Original Article

An in vitro comparison of ultraviolet versus white light in the detection of adhesive remnants during orthodontic debonding

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ABSTRACT

Objectives: To assess the effectiveness and efficiency of ultraviolet (UV) illumination compared to conventional white light in the detection of fluorescent-tagged adhesive remnants during orthodontic debonding.

Materials and Methods: Orthodontic brackets were bonded to extracted human premolars using one of two bonding resins having fluorescent properties (Pad Lock, Reliance Orthodontics, Itasca, Ill; Opal Bond MV, Opal Orthodontics, South Jordan, Utah; $n = 40$ each). The brackets were then debonded and, in each adhesive group, half the teeth had the remaining adhesive resin removed under illumination using the operatory light and the other half using a UV (395 nm) light emitting diode (LED) flashlight ($n = 20$/group). Time for teeth cleanup was recorded. Follow-up images were obtained under a dissecting microscope using UV illumination, and the surface area of adhesive remnants was calculated. Effectiveness of adhesive removal was also assessed using scanning electron microscopy imaging. Analysis of variance and Kruskal-Wallis tests were used to analyze time and adhesive remnants, respectively.

Results: Assessment using the dissecting microscope found groups using UV light during adhesive removal had statistically significantly lower amounts of adhesive remnants than groups using white light ($P \leq .01$). Time for adhesive removal was significantly lower with Opal Bond MV adhesive using UV light when compared with the white light ($P \leq .01$). Assessment by scanning electron microscopy showed that thin remnants of adhesive (<2 μm) remained undetected by UV illumination.

Conclusions: UV light is more effective and tends to be more efficient than white light in the detection of fluorescent adhesive during orthodontic debonding. Although there are limitations, the use of UV LED lighting is a practical tool that aids in adhesive detection. (*Angle Orthod.* 2019;89:438–445.)

KEY WORDS: Adhesive; Orthodontics; Debonding; UV light

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INTRODUCTION

To minimize potential damage to teeth during the removal of orthodontic brackets, the ideal location for mechanical failure is the adhesive–bracket interface, resulting in the bulk of the resin remaining on the tooth.[1–4] Subsequently, complete removal of adhesive is important as remnants can result in increased plaque accumulation, white spot lesions, periodontal inflammation, and discoloration.[5–8] To achieve complete and efficient removal of adhesive as well as produce minimal damage to enamel, dentists need to differentiate adhesive from enamel accurately and rapidly. This task has challenges as a result of the similarity in shade between resin and enamel, as documented in both orthodontic and restorative settings.[7,9–15]

Fluorescence allows a substance to emit more visible light than it receives. Teeth naturally fluoresce when exposed to light sources containing ultraviolet

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Table 1. Adhesives Evaluated for Study Inclusion

Adhesive Brand	Manufacturer
APC II Adhesive Coated Appliance System	3M Unitek, St. Paul, Minn
FlowTain	3M Unitek, St. Paul, Minn
Heliomolar	Ivoclar Vivadent, Amherst, N.Y.
Opal Bond MV[a]	Opal Orthodontics, South Jordan, Utah
Pad Lock[a]	Reliance Orthodontics, Itasca, Ill
Tetric EvoCeram	Ivoclar Vivadent, Amherst, N.Y.
Transbond XT	3M Unitek, St. Paul, Minn

[a] Met inclusion criteria.

(UV) wavelengths, projecting a quality of vitality and health.[10] Fluorescent additives have been incorporated into resins to help mimic a natural tooth and also aid in detection of the resin. Illumination with the correct wavelength helps distinguish resin from enamel.[9–12,14,16]

Multiple studies evaluated UV light as an adjunct in the detection of composite restorations in standard dental examinations and in forensic identification in postmortem odontograms.[9,11,12,14] A recent study by Ribeiro and associates[17] evaluated the application of UV light in an orthodontic setting. This and other studies concluded UV illumination was a valuable adjunct when detection or complete removal of resin is warranted.[9,11,12,14,17]

The aim of this study was to evaluate the effectiveness and efficiency of UV light versus white (W) light in the detection of florescent adhesive during orthodontic debonding. The null hypothesis was there were no significant differences in effectiveness and efficiency when using UV versus W light. Results unique to this study included the amount of time spent on adhesive removal, comparison of two adhesives, and use of scanning electron microscopy (SEM) for detailed assessment of adhesive removal.

