Comparative Evaluation Of Effect Of Curing Lights On Shear Bond Strength And Ari Of Different Adhesive Materials: An In Vitro Study

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ABSTRACT

Introduction: Orthodontists initially used bands to straighten teeth, but banding was intensive and prone to obstacles. With the advent of adhesives, the ideal adhesive should have optimal bond strength that can withstand orthodontic forces and leaving minimal residual after debonding.

Material and methods: This study comprised of 60 non-carious human premolars using three adhesive materials and six subgroups of LED curing lights (Low Intensity and High Intensity). Each subgroup had 10 samples bonded with metal brackets on the buccal surface using different adhesives at varying intensities and times. The specimens were tested for SBS using a UTM machine at 1mm/min, and the maximum load required to debond the bracket was recorded. Fracture modes were evaluated using a stereomicroscope.

Results:SBS was significantly higher in groups using high-intensity LED curing light, with Enlight having the highest, followed by Transbond XT and Heliosit. Low-intensity LED curing light showed a similar pattern, resulting in low ARI scores while high-intensity LED curing light increased them.

Conclusion:Both high-intensity and low-intensity LED curing lights bonded effectively, with no significant difference in SBS and ARI. High-intensity LED curing lights are recommended for time savings, patient, and orthodontist comfort.

Keywords: Bonding, Banding, SBS, LED and ARI.

INTRODUCTION

When orthodontics was developed, Orthodontists used bands to straighten teeth for malocclusion, but banding was intensive. Acid etching introduced a new concept, leading to significant changes in orthodontics[17]. In 1955, Buonocore presented a straightforward technique that involved pre-treating the enamel with 85% phosphoric acid to increase the adherence of acrylic filler material. This method was utilized by Newman in 1965 for bonding plastic brackets using epoxy resin[11].

The direct bonding approach uses both trans-illumination and direct illumination from different angles to cure the material under metal-based brackets[14].Adhesive bond strength is crucial for successful orthodontics. Ongoing appliance failure increases treatment costs, time, and chair side time. A clinical bond strength of 5.9MPa to 7.8MPa is recommended[13].

Tavas and Watts (O'Brien et al., 1989) were the first to report using visible light-cured adhesives to bond orthodontic brackets[14]. Since 1970, Quartz Tungsten Halogen units have been the most widely used light source in dentistry for bonding, but they have drawbacks[16].In 1995, Mills suggested using solid-state Light-Emitting Diode (LED) technology to cure light-activated dental materials[6].

Bracket bond failures can significantly increase chairside time, treatment duration, and efficiency. Consequently, much effort has been invested in improving the standards of direct bonding adhesives[15].

Artun and Bergland used an Adhesive Remnant Index (ARI) system to assess residual adhesive on teeth after debonding. ARI scores are frequently assessed in orthodontic adhesive studies due to their qualitative and subjective nature. Various modifications and new quantitative methods have been developed to improve the accuracy of adhesive remnant assessment[8].

MATERIAL AND METHODS

A total of 60 human bicuspid teeth extracted for orthodontic treatment purposes were collected and used in the study with inclusion criteria of non-carious premolar teeth, intact enamel on buccal surfaces of crown, no surface cracks due to pressure from extraction forceps and teeth with normal morphology. The exclusion criteria included fracture or attrition, Fluorosed teeth, and teeth with restorations or RCT treated teeth. The extracted teeth were divided into three groups based on orthodontic adhesives used i.e., Enlight (n=20), Heliosit (n=20) and Transbond XT (n=20), these groups were further sub-divided into 6 subgroups based on the intensity of LED curing light used, with 10 samples in each subgroup. The cold cure acrylic blocks were fabricated using a custom-made mould of dimension 50mm × 25mm × 25mm in which roots of premolar teeth were embedded so that the long axis of the tooth was perpendicular to the base of the moulds.

