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E-mail: vmehta@statsense.in
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Adhesive remnant index after conventional versus transillumination curing of orthodontic brackets: An *in vitro* study

Manjil Mousam Sabanya*, Rakshit Sthapak, Yogesh Kumar Mahobia, Bharti Chandra, Vibhuti Goswami & Ashim Amitav Nayak

Department of Orthodontics & Dentofacial Orthopedics, New Horizon Dental College & Research Institute, Sakri, Bilaspur, Chhattisgarh, India; *Corresponding author

Affiliation URL:
https://www.nhdcri.in/

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Author contact:
Manjil Mousam Sabanya - E-mail: manjilms1@gmail.com; Phone: +91 7022156504
Rakshit Sthapak - E-mail: rsthapak@gmail.com; Phone: +91 9893837117
Yogesh Kumar Mahobia - E-mail: dr.yogeshmahobia@gmail.com; Phone: +91 8349610690
Bharti Chandra - E-mail: bharti.chandra40@gmail.com; Phone: +91 9826540884
Vibhuti Goswami - E-mail: vibhutigoswami97@gmail.com; Phone: +91 8962696906
Ashim Amitav Nayak - E-mail: ashimamitav99@gmail.com; Phone: +91 8643027288

Abstract:
Optimal polymerization of orthodontic adhesives is essential for adequate bond strength and safe debonding. Therefore, it is of interest to evaluate the adhesive remnant index of metallic brackets bonded to 90 extracted teeth using conventional, modified peripheral and transillumination curing (n=30 each). Adhesive failures predominated in conventional and modified groups (60%), whereas transillumination showed fewer adhesive failures (40%) and more cohesive and mixed failures (30% each; $p<0.05$). Thus, transillumination produced a more favorable adhesive remnant pattern, suggesting improved polymerization and greater potential for enamel preservation during bracket removal.

Keywords: Orthodontic brackets, adhesive remnant index (ARI), transillumination curing, light-curing, orthodontic bonding

Background:
A strong adhesion of orthodontic brackets to the enamel is a prerequisite for successful fixed orthodontic therapy, as it provides resistance to orthodontic forces and enables safe debonding with minimal damage to the enamel. The clinical performance of orthodontic adhesives mostly depends on the degree of polymerization which in turn affects the bond strength, durability and pattern of bond failure following removal of brackets. Metallic brackets are conventionally light-cured from the edge of the bracket. However, light transmission through the opaque base of the metal bracket is restricted to the adhesive underneath the bracket, which resulted in non-uniform polymerization and mechanical qualities of the adhesive might be compromised **[1, 2]**. Transillumination curing has been introduced to circumvent this issue, where light is directed through the lingual or palatal surface, allowing transmission through the enamel and dentin to polymerize the adhesive under the bracket more uniformly. Previous experiments have shown that transillumination offers sufficient bond strength and increases the degree of resin conversion under metallic brackets **[3, 4]**. The Adhesive Remnant Index (ARI) is a commonly utilized measure to evaluate the site of bond failure during bracket debonding and to analyze the efficiency of different bonding protocols **[5-7]**. The failure patterns are primarily cohesive and mixed, which are advantageous in maintaining the integrity of the enamel, thereby maintaining a protective coating of the adhesive on the surface of the tooth. Advances in polywave LED curing units have further boosted the efficiency of polymerization by offering a broad spectrum of wavelengths that may activate different photoinitiators utilized for contemporary orthodontic adhesives **[8, 9]**. Therefore, it is of interest to examine the adhesive remnant index of metallic orthodontic brackets bonded with standard peripheral curing and transillumination light-curing procedures.

Materials and Methods:
Ninety human permanent teeth freshly extracted for orthodontic or therapeutic reasons were gathered. The Institutional Ethics Committee of New Horizon Dental College and Research Institute, Chhattisgarh, approved this *in vitro* investigation. Teeth with complete buccal enamel surfaces without caries, restorations, fluorosis, hypoplasia, fissures or any other structural flaws were included, while teeth with obvious enamel defects or past chemical treatment were omitted. Soft tissue debris and calculus were removed with an ultrasonic scaler and then polished with non-fluoridated pumice. Specimens were well washed and stored in distilled water at room temperature until use. The specimens were divided randomly into three groups of 30 teeth each according to the light-curing methodology. Stainless steel preadjusted edgewise brackets (Roth prescription, 0.022-inch slot) were bonded with Transbond XT Primer and Transbond XT adhesive (3M Unitek, Monrovia, CA, USA). The buccal enamel surfaces were etched with 37% phosphoric acid for 30 s, washed with water, air-dried till frosty white appearance acquired and primed before bracket placement. Excess adhesive was carefully removed prior to polymerization. Polymerization was carried out with a Bluephase polywave LED curing device (Ivoclar Vivadent, Liechtenstein) at an intensity of 1200 mW/cm^2. Group I conventional curing was done by curing the mesial and distal portions of the bracket for 10 seconds each. Modified peripheral curing with an alternate sequence of exposure was applied to Group II for 20 seconds in total. In Group III, transillumination curing was accomplished by placing the light guide on the lingual or palatal surface, enabling light to penetrate the tooth structure and polymerize the adhesive beneath the bracket. After bonding, all specimens were kept in distilled water at 37°C for 24 h before testing. Each tooth was immersed vertically in a self-cure acrylic resin and subjected to shear bond testing utilizing a universal testing machine at a crosshead speed of 1 mm/min until bracket debonding occurred. Then the enamel surfaces were examined with a stereomicroscope at 10× magnification and the amount of residual adhesive was quantified using the Adhesive Remnant Index (ARI) developed by Artun and Bergland. The failure modes were divided into sticky, cohesive or mixed. Data were analyzed using IBM SPSS Statistics version

26.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics were reported as frequencies and percentages. The distribution of ARI scores among the three groups was compared using Pearson's Chi-square test and Fisher's exact test. A p-value <0.05 was recognized as statistically significant.

