

Nano-composite versus conventional light-cure composite: A comparative assessment of orthodontic bracket bond failure rates

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Abstract

Objective: To compare the bond failure rates of orthodontic brackets bonded with nano-composite and conventional light-cure composite using a fourth-generation curing unit.

Method: The randomised double-blind parallel group, clinical trial was conducted on 50 patients at the Department of Orthodontics, Foundation University College of Dentistry and Hospital, Islamabad, Pakistan, from January to December 2022, and comprised patients aged 12-35 years requiring fixed orthodontic treatment. They were randomly assigned to two groups. Control (group A) and experimental (group B). In group A patients brackets were bonded using conventionally used composite with micro sized filler particles (Transbond XT) however in Group B patients brackets were bonded using composite with nano hybrid sized filler particles (Filtek). Composites in both groups were cured using same LED light. Bond failure rates were measured as number of brackets getting deboned over a assessment period of 3 months and 6 months respectively. Data were analysed using SPSS 26.

Results: Of the 50 patients with mean age 22.9 ± 5.0 years (range: 12-35 years), 31(62%) were female and 19(38%) were male. There were 25(50%) patients in each group. A total of 1,000 orthodontic brackets were evaluated; 500(50%) in each group. A total of 18(1.8%) bracket failures were observed; 11(2.2%) in Group A, and 7(1.4%) in Group B ($p=0.61$). The highest failure rate was observed in second premolars 12(6%). Early failure peaks were noted in Group A during the second ($p=0.04$) and fourth ($p=0.02$) months. No significant intergroup or intragroup differences were detected at either of the two follow-ups ($p>0.05$).

Conclusion: Both the composites demonstrated clinically acceptable bond failure rates (<5%). Although the nano-composite showed a numerically lower failure rate, the difference was not statistically significant.

Trial registration: ClinicalTrials.gov Identifier: NCT05644860.

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Introduction

Bonding is the most extensively studied and documented procedure in orthodontics. Establishing optimal bond strength between the bracket and the tooth surface is crucial for effective tooth movement as it ensures that the forces generated by succession of orthodontic wires at each clinical visit are tolerated by the brackets and eventually transmitted to the teeth.¹ The success of bracket bonding not only affects the treatment duration, but also the overall quality of care and patient satisfaction. Repeated bond failure interferes with continuous tooth movement, and may increase the number of appointments, hence reducing patient compliance.²

Constituents of bonding materials are diglycidyl ether methacrylate, coupling agents and inorganic fillers quartz

and silica.³ Inorganic filler particle size in orthodontic adhesives varies from a few micrometres (5-100 μ m) in the conventional dental composite to nanometres (5-100nm) in the recently introduced restorative nano-composite in dentistry. Inorganic filler particle size in nano-filled composites typically contain fillers ranging 5-100nm.⁴ A new class of materials, called polymer nano-composite, has been produced recently, containing 0.005-0.01 microns-sized nano fillers. The reduction in size of filler particles allows an increased inorganic filler load, which, in turn, improves the properties of composites, such as ability to withstand occlusal load, enhancing resistance against fracture, tensile strength, and compressive strength.⁵ Jhunjhunwala et al.⁶ demonstrated that the choice of reattachment material significantly influences the fracture resistance and bonding performance of reattached crown fragments, with contemporary adhesive and composite systems showing superior outcomes.

Light-cured orthodontic bonding materials need a specific light cure device with wavelength within range 400-520nm of visible light.⁷ The same applies for composites used in restorative dentistry, but in nano-composite, due to

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variable filler content and addition of colouring agents, the range for wavelength increases.⁸⁻¹⁰ Recently, fourth-generation light-curing units have been introduced incorporating an additional light emitting diode (LED) that increases the range of visible light, resulting in better curing of restorative nano-composite in a shorter duration of time. Due to this reason, most researchers have recommended using fourth-generation LED curing light for nano-composite.^{11,12}

Re-bonding can be a demanding procedure in case of repeated breakages, making achieving the right bond strength a crucial clinical goal.^{13,14} Different adhesives, including micro-filled, micro hybrid and flowable composites, are currently in use, but there is a growing expectation that nano-filled adhesives will supersede others soon.^{15,16}

Despite the widespread adoption of nano-adhesives in restorative dentistry, their application in orthodontics remains relatively underexplored and less frequently employed. Until now very few studies have been reported in literature to endorse the clinical effectiveness of nano-composite in orthodontic bonding.^{17,18}

The current study was planned to observe and evaluate long-term clinical effectiveness of nano-composite in orthodontics by comparing bond failure rates of brackets bonded with nano-composite to those bonded with conventional light-cured composites using fourth generation LED curing unit.