MATERIALS AND METHODS

This in vitro study was approved by the University at Buffalo Institutional Review Board (Buffalo, N.Y.; no. 00001372). All experimental procedures were performed by one investigator (Dr Lai). A pilot investigation involved seven commonly used orthodontic adhesives to evaluate for inclusion (Table 1). Inclusion criteria were (1) manufacturer's indication for use as bracket adhesive for direct bonding and (2) fluorescence visible under UV illumination.

To examine for fluorescence, the adhesives were illuminated with a 5 light emitting diode (LED) ultraviolet flashlight at 395 nm wavelength (INOVA, Nite Ize, Boulder, Colo). Only Pad Lock (P) and Opal Bond MV (O) met the inclusion criteria.

Sample Size Calculation

A sample size of 20 premolar teeth was found to be adequate for each group based on findings from Riberio and associates.[17] The number was determined with significance of 0.05, power of 80% to detect a difference greater than 0.5 mm^2, and a standard deviation of 0.4 mm^2.

Teeth Selection

Extracted human premolars (n = 135) were obtained from a dental research facility and stored in 0.5% chloramine-T.[18,19] Inclusion criteria were premolars with sound buccal enamel and no caries or previous restorations when inspected visually under W and UV illumination. A total of 108 teeth met the inclusion criteria from which 80 were randomly selected for the four experimental groups (Figure 1).

Sample Preparation

The teeth were mounted into a ModuPRO Endo module (Acadental, Oakland Park, Kans) using the maxillary left first molar socket. Each tooth's buccal surface was cleaned and polished with pumice using a rubber cup in a low-speed handpiece for 10 seconds,

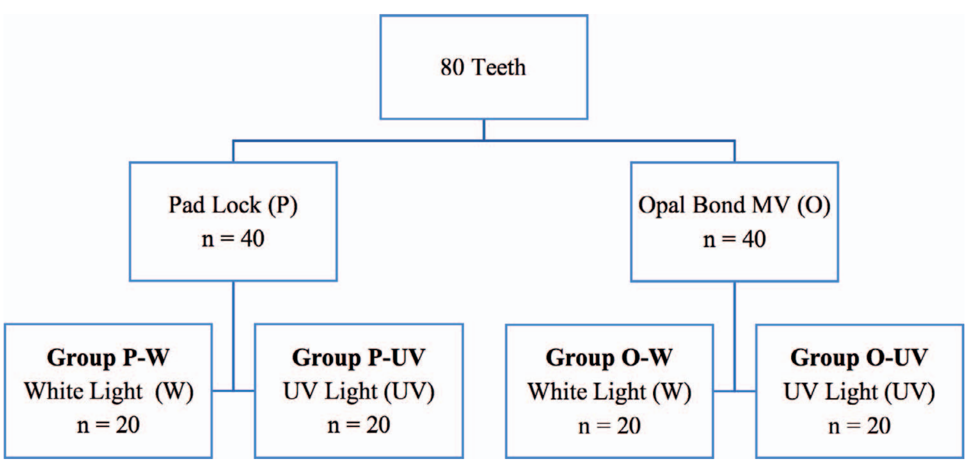

Figure 1. Flow chart of assignments into four groups.

