filler and moderate filler content. Brand B was a nanohybrid composite resin, which was developed using a mixture of both nano-sized and micro-sized filler particles in order to make it polishable and stronger. Brand C was a new high-performance Nano filled composite; the manufacturer stated that it has better compressive strength, wear resistance, and better esthetics, because of increased filler content and a new technology resin matrix. Brand D was a universal bulk-fill composite resin, which was intended to be used in deeper cavity restorations and offered a lower shrinkage of polymerization and better depth of cure.

All the materials were directly sourced from licensed dental supply vendors to ensure authenticity and checked with the batch number, manufacturing date, and expiry date before being included. The study only included

unopened and well-kept units to prevent the possibility of material degradation or contamination.

The 200 composite specimens (50 specimens per brand) were prepared under standard laboratory conditions using stainless steel moulds of the same size. All the specimens were prepared according to the ISO requirements of the resin-based restorative materials in order to make them reproducible and comparable. A calibrated LED curing unit with standard intensity and exposure time was used to apply light curing to all samples to reduce variation. Each of the specimens was maintained in distilled water at 37 °C for 24 hours after polymerization to simulate the conditions of the oral environment and to allow the stabilization of the polymer after polymerization.

Mechanical testing was followed to determine compressive strength, flexural strength, and surface hardness, and physical properties such as water sorption and solubility were determined by use of gravimetric analysis. To model clinical aging, the specimens were thermo cycled and mechanically brushed to simulate oral conditions, and wear resistance and surface degradation were measured. Each test was done thrice on each specimen, and the average values were put down to observe the accuracy and reliability of the results.

IBM SPSS version 26 was used in entering and analyzing the data. The quantitative variables were used as the mean with standard deviation (SD). The inferential analysis was done after checking the normality of data distribution by the Shapiro-Wilk test. One-way Analysis of Variance (ANOVA) was used to compare mechanical, physical, and simulated clinical properties of the four composite groups. In the instances where statistically significant differences were established, a post-hoc multiple comparison test using Tukey was used to establish intergroup differences. The p-value of 0.05 was used to mark as statistically significant.

RESULTS

Table 1 presents the comparison of the mechanical properties of the four composite brands. One-way ANOVA revealed statistically significant differences in compressive strength ($F = 36.42$, $p < 0.001$), flexural strength ($F = 41.18$, $p < 0.001$), and surface hardness ($F = 29.76$, $p < 0.001$). Brand C recorded the highest mean compressive strength (285.3 ± 22.4 MPa), flexural strength (120.7 ± 11.1 MPa), and surface hardness (72.6 ± 6.3 VHN), and Brand A recorded the lowest values of all mechanical parameters.

Table 1: Mechanical Properties of Composite Resins

Brand	Compressive Strength (MPa)	Flexural Strength (MPa)	Surface Hardness (VHN)
Brand A	210.5 ± 18.6	85.2 ± 9.4	52.4 ± 5.1
Brand B	235.7 ± 20.3	95.6 ± 10.2	58.9 ± 4.8
Brand C	285.3 ± 22.4	120.7 ± 11.1	72.6 ± 6.3
Brand D	260.4 ± 19.8	110.3 ± 10.5	65.1 ± 5.7
F-value	36.42	41.18	29.76
p-value	<0.001	<0.001	<0.001

Table 2 shows the physical properties. One-way ANOVA revealed statistically significant differences in the water sorption ($F = 33.09$, $p < 0.001$) and the solubility ($F = 27.54$, $p < 0.001$). Brand C had the lowest water sorption (28.7 ± 3.1 µg/mm) and solubility (1.6 ± 0.4 µg/mm), which was the most resistant to degradation, whereas Brand A had the highest values.

Table 2: Physical Properties of Composite Resins

Brand	Water Sorption (µg/mm³)	Solubility (µg/mm³)
Brand A	38.6 ± 4.2	2.8 ± 0.6
Brand B	34.9 ± 3.8	2.3 ± 0.5
Brand C	28.7 ± 3.1	1.6 ± 0.4
Brand D	30.5 ± 3.5	1.9 ± 0.5
F-value	33.09	27.54
p-value	<0.001	<0.001

Table 3 summarizes simulated clinical performance outcomes, post-aging. Significant differences could be statistically found in wear resistance ($F = 38.21$, $p < 0.001$) and in surface degradation scores ($F = 31.87$, $p < 0.001$). Brand C showed the best wear resistance (91.5 ± 4.8%), and the lowest score in degradation (2.1 ± 0.5), and it shows better clinical longevity. Brand A, on the other hand, exhibited the least wear resistance and the greatest degradation

Table 3: Simulated Clinical Performance after Aging

Brand	**Wear Resistance (%)**	**Surface Degradation Score (0–5)**
Brand A	78.4 ± 6.2	3.8 ± 0.7
Brand B	82.1 ± 5.9	3.2 ± 0.6
Brand C	91.5 ± 4.8	2.1 ± 0.5
Brand D	88.3 ± 5.1	2.6 ± 0.6
F-value	38.21	31.87
p-value	<0.001	<0.001