Materials and Methods

The in-vivo, randomised, double-blind, parallel-group clinical trial was conducted at the Department of Orthodontics, Foundation University College of Dentistry and Hospital, Islamabad, Pakistan, from January to December 2022. After approval from the institutional ethics review committee, the study was registered with ClinicalTrials.gov Identifier: NCT05644860.

The sample size was calculated for a two-group comparison of proportions using the Fleiss formula¹⁹ with continuity correction through OpenEpi software (version 3.01),²⁰ assuming a bond failure rate of 5% in the control group ($p_1=0.05$) and 2% in the experimental group ($p_2=0.02$), with a level of significance of 5% ($\alpha=0.05$) and power of 80% ($1-\beta=0.80$). Based on these assumptions, the required sample size was 25 patients per group (total $n=50$). Each participant contributed multiple bonded brackets, resulting in a total of 1,000 brackets (500 per group) being evaluated.

The sample was recruited using non-probability

consecutive sampling from patients presenting to the Orthodontic Department who met the inclusion criteria and were diagnosed with malocclusion necessitating treatment with fixed appliances on both arches. Those included were patients aged 12-35 years who had a complete set of permanent teeth, with all premolars erupted. Patients with variations in dental morphology, like hypoplasia, fluorosis, microdontia, macrodontia, hypodontia and heavily-restored teeth, were excluded, and so were those having parafunctional habits, gastroesophageal reflux or using any other appliance before the placement of fixed braces. Patients who were planned for fixed functional appliances were also excluded due to higher rates of lower canine bracket failures.

After taking informed consent, participants meeting the eligibility criteria were randomly allocated into two equal groups using a computer-generated random sequence with allocation concealment through sealed opaque envelopes. Blinding was maintained for both the participants and the outcome assessor.

- **Group A (Control):** Conventional light-cure composite (Transbond XT)
- **Group B (Experimental):** Nano-composite resin (Filtek Z250)

All bonding procedures were standardised and performed by a single operator. The primary outcome was orthodontic bracket bond failure rate, assessed over a 6-month follow-up period at 3 and 6 months.

In control Group A, brackets were bonded using a conventional composite resin comprising bisphenol A-glycidyl methacrylate (BIS-GMA), bisphenol A-ethoxylated dimethacrylate (BIS-EMA), silylated filler, silylated quartz, and submicron silica (77 wt%), (Transbond XT; 3M Unitek, Monrovia, CA, USA).

In Group B, brackets were bonded using a nano-composite resin containing bisphenol A-glycidyl methacrylate (BIS-GMA), urethane dimethacrylate (UDMA), triethylene glycol dimethacrylate (TEGDMA), polyethylene glycol dimethacrylate (PEGDMA), BIS-EMA, zirconia fillers (4–11 nm), silica (20 nm), and cluster particles (0.6–10 μm ; 78.5 wt%), (Filtek Z250; 3M ESPE, St. Paul, MN, USA).

The same operator carried out the bonding procedure. The protocol started with surface treatment of enamel, using pumice and water to remove any salivary proteins. The enamel was then conditioned using 37% phosphoric acid for 15 seconds, followed by washing and gentle drying. Afterwards, a thin layer of bonding agent was applied and light-cured. Standardised metallic orthodontic brackets

(MBT prescription, 0.022-inch slot; Sky Dent Ortho Line, USA) were used for all patients. Brackets were bonded from the second premolar on one side to the second premolar on the contralateral side in both the maxillary and mandibular arches in both groups. Each bracket in both groups was light-cured for 5 seconds using a fourth-generation LED curing unit (O-Light Plus; Woodpecker, Guilin, China).

