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Modification of Curing Light Duration through Indirect Bonding Trays

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Abstract:

Objective: The study's aim is to determine if variation of curing light duration and strength affects shear bond strength (SBS) when using an indirect bonding tray (IBT) in comparison to direct bonding.
Materials and Methods: 288 bovine incisors were divided into 3 groups: direct bonding with no IBT, IBT, and IBT with a 3 second cure after IBT removed. The 3 groups were divided into 2 subgroups based on curing light power: Standard (1200 mW/cm2) and Xtra (3200 mW/cm2). Each subgroup was divided into 4 groups based on curing time: 5, 10, 15, 20 seconds for Standard and 1, 3, 6, 12 seconds for Xtra (n=12). Brackets were cured with a LED device (VALO Ortho, Ultradent, South Jordan, Utah) and a 3 mm Star VPS (Danville Materials, Carlsbad, California) transfer tray was used for IBTs. 24 hours after bonding, brackets were subject to an SBS test performed with the Instron universal testing machine, and the adhesive remnant index (ARI) was recorded for each bracket.
Results: 2-way ANOVAs with Tukey post hoc tests identified statistically significant differences between the groups ($p<0.05$).
Conclusion: SBS is affected by curing through an IBT, and curing light duration must be modified based on power setting.

Keywords: Shear bond strength, indirect bonding tray, adhesive remnant index, orthodontic brackets

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The experiments reported herein were conducted according to the principles set forth in the National Institute of Health Publication No. 80-23, Guide for the Care and Use of Laboratory Animals and the Animal Welfare Act of 1966, as amended.

Biographical notes:
Dr. Mohr is a resident at the Tri-Service Orthodontic Residency Program, Class of 2021. This research and manuscript were completed to partially fulfill her requirements for completing her

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Modification of Curing Light Duration through Indirect Bonding Trays

Introduction

In general, efficiency in orthodontic chairside workflow while achieving great clinical results has always been a goal of orthodontists. Over the past few years, indirect bonding has increased in popularity as an efficient way of bonding orthodontic brackets. Additionally, curing lights have been marketed to decrease the amount of time needed to effectively cure composite when bonding orthodontic brackets. Both of these variables contribute to the efficiency of the orthodontic bonding appointment.

The concept of indirect bonding was introduced to clinical orthodontics in 1972 when Silverman and Cohen investigated different adhesives to bond plastic brackets to stone casts. The goal was to increase patient comfort while decreasing the amount of time they were in the chair [1]. This technique was modified in 1979 by Thomas to include fabricating a "custom composite base" and flexible transfer tray to place the brackets in the patient's mouth [2]. Originally, transfer trays were fabricated with an opaque material, which required self-cure composite to bond the brackets. This would often result in excess material or "flash" around the brackets which required removal and reduced the time savings for the provider and the patient. Additionally, bracket failure occurred if the tray was removed too early, but leaving the tray in too long caused the patient discomfort [3]. By 1990, Read and O'Brien incorporated light-cured resins as a bonding option [4]. In 1997, Kasrovi et al. modified the technique to allow the provider direct visualization of the brackets during the entire bonding process. His transfer tray allowed the time saving options of light-cured resin and the ability to remove excess composite before curing. [5] Miles introduced flowable composite to the indirect bonding workflow in 2002, to fill voids in the custom resin base [6]. Further advances include the use of three-dimensional computer-aided design and computer-aided manufacturing (3D CAD-CAM) for fabrication of indirect bonding trays [3].

Indirect bonding provides numerous advantages for the orthodontic clinical practice. The largest advantage is the decreased time the patient spends in the chair for the bonding appointment. The indirect bonding technique also increases the accuracy of bracket positioning. [3] It is much quicker to place the transfer tray in the patient's mouth as opposed to placing the brackets on each individual tooth. The process of indirect bonding also gives orthodontic assistants more responsibility. This workflow allows the assistant to be very engaged from the beginning of the patient's treatment. Additionally, this frees the orthodontist's time to see more patients throughout the day. Orthodontic assistants can be trained on the process, while the orthodontist checks the bonding, adds bite turbos as needed, and determines the initial archwire. Originally, the ability to bend wire was the largest factor in achieving excellent clinical results [7]. However, in 1998, McLaughlin stated, "the best results in the future will be achieved by those orthodontists who are best at bracket positioning." [8] In order for the bracket prescription to be expressed correctly, the bracket must be in the proper position on the tooth. Indirect bonding allows the orthodontist the ability to check placement from every angle without worrying about time and contamination from the oral environment. [3] In a 2019 study, Li et al. found that the total working time for indirect bonding was significantly longer than that for direct bonding, but the indirect bonding involved significantly less clinical chairside time than the direct bonding. [9] Additionally, indirect bonding may be advantageous when bonding ceramic brackets, since these brackets provide a few challenges when bonding. For example, they have different adhesive properties, and the bracket slot for proper placement is not as clearly visualized intraorally, so the indirect bonding technique allows for more efficient placement of these brackets as well. [3]

While there are multiple benefits for using the indirect bonding technique, there also several disadvantages. First, there is increased lab time for both the orthodontist and the assistants. The assistants can be trained to do most of the indirect process which includes placing and curing the brackets as well as fabricating the transfer trays. However, the orthodontist is still required to check the bracket positioning before the assistant cures them. An additional set of impressions is required close to the bonding date so that they are an accurate representation of the teeth, and all of this results in an increased cost for the materials. Another consideration is that without proper seating of the tray, the brackets will not be bonded in the correct position which would require debonding and repositioning multiple brackets [10]. Also, if too much resin is applied to the brackets in the transfer tray, excess resin will have to be removed by the orthodontist once the tray is removed. [3]