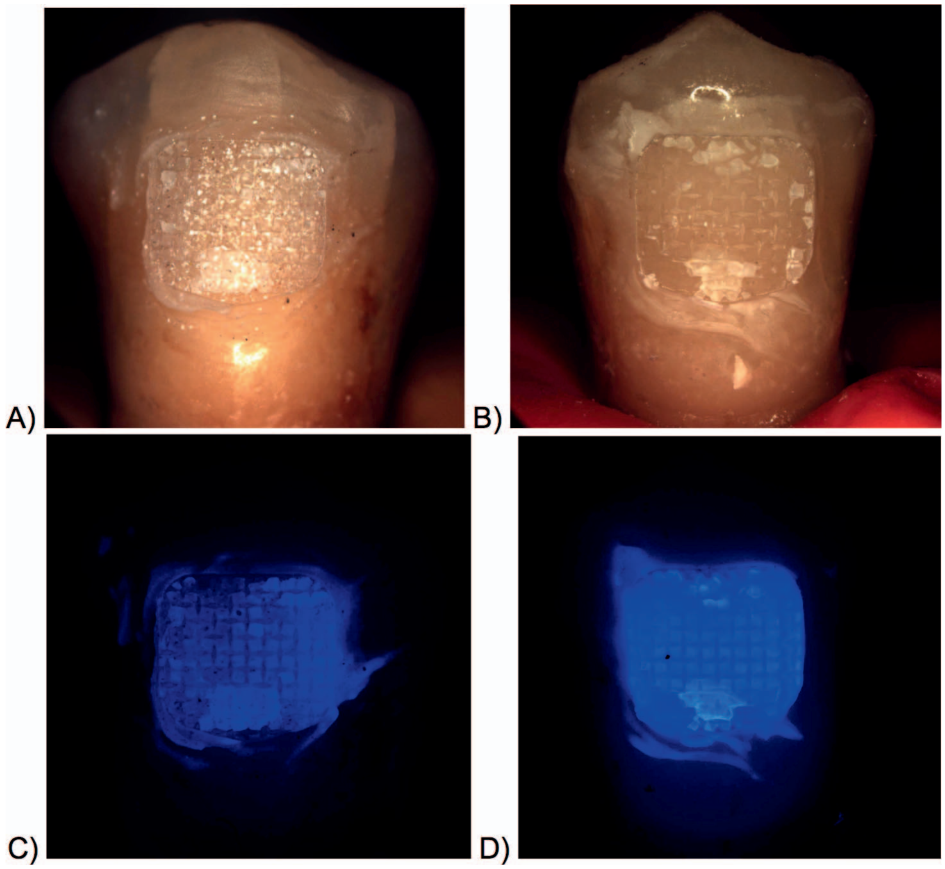

Figure 2. Stereomicroscope images of adhesive remaining following bracket debonding using white or ultraviolet light: (A) P–W, (B) O–W, (C) P–UV, (D) O–UV. P indicates Pad Lock; O, Opal Bond MV; W, white light; UV, ultraviolet light.

then rinsed and dried using an air-water syringe. The enamel was then etched with 35% phosphoric acid (Ultra-Etch, Ultradent, South Jordan, Utah) for 30 seconds, rinsed with water for 10 seconds, and air dried for 5 seconds and primer (Assure PLUS, Reliance Orthodontics, Itasca, Ill) was applied using a microbrush according to the manufacturer's instructions.

Premolar orthodontic brackets (Dentsply GAC, Islandia, N.Y.) were bonded to the teeth, half using P and the remainder using O. The bracket was pressed firmly onto the enamel surface, excess adhesive was removed with an explorer, and the adhesive light was cured for 3 seconds from occlusal, gingival, mesial, and distal aspects using the "extra power" setting of a VALO LED curing light (Ultradent). The teeth were then stored in a humid chamber at 37°C for 24 hours.

Brackets were debonded by compressing and distorting the bracket using a bracket removing plier (#098; Orthopli, Philadelphia, Pa). The amount of adhesive remaining was assessed with UV light under a stereomicroscope (Figure 2) and scored using a modified Adhesive Remnant Index (Table 2).[20] Only teeth with a score of 4 and 5 were included.

Adhesive Removal

The typodont was mounted to a mannequin head to simulate patient treatment. Adhesive removal was conducted with a 30-fluted, flame-shaped tungsten carbide bur (H48LF.31.010, Brasseler USA Dental, Savannah, Ga) in a high-speed handpiece,[21–25] with the operator using dental loupes (2.5x).[26] A new bur was used after every 10 teeth.[15] The handpiece was used with air-cooling but without water spray.