The outcome measured was the rate of bracket failure i.e., the total number of brackets becoming loose over the assessment period of 3 months and 6 months, respectively. Throughout the initial 6 months, the clinician documented any instances of bracket failure at each appointment. Loose brackets that were unacceptable for re-bonding were discarded, and replaced with new brackets.

Data were analysed using SPSS 26. Normality of continuous variables was assessed using the Shapiro-Wilk test. Descriptive statistics were presented as frequencies and percentages, or as mean $\pm$ standard deviation. Intergroup comparisons were performed using the Mann-Whitney U test for non-parametric data. For survival analysis, each bonded bracket served as the unit of analysis. A bond failure (event) was defined as the detachment of a bracket requiring rebonding. Time-to-event was measured in months from initial bonding to the date of failure, whereas brackets that remained intact at the end of the six-month follow-up were treated as censored observations. Kaplan-Meier estimates were used to calculate cumulative survival probabilities, and intergroup differences were assessed using the log-rank test. $P \leq 0.05$ was considered statistically significant.

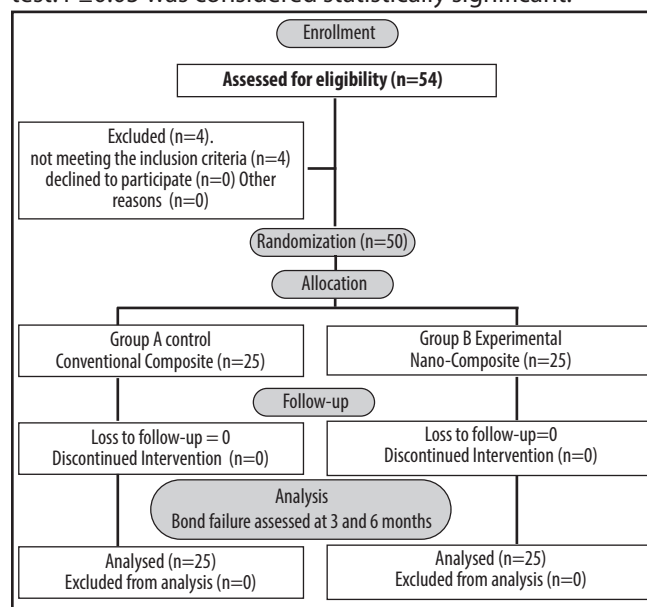


Figure-1: Consolidated Standards of Reporting Trials (CONSORT) flow diagram.

Results

Of the 54 patients initially screened, 50(92.6%) were included (Figure 1). Of these patients with mean age 22.9 ± 5.0 years (range: 12-35 years), 31(62%) were female and 19(38%) were male. There were 25(50%) patients in each group. A total of 1,000 orthodontic brackets were evaluated; 500(50%) in each group (Table 1).

A total of 18(1.8%) bracket failures were observed; 11(2.2%) in Group A, and 7(1.4%) in Group B ($p=0.61$) (Table 2).

Intergroup comparison of mean bracket failures at three months ($p=0.61$) and six months ($p=0.63$) showed no significant difference between the groups. Similarly, intragroup comparisons over time demonstrated no significant change in failure rates within either Group A ($p=0.24$) or Group B ($p=0.98$) (Table 3).

Monthly comparison of bond failures showed that most detachments occurred within the first four months, with Group A showing significant peaks during the second ($p=0.04$) and fourth ($p=0.02$) months. By the end of six months, the nano-composite exhibited a lower cumulative

Table-1: Intergroup comparison of gender, age and malocclusion ($n=50$).

Adhesive Type	Age Range (years)	Mean $\pm$ SD (years)	Males n (%)	Females n (%)	Class I n (%)	Class II n (%)
Conventional Composite (Group A)	17–35	24.8 ± 4.6	9 (36)	16 (64)	10 (40)	15 (60)
Nano-composite (Group B)	12–31	21.3 ± 5.2	10 (40)	15 (60)	9 (36)	16 (64)
Total	12–35	22.9 ± 5.0	19 (38)	31 (62)	19 (38)	31 (62)

Table-2: Intergroup comparison of bond failure rate with respect to adhesive type and tooth type (Cumulative scores).