Each acrylic block contained five pre-molars,and the acrylic blocks were colour coded to demarcate six different adhesive groups based on the intensity of the LED used.

STATISTICAL ANALYSIS

The SBS and ARI of all groups were compiled and statistically examined using SPSS. Descriptive analysis included mean and standard deviation for SBS and ARI. Homogeneity was checked using Levene's test. One-way ANOVA was used for SBS comparisons, with Post-Hoc Tukey's Test for multiple comparisons. Independent t-tests were used for within-group comparisons of SBS. Chi-square tests were used for comparisons between groups for ARI, with non-parametric Kruskal-Wallis tests for multiple comparisons. Mann-Whitney U tests were used for within-group comparisons of ARI.

RESULTS

Shear Bond Strength: The samples were subjected to shear bond testing with the UTM at the tooth and bracket interface.

In groups cured using Low Intensity LED LCU, the maximum SBS was 140.02N in Enlight (Group A1), followed by Transbond XT (Group B1) with 131.68N and minimum SBS in Heliosit (Group C1) with 123.14N. **Graph 1** depicts the mean SBS.

Groups	Orthodontic Adhesives	Subgroups	Intensity	(n)	Colour Coding
A	Enlight	A1	Low	10	Red
		A2	High	10	
B	Transbond XT	B1	Low	10	Blue
		B2	High	10	
C	Heliosit	C1	Low	10	Green
		C2	High	10	

Table 1: Samples partitioned into separate groups &subgroups based on different orthodontic adhesivesand light cure used at different intensities

The buccal tooth surfaces were polished with fluoride-free pumice, etched for 30 seconds with 37% ortho-phosphoric acid, rinsed with water for 30 seconds, and dried for 20 seconds. A thin primer coat was applied and light cured. The bracket was placed on the tooth crown using an MBT gauge, bonded with different adhesive materials and light cured at varying intensities and times. The LCU tip was positioned as close to the tooth surface as possible.

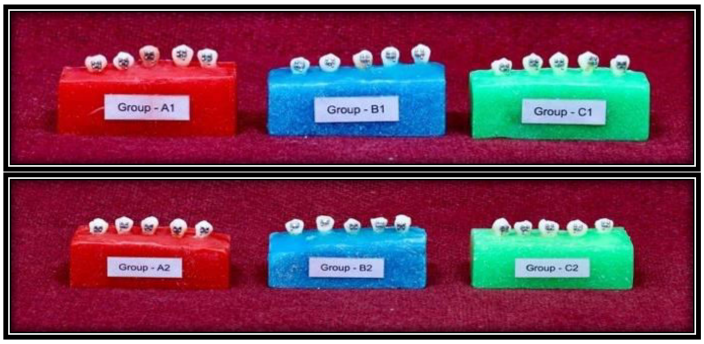


Figure 1: Groups with bonded Orthodontic Brackets

The specimens were tested for shear bond strength using universal testing machine. A jig secured the embedded specimens to the base plate of the universal testing machine. A chisel-edge plunger in the movable crosshead positioned along the occluso-apical axis of the teeth aimed at the tooth and bracket interface at a crosshead speed of 1mm/min, and the maximum load necessary to debond the bracket was recorded.