Groups P-W and O-W used only the W light from the dental operatory light unit, whereas groups P-UV and O-UV used the 395 nm wavelength UV LED flashlight with the dental operatory light turned off. The UV light

Table 2. Modified Adhesive Remnant Index

Score	Definition
0	No adhesive left on the tooth
1	1%–25% of adhesive left on the tooth
2	26%–50% of adhesive left on the tooth
3	51%–75% of adhesive left on the tooth
4	76%–99% of adhesive left on the tooth
5	All adhesive left on the tooth with distinct impression of bracket mesh

Table 3. Intraclass Correlation Coefficient for Adhesive Remnant Measurements[a]

Group	N	ICC	95% Confidence Interval
P–W	10	0.997	0.988, 0.999
P–UV	10	0.795	0.370, 0.945
O–W	10	1.000	0.999, 1.000
O–UV	10	0.904	0.662, 0.975
All Groups	40	0.999	0.998, 0.999

[a] ICC indicates intraclass correlation coefficient; P, Pad Lock; O, Opal Bond MV; W, white light; UV, ultraviolet light.

source was chosen based on previous evaluations of optimal wavelength for most dental resins.[11,14] The hand-held flashlight could be freely moved by the operator during the procedure. In both groups the handpiece had a W light that would illuminate when the handpiece was in use. Resin removal was carried out until the adhesive was visually determined to be completely removed and the time taken was recorded in seconds.

Quantitative Assessment of Adhesive Remaining

Using a stereomicroscope (Nikon SMZU, Nikon Metrology, Brighton, Mich), photographs were obtained following debonding and after adhesive removal. The teeth were illuminated under UV using a stereomicroscope fluorescence adapter (Nightsea, Lexington, Mass) placed in a standardized position.

Photographic images were scaled and the surface area of adhesive remaining after adhesive removal was traced and calculated (mm^2) using Image J software (National Institutes of Health, Rockville, Md). All measurements were made twice, 1 week apart. The repeat measurements were used for assessing intrarater reliability, and the average was used in the statistical analysis.

Qualitative Assessment of Adhesive Remaining

For assessment under SEM (Hitachi SU70, Hitachi High-Technology, Clarksburg, Md), two samples with high amounts of adhesive remaining and two with no adhesive remaining were selected from each adhesive group. SEM backscatter electron images were obtained to compare the sensitivity of UV light in the detection of adhesive remnants relative to the more definitive detection possible with SEM. The SEM used in this study had a spatial resolution of 1 nm.

In conjunction with SEM, energy-dispersive X-ray spectroscopy (IXRF, Austin, Tex) was conducted on selected areas of the images to analyze elements present and thereby confirm the absence/presence of adhesive. The SEM was operated at 20 kV, providing a penetration depth of 2 μm.[27] The penetration depth provided information regarding the thickness of the adhesive remnant.

Statistical Analysis

SPSS software (version 24, IBM, Armonk, NY) was used with a significance level $P < .05$. Intraclass correlation coefficients (ICC) were calculated to assess the intrarater reliability when measuring surface area of adhesive remaining for each adhesive-light group. ICC was also calculated for all 40 repeat measurements combined.

The Shapiro-Wilk test was used to evaluate normality of data along with Levene's statistic for homogeneity of variances. An analysis of variance was used to test for differences in time and surface area followed by the Tukey Honestly Significant Difference post hoc tests. The Kruskal-Wallis test was used when normality/homogeneity of variance requirements were not met, followed by post hoc pairwise Mann-Whitney tests. The Pearson correlation coefficient was calculated to determine associations between time and surface area.

RESULTS

Intrarater Reliability

Intrarater reliability was excellent in three groups (ICC: P–W = 0.997, O–W = 1.000, O–UV = 0.904) and good in one (ICC: P–UV = 0.795; Table 3). Excellent overall reproducibility (ICC = 0.999) was also found when all 40 repeat measurements were combined.