Adhesive Type	Bonded n (%)	Failures in 3 months n (%)	Failures in 6 months n (%)	p-value (Mann–Whitney U test)
Conventional Composite	500 (50)	10 (2)	11 (2.2)	0.61
Nano-composite	500 (50)	6 (1.2)	7 (1.4)	
Total	1,000 (100)	16 (1.6)	18 (1.8)	

Tooth type	Bonded n (%)	Failures within 6 months n (%)	p-value (Chi-square test)
Lateral incisor	200 (20)	3 (1.5)	0.82
First premolar	200 (20)	3 (1.5)	
Second premolar	200 (20)	12 (6)	
Total	1,000 (100)	18 (1.8)	

Table-3: Intergroup and intragroup comparison of bracket bond failure.

Comparison	Mean $\pm$ SD	Statistical test	p-value
Group A vs Group B at 3 months	0.93 ± 0.52	Mann–Whitney U = 12.00	0.61
Group A vs Group B at 6 months	0.68 ± 0.49	Mann–Whitney U = 11.50	0.63
Group A (3 vs 6 months)	0.80 ± 0.58	Wilcoxon signed-rank test	0.24
Group B (3 vs 6 months)	0.72 ± 0.46	Wilcoxon signed-rank test	0.98

SD; Standard deviation.

bond failure rate 7(1.4%) compared to the conventional composite 11(2.2%) ($p>0.05$). Overall, the nano-composite demonstrated numerically fewer failures and more consistent stability across the six-month period, although

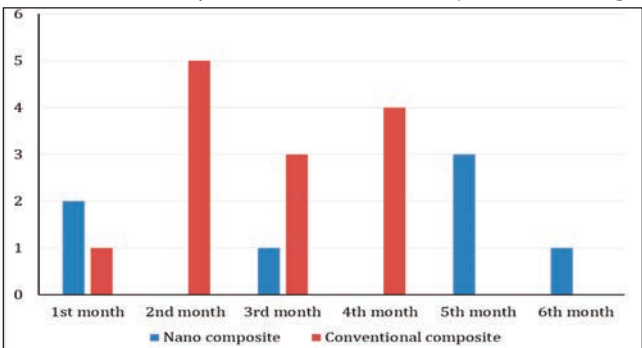


Figure-2: Comparison of bond failure rate over six months between the study groups.

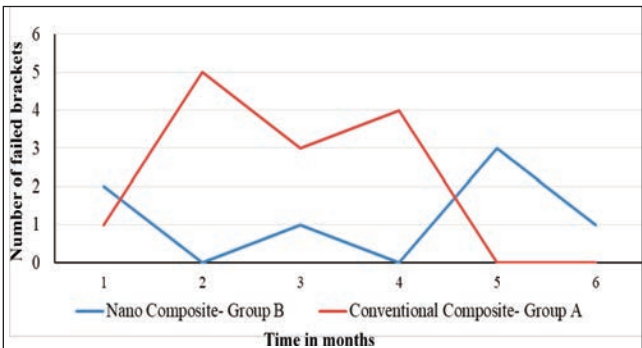


Figure-3: Comparison of monthly bond failure rates between the study groups.

no significant difference was found between the two adhesive systems (Tables 1-3, Figures 2-3).

Risk analysis evaluated factors that may influence the bracket bond-failure rate for both the groups (Table 4). The Kaplan-Meier survival curves showed only a minimal decline in cumulative survival for both the groups reflecting the low overall failure rate (1.8%) among the large number of brackets evaluated ($n=1,000$). (Figure 4).

Discussion

The randomised clinical trial evaluated the bond failure rates of orthodontic brackets bonded with nano-hybrid and conventional light-cure composites over a six-month period. The results revealed a lower failure rate in the nano-composite group (1.4%) compared to the conventional composite group (2.2%), though the difference was not

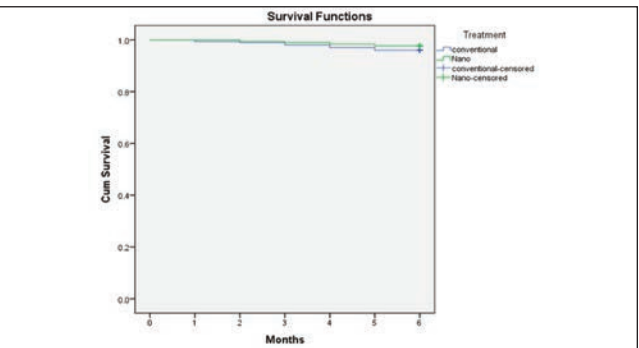


Figure-4: Kaplan-Meier survival plot showing bond failure rate over 6 months.