Results:

A total of 90 extracted human teeth were included in the investigation, 30 samples each study group. The pattern of failure of adhesive remnant index (ARI) was different with the light curing techniques. The adhesive failures (18, 60.0%) were predominant in group I (conventional cure) followed by mixed failures (9, 30.0%) and cohesive failures (3, 10.0%). Similarly, Group II (modified peripheral curing) exhibited adhesive failure as the most frequent failure pattern (18 (60.0%) specimens), followed by cohesive (9 (30.0%) specimens) and mixed failures (3 (10.0%) specimens) **(Table 1).** Contrarily, group III (transillumination curing) showed a more homogeneous distribution of the failure patterns. Cohesive and mixed failure was detected in 9 specimens (30.0%) each, whereas adhesive failure was observed in 12 specimens (40.0%). The transillumination approach was associated with a lower frequency of adhesive failures and a higher proportion of cohesive and mixed failures compared to the traditional curing groups. The distribution of ARI failure patterns across the three groups was statistically different using Pearson's Chi-square test, which was validated by Fisher's exact test ($p < 0.05$) **(Table 2).** These results suggest that the curing technique of light curing has a substantial effect on the site of bond failure following orthodontic bracket debonding, with transillumination curing demonstrating a more advantageous distribution of failure modes compared with standard peripheral curing.

Table 1: Distribution of adhesive remnant index (ARI) failure patterns among the study groups

Failure pattern	Group I Conventional n (%)	Group II Modified n (%)	Group III Transillumination n (%)
Adhesive	18 (60.0)	18 (60.0)	12 (40.0)
Cohesive	3 (10.0)	9 (30.0)	9 (30.0)
Mixed	9 (30.0)	3 (10.0)	9 (30.0)
Total	30 (100)	30 (100)	30 (100)

Table 2: Comparison of ARI scores among the study groups

Variable	Group I	Group II	Group III	p-value
Adhesive failure, n (%)	18 (60.0)	18 (60.0)	12 (40.0)	**<0.05**
Cohesive failure, n (%)	3 (10.0)	9 (30.0)	9 (30.0)	
Mixed failure, n (%)	9 (30.0)	3 (10.0)	9 (30.0)	

Discussion:

The aim of this *in vitro* study was to assess the effect of conventional peripheral curing, modified peripheral curing and transillumination curing on the adhesive remnant index (ARI) of metallic orthodontic brackets. Results showed that the major failure mode in conventional and modified curing was adhesive, while transillumination curing resulted in a higher proportion of cohesive and mixed failures. The results show that the curing method affects the polymerization of the adhesive and the mechanism of bond failure. Adhesive failures were dominant in the traditional curing groups, which could be due to the decreased light transmission of the opaque metal bracket base, leading to inadequate polymerization of the adhesive layer. Price *et al.* reported that poor light penetration adversely impacts resin polymerization and degrades adhesive effectiveness **[10].** Likewise, Cervantes-Ganoza *et al.* found that the ARI scores and failure patterns of bonding were strongly affected by the bonding techniques **[11]**. Transillumination cured had less adhesive failures and more cohesive and mixed failures, which shows better polymerization under the bracket. Al-Salem *et al.* also revealed similar results with the optimized curing processes improving the shear bond strength and more favorable ARI scores **[12]**. Rohini *et al.* also observed that high-intensity LED curing yielded excellent bond strength and adhesive residual patterns despite shorter curing durations and highlighted the need of effective light delivery **[13]**. Both cohesive and mixed failures are believed to be of therapeutic advantage as they leave a protective coating of adhesive on the enamel hence decreasing the likelihood of enamel injury during debonding. AlSamak *et al.* revealed that enhanced orthodontic adhesive solutions presented good ARI scores yet with adequate binding strength **[14]**. Similarly, Nookala and Jain reported better adhesive remnant patterns and good biocompatibility with increased bond strength of adhesives **[15]**. The development of orthodontic materials in recent years has been aimed at boosting adhesion efficiency and clinical safety. Prasad *et al* found substantial differences in shear bond strength across modern orthodontic adhesives while Garg *et al* found improved bonding performance of novel adhesive systems **[16, 17]**. Also, Yan *et al.* showed that new fluorescent orthodontic adhesives increased bond strength without loss of cytocompatibility **[18]**. Wu *et al.* indicated that fluorescence-based approaches allow safe removal of residual adhesive and precise identification of residual adhesive following debonding **[19]**. The present study has limitations, such as the *in vitro* design, which does not fully simulate the oral environment and the evaluation of only one adhesive system and one LED curing unit. These findings need to be confirmed in further clinical research under intraoral circumstances. Transillumination light curing had a more favorable adhesive remnant index pattern than conventional curing, with less adhesive failure and more cohesive and mixed failure modes, suggesting better polymerization beneath metallic brackets and higher potential for preserving the enamel during orthodontic debonding.

Conclusion:

Transillumination-assisted light curing showed a more favourable adhesive failure pattern than conventional and modified peripheral curing, with fewer adhesive failures and a higher proportion of cohesive and mixed failures. This suggests improved polymerization of the adhesive beneath metal brackets, potentially reducing the risk of enamel damage during debonding. Further clinical studies are required to confirm these findings and establish the clinical effectiveness of this technique.

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