Table 4. Descriptive Statistics for Surface Area of Adhesive and Time Per Group[a]

Variable	Group[b]	Mean	SD	Minimum	Maximum	Median
Surface area (mm^2)	P–W	2.03	1.64	0.30	5.49	1.38
	P–UV	0.09	0.06	0.00	0.19	0.10
	O–W	1.35	2.13	0.03	0.53	0.72
	O–UV	0.06	0.08	0.00	0.26	0.02
Time, sec	P–W	38.30	7.37	25	51	36.50
	P–UV	36.10	7.50	27	54	34.50
	O–W	43.65	4.93	37	55	42
	O–UV	33.40	7.66	20	45	34.50

[a] SD indicates standard deviation; P, Pad Lock; O, Opal Bond MV; W, white light; UV, ultraviolet light.
[b] N = 20 per group.

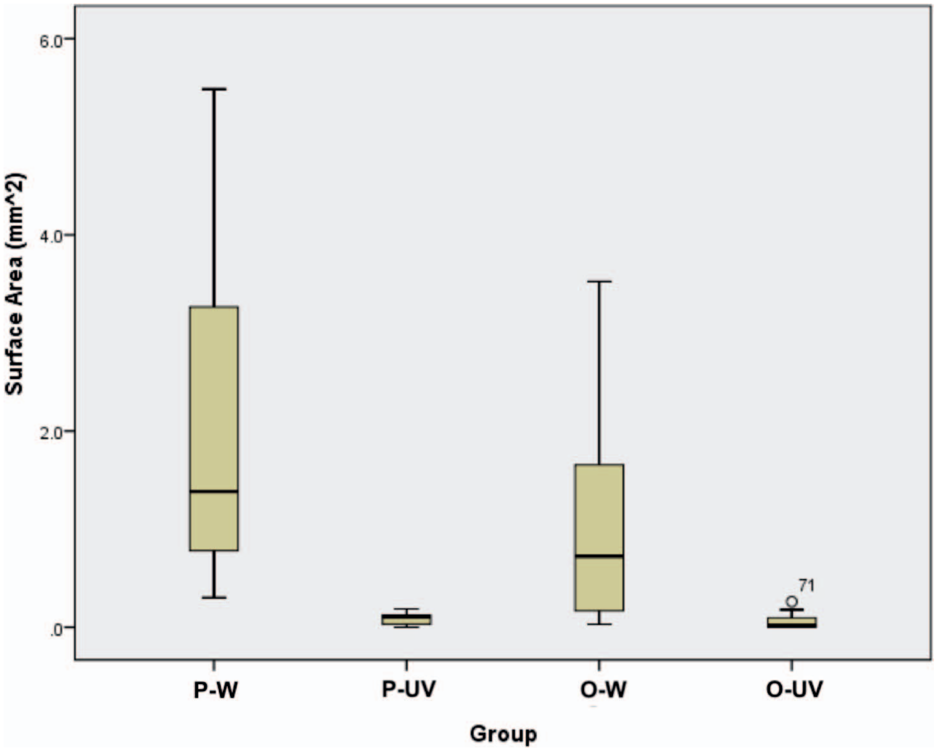

Figure 3. Box plot for surface area of adhesive remaining (mm²) with all groups.

Surface Area of Adhesive Remnants

Median adhesive surface area ranged from 0.72 to 1.38 mm² in groups with W light and from 0.02 to 0.10 mm² in groups with UV light (Table 4, Figure 3). Data for surface area of adhesive remnants in three groups did not fulfill the assumption of normality and therefore the Kruskal-Wallis test was used (Table 5). Statistically significant differences in median surface area of adhesive remaining were found among the groups ($P \leq .001$). Post hoc pairwise Mann-Whitney tests found significant differences between all pairings that compared a group with W light versus UV light, despite the adhesive type (Table 6). No significant differences were found between pairings of groups that used the same type of light but different adhesive.