Table-4: Risk analysis evaluating factors that may influence the bracket bond failure rate in both the study groups.

Identified Risk	Description of Risk in Context of Study	Likelihood	Impact on Failure Rate	Overall Risk Level	Mitigation Measures (Applied in Study)	Residual Risk
1.Material-related failure	Variability in mechanical properties of nano vs conventional composite may influence early bracket detachment.	Moderate	Moderate	Moderate	Standardized bonding protocol; same operator; controlled curing time.	Low
2.Operator variability	Difference in bonding technique may affect bond strength.	Low	High	Moderate	Single experienced operator performed all procedures.	Low
3. Tooth surface contamination	Saliva/moisture contamination during bonding increases failure.	Moderate	High	High	Use of cheek retractors; strict moisture control; etching isolation	Moderate
4. Patient-related behavioral factors	Chewing habits, biting hard foods, and poor compliance may cause failure.	Moderate	Moderate	Moderate	Standardized oral hygiene instructions; patient counselling.	Moderate
5.Archwire/force related failure	High initial forces may increase early bracket loss.	Low	Moderate	Low	Uniform wire sequence used for all subjects.	Low
6.Tooth type variability	Certain teeth (canines, premolars) may experience higher shear forces.	Low	Moderate	Low	Equal distribution ensured; tooth-wise analysis performed (Table provided).	Low
7.Material fatigue over time	Long-term degradation of adhesive can increase late failure.	Moderate	Moderate	Moderate	Six-month follow-up; identical recall intervals.	Moderate
8.Inaccurate recording of failures	Missed or misrecorded failures could affect rates.	Low	High	Moderate	Double-entry verification; cross-checking with clinical notes.	Low
9. Loss to follow-up	Participant drop-out may bias failure rate	Very Low	High	Low	No participants lost (0% attrition).	Very Low
10.Statistical risk	Non-normal distribution affecting interpretation.	Moderate	Moderate	Moderate	Appropriate non-parametric tests (Mann-Whitney U, Wilcoxon).	Low

statistically significant. Despite this, the consistent trend towards fewer failures with the nano-composite suggest potential clinical benefits in maintaining bracket retention and reducing rebonding frequency. The outcomes of the trial are in line with findings reported earlier. Bishara et al. found that nano-filled composites and conventional adhesives showed comparable clinical performance, both maintaining acceptable bond strength and low failure rates within the 5% threshold considered clinically acceptable.²¹ The slightly lower failure rate observed with the nano-composite in this study may relate to its enhanced filler composition and improved curing depth, as previously discussed by Ferracane JL, who emphasised the role of increased filler loading in achieving superior compressive and tensile strength.²² These properties enhance stress distribution at the bracket-enamel interface, contributing to improved bond durability.

The reduced bond failures in the nano-hybrid group could also be linked to its smaller filler particle size (5-100nm), enabling uniform dispersion and increased filler-matrix interaction. Cramer et al. noted that such filler configuration minimises polymerisation shrinkage and enhances interfacial bonding.²³ Additionally, the use of a fourth-generation LED curing unit, as recommended by Shortall et al., provides optimal polymerisation even with deeper composite layers.²⁴ Together, the material and procedural factors may explain the improved clinical stability observed in the nano-composite group.

The time pattern of failures in this study, with most detachments occurring in the first four months, aligns with previous clinical findings. Stasinopoulos et al. observed that early debonding is often attributed to operator technique errors or insufficient polymerisation rather than inherent material defects.² The present study's early stabilisation in failure rates for both composites suggests that the bonding procedures were consistent, and that both materials maintained adequate adhesive performance over time.