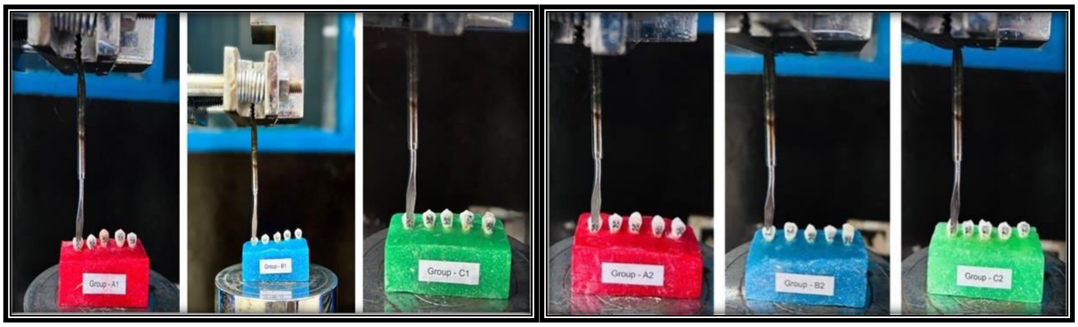


Figure 2: Orthodontic Brackets under maximum load in UTM

The ARI was used to evaluate the amount of adhesive resin retained on the buccal surfaces of each tooth after debonding. The evaluation of the composite and enamel surfaces in this study was done using a stereomicroscope at 12× magnification. The Adhesive Remnant Index (ARI) values as described by Artun and Bergland in 1948 are as follows:

0 : No adhesive remains on the tooth
1 : Less than half of the adhesive remains on the tooth
2 : More than half of the adhesive remains on the tooth
3 : All the adhesive remains on the tooth

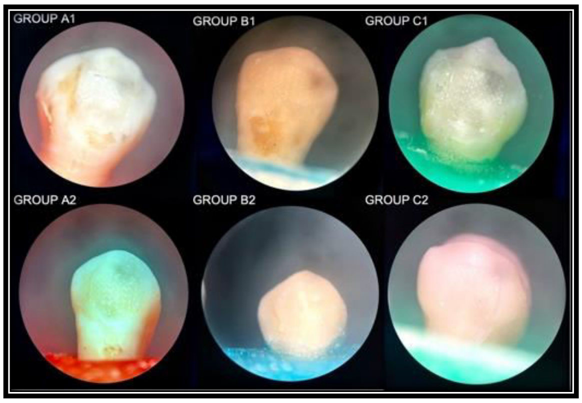
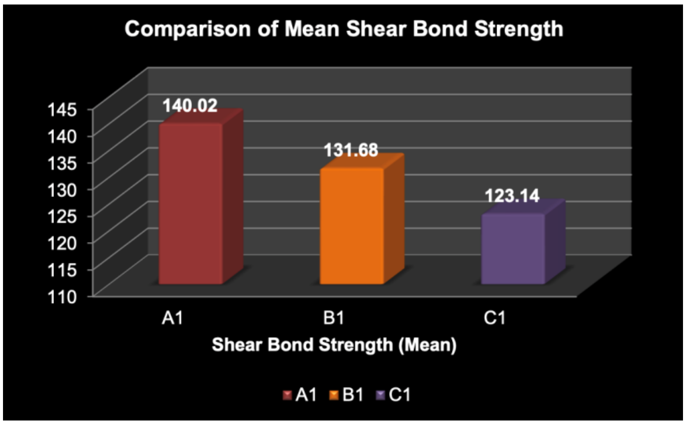


Figure 3: Teeth under stereomicroscope

Groups	N	Mean (SBS)	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum (SBS)	Maximum (SBS)
					Lower Bound	Upper Bound		
A1	10	**140.02**	41.82	13.22	110.09	169.94	49.4	181.4
B1	10	**131.68**	39.13	12.37	103.68	159.67	82.6	189.8
C1	10	**123.14**	37.65	11.9	96.20	150.07	48	186.4
Total	30	131.61	38.82	7.08	117.11	146.11	48	189.8