Table 5. Shapiro-Wilk Test for Surface Area of Adhesive and Time[a]

	Surface Area of Adhesive			Time		
Group	Statistic	*df*	Sig.[b]	Statistic	*df*	Sig.
P–W	0.867	20	0.011	0.957	20	0.485
P–UV	0.930	20	0.155	0.927	20	0.136
O–W	0.596	20	0.000	0.918	20	0.091
O–UV	0.783	20	0.000	0.932	20	0.166

[a] Sig. indicates significance; P, Pad Lock; O, Opal Bond MV; W, white light; UV, ultraviolet light.
[b] Significance level set at $P < .05$.

Time Needed for Adhesive Removal

Mean times for removal, in ascending order, were the following: O–UV = 33.4 seconds, P–UV = 36.1, P–W = 38.3, and O–W = 43.7 (Table 4). Data related to time was assessed with analysis of variance as the assumption of normality was upheld, and Levene's test confirmed homogeneity of variance ($P = .074$; Table 5). Statistically significant differences in mean time for adhesive removal were found among groups ($P \leq .001$; Table 7). Post hoc Tukey HSD showed that O with W light was statistically significantly higher in mean time for removal than O and P both with UV light (Table 7). There was no significant difference in mean

Table 6. Post Hoc Pairwise Mann-Whitney Test for Surface Area of Adhesive[a]

Paired Groups			
Group 1	Group 2	Sig.[b]	Adj. Sig.[c]
O–UV	P–UV	0.323	1.000
O–UV	P–W	0.000	0.000
O–UV	O–W	0.000	0.000
P–UV	P–W	0.001	0.003
P–UV	O–W	0.000	0.000
P–W	O–W	0.082	0.494

[a] Sig. indicates significance; Adj., adjusted; P, Pad Lock; O, Opal Bond MV; W, white light; UV, ultraviolet light.
[b] Significance level set at $P < .05$.
[c] Significance values have been adjusted by the Bonferroni correction for multiple tests.

Table 7. Analysis of Variance for Time[a]

	Analysis of Variance					Post Hoc Tukey HSD**		
	Sum of Squares	*df*	Mean Square	*F*	Sig.	Group 1	Group 2	Sig.
Between groups	1134.14	3	378.05	7.81	0.000	O–UV	P–UV	0.612
						O–UV	P–W	0.125
Within groups	3677.35	76	48.39			O–UV	O–W	0.000
						P–UV	P–W	0.750
Total	4811.49	79				P–UV	O–W	0.005
						P–W	O–W	0.080

[a] Sig. indicates significance; P, Pad Lock; O, Opal Bond MV; W, white light; UV, ultraviolet light.
** HSD = Honestly Significant Difference post hoc test.

time between the two types of adhesives with either light source.

Correlation Between Time and Surface Area of Adhesive

A statistically significant negative correlation was found between time and surface area of adhesive remaining when P was used with W light ($r = -0.707$, $P \leq .001$; Table 8). No other significant correlations existed in the remaining groups.

Sensitivity of UV Light in Detection of Adhesive

Areas of adhesive were found on the teeth examined under SEM in conjunction with energy-dispersive X-ray spectroscopy that had not been visible when illuminated by the UV light. This was true for both brands of adhesive.

DISCUSSION

The importance of complete adhesive removal following orthodontic treatment and the negative side effects that may occur if adhesive remains has been well documented.[5–8,15] Although studies have investigated various adhesive removal techniques that may yield the least damage to the tooth structure, few studies have suggested a technique that may aid in the detection of the adhesive.[24,25]

Current findings showed that, with use of UV illumination, smaller amounts of adhesive remained relative to use of W light. These results agreed with the findings of Ribeiro and associates who also found adhesive to be more effectively removed when using UV light.[17] Their study, also investigating Opal Bond MV as the fluorescent adhesive, found median adhesive remnants of 0.80 mm^2 with W light and 0.25 mm^2 with UV light.[17] Their results using Opal Bond MV were similar to the current study when using W light, with a median of 0.72 mm^2, but current results were much lower under UV light, with a median of 0.02 mm^2. The specific wavelength and handling of the UV light during adhesive removal were not specified in the previous study; those factors and differences in the operators likely accounted for the variation in results.