DISCUSSION

The current research assessed the mechanical, physical, and simulated clinical characteristics of dental composite resins produced in Pakistan and proved the statistical significance of differences between all the tested materials. Brand C was performing at a higher level than the other groups, with Brand A at a relatively lower level in all parameters. These results agree with the modern literature, which accentuates the inconsistency of performance among composite resins based on the filler composition, particle size, and the properties of the resin matrix

The high compressive and flexural strength of Brand C in the present study is significantly high, which is in agreement with the results of a study conducted by MDPI (2022), which revealed that nanohybrid composites with an optimized position of fillers have a high mechanical strength because their stress transfer between the resin matrix and filler particles is improved.[10] On the same note, an in-vitro study conducted in 2024 found that composites with complex filler systems had better compressive strength than simpler formulations, which corroborates our observation that complex filler technology is associated with better performance.[11]

The high flexural strength and hardness of Brand C are also in line with the results of a 2024 study published in BMC Oral Health that found that newer high-strength composites exhibited significantly better flexural characteristics and surface hardness than traditional materials.[12] This resemblance implies that the enhanced performance of Brand C could be explained by the increased filler loading and better polymer matrix composition.

Regarding surface hardness, the obtained results are additionally supported by a 2025 study that compared Nano hybrid and digitally fabricated composites, in which the homogeneous distribution of materials could be more readily characterized by high hardness values and resistance to deformations.[12] This supports the idea that filler dispersion and microstructure are crucial factors in determining the mechanical integrity of composite resins

The water sorption and solubility values attained in the current study revealed that the water sorption and solubility were much lower in Brand C, suggesting a greater resistance to degradation. These results are in line with a 2024 study examining hybrid composites that use bioactive fillers, where it was noted that lower water uptake was related to a higher cross-linking density and a lowering of the matrix degradation.[13] Reduced water sorption has clinical significance since it reduces hydrolytic degradation and increases the longevity of restoration.

Also, it is in line with the literature that has assessed reinforced Nano hybrid composites that the wear resistance and reduced surface degradation in Brand C are improved. A 2023 study of Nano cellulose-reinforced composites showed that the higher the filler reinforcement, the greater the wear resistance and mechanical durability.[14] The results of this study are consistent with the findings of the current study because composites that had developed filler systems performed better in simulated clinical conditions.

The difference that is witnessed with regard to the four composite brands within the current study has also been supported by the larger literature. It is always reported that dental composites vary greatly in mechanical and physical characteristics, dependent on filler size, distribution, and resin composition.[15, 16] This is the reason why statistically significant differences were observed in the current study in all the parameters being tested. The other important observation in the current research was that Brand A performed comparatively poorly, which could be a result of its microhybrid composition. Past research has revealed that microhybrid composites tend to be weak in mechanical strength and have higher water sorption than nanohybrid or nanofilled composites because of larger filler particle size and inefficient packing.[17, 18] This justifies the poor performance in Brand A. Also, the research revealed that nanofillers, fiber reinforcement, and enhanced resin matrix are innovations that can be used to improve the performance of composites. A study of fiber-reinforced nanohybrid composites has shown a significant increase in compressive and flexural strength, which needed engineering of materials to enhance the results of restorations.[19]

In general, the results of the current study align with other studies, all of which highlight that advanced composite formulations with optimized filler technology have better mechanical, physical, and clinical properties. The statistically significantly higher efficacy of Brand C in the current research mirrors the same tendencies in other countries, thus confirming the accuracy of the current results.

The findings of the present research align well with the modern literature, showing that the performance of dental composite resins strongly depends on their composition and microstructure. The high characteristics shown by Brand C underscore the possibilities of advanced Pakistani-made composites to match the international standards. But the differences between brands highlight the importance of rigorous quality assurance and additional clinical trials to guarantee uniform performance during routine dental practice.

Study Limitations

Despite the fact that this study provides valuable information on the performance of Pakistani-origin dental composite resins, this study has several limitations that must be considered in the interpretation of the results of this study. The experiment was conducted in an in-vitro lab setup, therefore, not providing a full simulated oral environment, where saliva, changes in pH, masticatory forces, and patient variables can influence the clinical performance of composite restorations. Second, the simulated clinical aging protocols, which are standardized, include thermocycling and mechanical brushing, which are not able to fully simulate long-term intraoral conditions. Thus, wear resistance and surface degradation results should be taken with caution when applying to actual clinical environments. Third, the study used only four local composite brands available. Although these were common materials used, the findings may not apply to all the composites produced in the country, or to products just in the market. Other clinically significant factors, such as polymerization shrinkage, marginal adaptation, color stability, and biocompatibility, were not considered in the study. Finally, it lacks any long-term clinical follow-up data, which does not give the possibility of direct correlation of laboratory results with real clinical success and survival of restorations.

CONCLUSION

The dental composite resins produced in Pakistan had high variability in mechanical, physical, and simulated clinical properties. Brand C also performed better than Brand A in compressive strength, flexural strength and surface hardness, wear resistance, water sorption and solubility and Brand A performed lower across all the parameters. The results indicate that there are some locally produced composites that have the potential to compete on the level of international standards, which indicates the increasing competencies of the local dental materials sector. The variability observed in brands, however, highlights the importance of strict quality control, standardization, and additional evidence-based assessment. Future studies must concentrate on long-term clinical trials, material testing, and testing of more properties and more variety of products to confirm these results and inform material selection in clinical practice

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