Table 2: Mean SBS (Newtons) of Groups using low intensity LED units

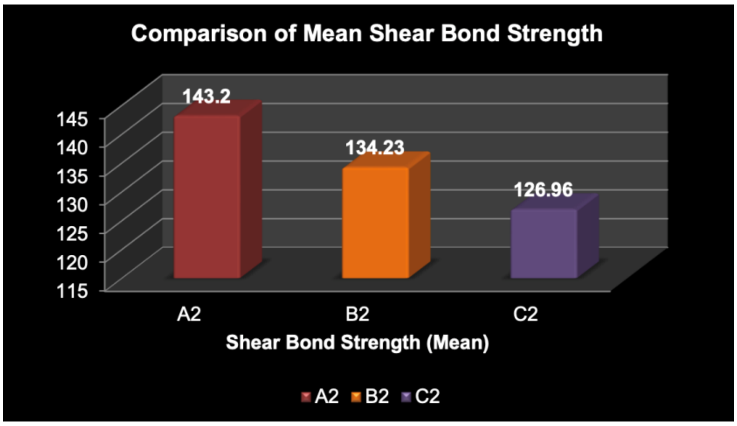


Graph 1: Comparison of mean SBS of Groups A1, B1 & C1

In groups cured using High Intensity LED LCU, the maximum SBS was 143.2N in Enlight (Group A2), followed by Transbond XT (Group B2) with 134.23N, and minimum SBS was 126.96N in Heliosit (Group C2). **Graph 2** depicts the mean SBS.

Groups	N	Mean (SBS)	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum (SBS)	Maximum (SBS)
					Lower Bound	Upper Bound		
A2	10	**143.2**	49.13	15.53	108.05	178.34	61.4	209
B2	10	**134.23**	34.63	10.95	109.45	159.00	90.2	189.4
C2	10	**126.96**	32.48	10.27	103.71	150.20	87.6	186.2
Total	30	134.79	38.66	7.05	120.36	149.23	61.4	209

Table 3: Mean SBS (Newtons) of Groups using low intensityLED units



Graph 2: Comparison of mean SBS of Groups A2, B2 & C2

Comparing mean differences among low-intensity LED LCUs, Group A1 (Enlight) had the highest mean difference, followed by Groups B1 and C1. This indicated Group A1 had a higher SBS, requiring more force to debond the bracket. Post-hoc Tukey's test showed a 'p' value >0.05, indicating statistical non-significance.

Study Group	Comparison Group	Mean difference	Standard Error	'p' value	95% Confidence Interval		Inference
					Lower Bound	Upper Bound	
A1	B1	8.34	17.69	0.88	-35.54	52.22	Non-Significant
	C1	16.88	17.69	0.61	-27.00	60.76	Non-Significant
B1	A1	-8.34	17.69	0.88	-52.22	35.54	Non-Significant
	C1	8.54	17.69	0.88	-35.34	52.42	Non-Significant
C1	A1	-16.88	17.69	0.61	-60.76	27.00	Non-Significant
	B1	-8.54	17.69	0.88	-52.42	35.34	Non-Significant

Table 4: Multiple comparisons of Groups A1, B1 and C1 using Post-Hoc Tukey Test. The mean difference was non-significant in all the Groups

Comparing mean differences among high-intensity LED LCUs, Group A2 (Enlight) had the highest mean difference, followed by Group B2 and Group C2. This indicated Group A2 (Enlight) had a higher SBS, requiring more force to debond the bracket. Post-hoc Tukey's test showed a 'p' value >0.05, indicating statistical non-significance.

Study Group	Comparison Group	Mean difference	Standard Error	'p' value	95% Confidence Interval		Inference
					Lower Bound	Upper Bound	
A2	B2	8.97	17.64	0.86	-34.77	52.71	Non-Significant
	C2	16.24	17.64	0.63	-27.50	59.98	Non-Significant
B2	A2	-8.97	17.64	0.86	-52.71	34.77	Non-Significant
	C2	7.27	17.64	0.91	-36.47	51.01	Non-Significant
C2	A2	-16.24	17.64	0.63	-59.98	27.50	Non-Significant
	B2	-7.27	17.64	0.91	-51.01	36.47	Non-Significant

Table 5: Multiple comparisons of Groups A2, B2 and C2 using Post-Hoc Tukey Test. The mean difference was non-significant in all the Groups

The descriptive statistics, including the mean and standard deviation, were calculated for the SBS data within the groups using independent t-test -

On comparing Group A1 & A2, B1 & B2, and C1 & C2 using independent t-test non-significant differences were revealed between them. Group A2, B2 & C2having higher bond strength as compared to Group A1, B1 & C1.