Potential limitations in the current study included the wavelength of UV light used, which was 395 nm. Although this was determined to be the optimal wavelength for several composite resins, the ideal wavelength for each orthodontic adhesive is potentially different.[11,14]

Under both light conditions, there was a trend for Opal Bond MV to have lower median adhesive remnant scores than Pad Lock. This result under UV light may have been a result of the stronger fluorescence intensity observed for Opal Bond MV. An explanation for the finding with W light could be that the reflective behavior of a thinner layer of Pad Lock camouflaged it with the reflective behavior of the enamel surface. In contrast, Opal Bond MV was observed to have a matte, chalky appearance during removal, allowing for easier distinction from enamel.

Regarding the efficiency of adhesive removal with the aid of UV light when compared with W light, the differences were statistically significant between Opal Bond MV with W light and Opal Bond MV with UV light, and Opal Bond MV with W light and Pad Lock with UV light. Although Pad Lock with W light had relatively low mean removal times, it had the highest mean surface area of adhesive remaining. As discussed previously, the reflective nature of Pad Lock may have resulted in camouflage, causing the operator to prematurely assume complete removal. Although the removal time of Pad Lock with W light was similar to Pad Lock with UV and Opal Bond MV with UV light, the objective to remove all adhesive was not accomplished as effectively without the UV light.

Table 8. Correlation Between Time and Surface Area of Adhesive[a]

Group	N	*r*	Sig.
P–W	20	−0.707	0.000
P–UV	20	−0.208	0.378
O–W	20	0.221	0.348
O–UV	20	0.053	0.823
All groups	80	0.048	0.676

[a] Sig. indicates significance; P, Pad Lock; O, Opal Bond MV; W, white light; UV, ultraviolet light.

Other investigators have examined differences in removal efficiency among various methods of adhesive removal.[24,25] Of four studies that evaluated a tungsten carbide bur using high speed, mean times ranged from 5.26 to 10.18 seconds per tooth.[2,22,25,28] Mean times in this study were much higher, ranging from 33.4 to 43.7 seconds across groups. This difference may be attributable to variations in the adhesives and burs used and the Adhesive Remnant Index prior to adhesive removal. Another factor was the difference in operator technique. Oliver and Griffiths[29] found large differences in time for removal (65.9 seconds vs 191 seconds) when two operators with different experience levels were used. The current study used a single operator to eliminate operator variability.

Findings using SEM/energy-dispersive X-ray spectroscopy, where penetration of the electron beam has been shown to be 2 μm,[27] demonstrated that resin detectable under the stereomicroscope with UV light was $>2\ \mu$m in thickness. The assessment also showed that enamel that appeared free of resin under UV light can have thin ($<2\ \mu$m) adhesive present. No previous study has determined the minimum thickness of adhesive detectable by UV light that was found to be $>2\ \mu$m in the current study. This study, however, did not investigate enamel damage after removal. If significantly more enamel is removed when using UV light, then such negative effects may outweigh the benefits.[30] Future research should be done to evaluate enamel damage.

Based on the findings of this study, the null hypothesis was rejected, and it is recommended that fluorescent adhesives be used in conjunction with UV LED illumination to ensure more complete adhesive removal. Additional advantages of UV LED illumination include portability, affordability, and ease of use intraorally.

CONCLUSIONS

- The use of UV light resulted in less fluorescent adhesive resin remaining on tooth surfaces when compared with W light.
- When Opal Bond MV was used with UV light, there was a statistically significant decrease in mean time spent on adhesive removal when compared with W light.
- There was no significant difference between the two fluorescent adhesives regarding effectiveness and efficiency under UV illumination.
- Fluorescent adhesives with a thickness $<2\ \mu$m may not be detectable by UV illumination. For thicker remnants, UV light at 395 nm is a reliable method for adhesive detection.

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