From a practical standpoint, the overall bond failure rate of 1.8% falls well below the acceptable clinical threshold of 5%, supporting the suitability of both materials for orthodontic use. Pasquale et al. emphasised that adhesives yielding <5% failure rates ensure predictable clinical performance.²⁵ Similarly, Uysal et al. confirmed that both conventional and nano-composite adhesives achieve comparable clinical outcomes with minimal failures.²⁶ The results of this study, therefore, reinforce that nano-composites are a reliable and efficient option in orthodontic bonding.

The compositional differences between the tested

adhesives provide further insight. The nano-hybrid resin (Filtek Z250) incorporates zirconia-silica fillers averaging 20nm, allowing higher filler loading and improved handling. In contrast, the conventional composite (Transbond XT) contains submicron quartz and silica fillers, which, although effective, may yield less uniform polymer cross-linking. Similar observations have been documented by Beun et al., and Mitra et al., demonstrating that smaller filler sizes enhance material homogeneity and resistance to wear and shrinkage.^{17,27} These structural benefits could contribute to the improved mechanical stability noted with nano-composite in the current trial.

While the difference between the two groups did not reach statistical significance, nano-composites offer additional clinical advantages. They provide easier handling, better polishability, and enhanced resistance to staining, as described by Omanović-Miklićanin et al.¹¹ These qualities may be particularly valuable in aesthetically sensitive cases or longer orthodontic treatments. However, the lack of statistical significance in this study may reflect limitations in sample size and the relatively short follow-up period. Fleiss et al. highlighted that detecting subtle differences between small proportions (e.g., 2% vs. 1%) requires several hundred samples per group to achieve sufficient power.¹⁹ Hence, while the observed difference is clinically meaningful, it was not statistically detectable because of the sample size used.

Analysis by tooth type revealed that the second premolars exhibited the highest failure rate (6%), a finding that corroborates reports by Stasinopoulos et al. and Moraes et al.^{2,28} This may result from higher occlusal loads and limited access for adequate light curing in posterior regions. In contrast, anterior teeth showed the lowest failure rates, likely due to better visibility and reduced occlusal stress. These findings emphasise that bond strength is influenced not only by material properties, but also by tooth location, loading patterns and curing conditions.

The Kaplan-Meier survival curves showed only a minimal decline, this pattern may be explained by the large number of brackets evaluated and the low absolute number of failures, whereby proportional survival curves show only minimal decline despite multiple events. Given the large denominator (1,000 brackets) and the low absolute number of failures 18(1.8%), even multiple monthly failures produce only small downward shifts in survival probability. In contrast, the descriptive bar chart reported the total number of failures per month, which made the monthly fluctuation more visually pronounced. Therefore, the apparent difference between the descriptive chart and the Kaplan-Meier curves reflected differences in how the two methods represent the data, rather than an inconsistency

in the underlying failure distribution.

Although the nano-composite demonstrated lower failure rates, both materials performed within clinically acceptable limits. Future studies should include larger cohorts, extended follow-up durations, and multicentre participation to confirm these preliminary findings. Moreover, considering recent advances in nano-technology-based adhesives, future investigations should explore next-generation nano-composite incorporating bioactive or antibacterial agents to enhance longevity and oral health.

Overall, the findings of this study indicate that nano-composites offer a clinically sound alternative to conventional adhesives for orthodontic bonding. Their consistent performance, lower failure trend, and favourable handling properties highlight their suitability for modern orthodontic applications. Continued innovation and long-term evaluation will help determine whether these materials can provide significant improvements in treatment efficiency and patient outcomes.

Conclusion

The nano-composite demonstrated a lower bond failure rate compared to the conventional composite, but the difference was not statistically significant at both three-month and six-month follow-up intervals. Both the materials exhibited clinically acceptable bond strength sufficient to withstand functional and occlusal forces during orthodontic treatment. Given its comparable performance and favourable handling characteristics, nano-composite resin may be considered a suitable alternative to conventional composite resin for orthodontic bracket bonding.

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Author Contribution:

SA: Data analysis, interpretation, drafting, revision, proper investigation and resolution of questions.

RN: Design, drafting and final approval.

UA: Design, data analysis and interpretation.