Groups	N	Mean	Std. Deviation	Std. Error	Inference
A1	10	**140.02**	41.82	13.22	Non-Significant
A2	10	**143.2**	49.13	15.53	Non-Significant

Table 6: Comparisons between Group A1 and A2 using independent t-test

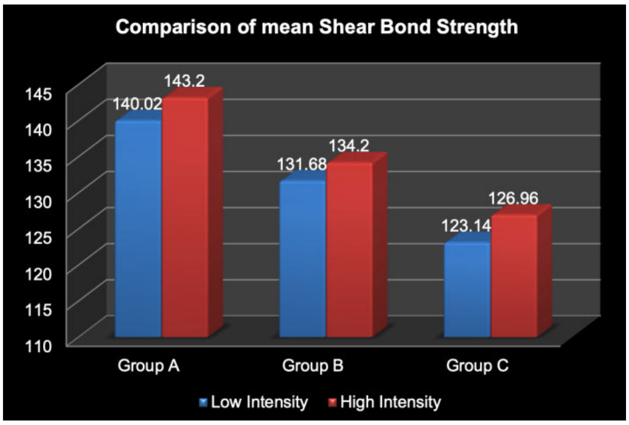
Groups	N	Mean	Std. Deviation	Std. Error	Inference
B1	10	**131.68**	39.13	12.37	Non-Significant
B2	10	**134.23**	34.63	10.95	Non-Significant

Table 7: Comparisons between Group B1 and B2 using independent t-test

Groups	N	Mean	Std. Deviation	Std. Error	Inference
C1	10	**123.14**	37.65	11.90	Non-Significant
C2	10	**126.96**	32.48	10.27	Non-Significant

Table 8: Comparisons between Group C1 and C2 using independent t-test

Graphical representation of mean SBS is depicted in **Graph 3.**



Graph 3: Comparison of mean SBS of Group A1 & A2, Group B1 & B2, Group C1 & C2

Adhesive Remnant Index: The ARI (ARI) scores for the failed samples or sites were analyzed using non-parametric Kruskal Wallis test. The scores were classified based on the Artun and Bergland's system. Notably, the brackets were debonded from all the tooth surfaces during the SBS testing and further examination for ARI was carried out under a stereomicroscope. Multiple failures were identified including cohesive failure at composite-bracket interface and adhesive failure at enamel-composite interface.
The descriptive statistics, including the mean, were calculated for the ARI data across all six groups using a chi-square test. Group C1 (Heliosit) had the highest ARI (16.4), followed by Group B1 (Transbond XT) (15.2), and Group A1 (Enlight) had the lowest ARI (14.9).

Group	N	Mean Rank
A1	10	14.9
B1	10	15.2
C1	10	16.4

Table 9: Mean ARI of A1, B1 & C1
The groups cured with a maximum ARI of 16.15 were Heliosit (Group C2), followed by Transbond XT (Group B2) with an ARI of 15.5, and Enlight (Group A2) with a minimum ARI of 14.85.

Group	N	Mean Rank
A2	10	14.85
B2	10	15.5
C2	10	16.15

Table 10: Mean ARI of A2, B2 & C2
The data was analyzed using the Kruskal-Wallis test to identify significant differences between the means. Pairwise comparisons among multiple study groups (Group A1, B1, and C1) were performed after a significant overall analysis of variance (ANOVA) result. Comparing the mean differences among the low-intensity LED LCUs, Group A1 (Enlight) had the maximum mean difference, followed by Group C1 and Group B1. This indicated Group A1 (Enlight) had the minimum ARI compared to Group B1 and C1. However, the 'p' value was >0.05, indicating the results were statistically non-significant.

Study Groups	Mean Difference	Standard Error	'p' value	Inference
A1-B1	-0.30	3.74	0.93	Non-significant
A1-C1	-1.50	3.74	0.68	Non-significant
B1-C1	-1.20	3.74	0.74	Non-significant

Table 11: Multiple comparisons of Groups A1, B1 and C1 using Kruskal Wallis Test. The mean difference was non-significant in all the Groups
Comparing mean differences among high-intensity LED LCUs, Group A2 (Enlight) had the maximum mean difference, followed by Group C2 and Group B2. This indicated Group A2 (Enlight) had the minimum ARI compared to Groups B2 and C2. The Kruskal-Wallis test's 'p' value was >0.05, indicating statistical non-significance.

Study Groups	Mean Difference	Standard Error	'p' value	Inference
A2-B2	-0.65	3.77	0.86	Non-significant
A2-C2	-1.30	3.77	0.73	Non-significant
B2-C2	-0.65	3.74	0.86	Non-significant

Table 12: Multiple comparisons of Groups A2, B2 and C2 using Kruskal Wallis Test. The mean difference was non-significant in all the Groups

Additionally, the difference in ARI Index within groups were done by using Mann-Whitney U test. On comparison of Group A1 & A2, B1 & B2 and C1 & C2, the Group A2, B2 & C2 had higher ARI as compared to Group A1, B1 & C1 but statistically no significant differences were observed.

Groups	N	Mean Rank	Sum of Ranks
A1	10	9.6	96
A2	10	11.4	114

Table 13: Comparison within Group using Mann-Whitney U test

Groups	N	Mean Rank	Sum of Ranks
B1	10	9.8	98
B2	10	11.2	112

Table 14: Comparison within Group using Mann-Whitney U test

Groups	N	Mean Rank	Sum of Ranks
C1	10	9.8	98
C2	10	11.2	112

Table 15: Comparison within Group using Mann-Whitney U test

DISCUSSION

Fixed-appliance orthodontic treatment traditionally used brackets welded to gold or stainless-steel bands to encircle teeth, creating interproximal space[5].Bonding orthodontic brackets to tooth enamel has been a standard clinical technique since 1970. It involves acid etching the enamel surface, applying adhesive primer, and then applying resin[1].

In 1995, solid-state Light Emitting Diode technology was introduced to polymerize light-activated dental materials[3]. The adhesive material employed for bonding must be reliable and durable, ensuring minimal treatment delays and patient discomfort[2].

With new adhesives, composite resins, and advanced bonding techniques in restorative dentistry, orthodontists adopted these advancements. Bowen's resin underwent modifications, including adding a co-monomer, varying filler amounts, and a silane coupling agent.[11]. Several factors affect enamel-bracket bond strength, including adhesive type, etching time, composition, curing mode, bracket material, base design, loading mode, and oral environment. Polymerization shrinkage, adhesive and filler conversion, and filler content also impact durability[9].

The present in-vitro study was conducted to assess the shear bond strength and mode of failure of three distinct adhesive materials employed to bond stainless-steel brackets using two different LED curing lights at varying intensities. A total of 60 extracted human premolars were bonded with stainless steel brackets, which were subsequently divided into six groups. Each group consisted of 10 samples, each bonded with a different adhesive material under varying intensity and time conditions. The study groups were divided into three groups based on adhesive material used i.e., Group A (Enlight), Group B (Transbond XT) and Group C (Heliosit). These groups were further divided into six groups based on the LED curing light used i.e., Low intensity and High intensity with Group A1, B1 & C1 for low intensity and Group A2, B2 & C2 for high intensity. The groups were further compared and analysed statistically to obtain the results.

In our present study premolars extracted during orthodontic treatment were selected for bonding of orthodontic brackets on their buccal surface[12]. The teeth were mounted on self-cured acrylic blocks, embedding the roots up to the cementoenamel junction, with the buccal crown surface perpendicular to the block base[11]. The vertical force was applied along the long axis of the tooth in the occlusogingival direction and parallel to long axis of each mounted tooth at a crosshead speed of 1mm/min using Universal Testing Machine[12].

Low-intensity curing light resulted in the highest shear bond strength for Group A (Enlight) at 140.02N, followed by Group B (Transbond XT) at 131.68N. The difference between these groups was negligible and statistically non-significant. Group C (Heliosit) had the lowest SBS at 123.14N. High-intensity curing light maintained the same pattern, with Group A (Enlight) maintaining its highest SBS at 143.2N, followed by Group B (Transbond XT) at 134.23N, and Group C (Heliosit) at 126.96N.

A study conducted by,Duvvuri et al.compared the SBS of Transbond XT and Enlight adhesives, confirming our findings. Both materials had comparable SBS. However, incorporating TiO_2 nanoparticles reduced the SBS of composites compared to unmodified ones[4].Shaik et al. compared the SBS of three visible light-cured composites (Enlight, Transbond XT, and Heliosit) and two self-cured composites (Rely-a-bond and Concise). They found that Enlight and Transbond XT had similar SBSs and could be used interchangeably. Heliosit had the lowest SBS but still acceptable bond strength[11].

Rai et al. compared SBS of four light-cure adhesives: Transbond XT, Enlight, Orthofix, and Heliosit. They directly bonded brackets using adhesive and photopolymerization, skipping the curing step for the primer. Heliosit had the lowest SBS, while Transbond XT and Enlight had a statistically non-significant difference[9].Linn et al. compared SBS and bond failure sites for brackets bonded to teeth using two indirect-bonding materials and a direct-bonding technique with Transbond XT and Enlight. Both materials produced comparable SBS, with no significant difference[7].

Artun and Bergland's ARI was used to score the residual adhesive. Our study found statistically insignificant results ($p > 0.05$) comparing ARI scores from different adhesive materials and LED curing lights. High-intensity curing light resulted in higher ARI scores than low-intensity curing light[1]. These findings align with Udomthanaporn, Nisalak, and Sawaengkit's study comparing the SBS and ARI of orthodontic brackets polymerized with high-intensity LED LCUs at various intensities and curing times. The study found that the ARI increased with the curing light intensity[16].

Scougall-Vilchis (2010) studied the SBSs of stainless-steel brackets bonded with seven light-cured orthodontic adhesives. They conditioned enamel with a self-etching primer and used Transbond XT, Blugloo, BeautyOrtho Bond, Enlight, Light Bond, Transbond CC, and Xeno Ortho. Enlight and Transbond XT had similar adhesive on tooth surfaces after bracket debonding, with a mean ARI score of 3. This aligns with our study's finding of no significant difference in ARI between Enlight and Transbond XT[10].

The study faced limitations due to the difficulty in accurately simulating clinical settings in vitro. Generalizing our findings to the clinical environment requires caution. Factors like salivary presence, humidity, temperature, masticatory forces, and normal tooth movements cannot be replicated in the in vitro setup.

CONCLUSION

This in-vitro study evaluated SBS and ARI of metal brackets bonded with various adhesives and cured with varying LED intensities and times.

1. All orthodontic adhesives met clinically acceptable SBS requirements, making any one suitable for bonding.
2. High-intensity LED curing light significantly increased SBS, with Enlight exhibiting the highest and Heliosit the lowest. Low-intensity LED curing light also showed similar patterns among adhesives with statistical analysis revealing no significant difference in SBS across all adhesives groups.
3. Low-intensity curing light resulted in low ARI scores, suggesting adhesive failure at the enamel-adhesive interface.High-intensity curing light increased ARI scores, indicating higher adhesive on the tooth surface and bracket-adhesive interface failure.
4. Based on these findings, high-intensity LED curing light is recommended to save chairside time and enhance patient and orthodontist comfort, as it showed no significant difference in SBS or ARI between the two intensities.

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