In addition to modification of indirect bonding trays, there have been significant developments with light-emitting diode (LED) light-curing units (LCUs). As new LED LCUs are available, better polymerization of resin-based materials is achieved with less exposure time. [11] The decreased time for curing with a higher-powered light is advantageous because it reduces the amount of time needed to cure the brackets during an orthodontic bonding appointment. One of the ways to evaluate the effectiveness of curing lights is tested is through shear bond strength (SBS) studies. These studies measure the amount of force that is needed to debond the bracket. In 2016, Verma looked at the SBS of brackets using three different LED curing units with different intensities and curing times. He compared curing the brackets from one side or two sides to see if this made a difference on bond strength. The study showed that LED lights with an intermediate energy density and a longer exposure time had a higher degree of cure than one with a high energy density and a shorter exposure. Both SBS values were higher than what is required to be deemed clinically acceptable, and curing from the buccal side only resulted in lower SBS than having two exposures – one from each side. [12] Almeida et al. conducted a study that looked at the effects of decreasing the curing time with a high-power LED device on SBS of metal brackets in vitro. This study showed curing time and type of composite affected SBS. Decreasing exposure time to 3 seconds as opposed to 6 seconds decreased SBS, but these values were still likely to be clinically acceptable. [13] A study by Ward et al. in 2015 looked at the number of bracket bonding failures when using a high-powered LED light for 6 seconds compared to a standard LED light for 20 seconds. The results showed no statistically significant difference and supported the use of the high-powered LED due to the reduction of clinical chair time. [14] Additionally, studies have been conducted to determine how the conversion of composite is affected by decreasing curing light time. While some claim a higher degree of conversion with shorter time and higher-powered lights, others have shown that the shorter time does not result in higher conversion of the composite. However, these studies used different chemical composition of composites, which may explain the inconsistencies. Studies are still needed to determine what degree of conversion is acceptable for orthodontic composites so the relationship between time and power can be established. [15]

While studies exist that have investigated the accuracy of indirect bonding trays and the effectiveness of new curing lights, there is no research that shows how the curing light is affected by curing through an indirect bonding transfer tray. The purpose of this study was to determine the effect on SBS when curing through an indirect bonding transfer tray and investigate which curing light setting is the most efficient at achieving clinically acceptable bond strength of the orthodontic bracket to the enamel surface. The null hypothesis investigated was no increase in curing light duration is needed to achieve the same SBS of orthodontic brackets when curing through an indirect bonding tray as compared to direct bonding.

Materials and Methods

Study Groups

This study was divided into two treatment groups. Both treatment groups were tested at four different lengths of cure using the Valo Ortho curing light (Ultradent Products, South Jordan, UT). The two treatment groups were based on the curing light setting: Standard (1200 mW/cm^2) and Xtra Power (3200 mW/cm^2). The curing light time increments for the Standard setting were 5, 10, 15, 20 seconds. The curing light time increments for the Xtra Power setting were 1, 3, 6, 12 seconds. Star VPS is a single layer material that was used to create the indirect bonding transfer tray. A variable group was added where the bracket was cured for an additional 3 seconds on the Xtra Power setting after the indirect bonding transfer tray was removed. The control group was direct bonding to the tooth with the same curing light durations in the absence of the indirect bonding transfer tray. See Table 1.

Table 1: Study Groups

Curing Light Setting	Tray	Time (seconds)	Cure after Tray Removal (3 sec Xtra Power)	Total Sample Size
Standard	Yes	5, 10, 15, 20	No	48
Standard	Yes	5, 10, 15, 20	Yes	48
Standard	No	5, 10, 15, 20	No	48
Xtra Power	Yes	1, 3, 6, 12	No	48
Xtra Power	Yes	1, 3, 6, 12	Yes	48
Xtra Power	No	1, 3, 6, 12	No	48

Tooth, Cast, and Transfer Tray Preparation for Indirect Bonding

For this in vitro SBS study, indirect bonding was done with bovine teeth (Animal Technologies, Inc, Tyler, TX) mounted in cold-cure acrylic resin to simulate the human dentition. The bovine teeth were mounted taking into consideration the limitations of the universal testing machine (Model 5943, Instron, Norwood, MA). The teeth were placed to optimize the vertical forces from the machine for SBS testing. Four teeth were positioned into the plastic block template. Each group required 3 acrylic blocks (4 teeth in each block for a total of 12 teeth per group). Cold-cure acrylic resin was flowed into the block former to the height of the cemento-enamel junction and cured according the manufacturer's instructions for use.

- Once the teeth were set, alginate impressions were made of the dentition and poured up in dental yellow stone. Alcote separator (Dentsply International, York, PA) was painted on the facial surface of the casts. MBT Victory Twin series central incisor brackets (3M, Saint Paul, MN) were placed on the stone teeth, excess flash composite removed, and then cured using the Triad light curing unit (Patterson Dental, Saint Paul, MN) for 6 minutes.
- Indirect bonding transfer trays were fabricated with Star VPS (Danville Materials, Carlsbad, CA) using a jig. The jig was printed by the Stratasys Objet Eden 260VS Polyjet printer (Stratasys LTD, Eden Prairie, MN) using VeroDent Med670 material (Stratasys). The jig allowed the specific thickness (3mm) of the indirect bonding transfer tray to be consistent for each sample.
- The casts were soaked in water for fifteen minutes to dissolve the Alcote separator and allowed for the indirect bonding transfer tray to be removed from the cast. Any stone debris on the brackets was removed, and the transfer tray was dried. Revolution Flowable 2 flowable composite (Kerr Corporation, Orange, CA) was placed on the bracket base, and the tray was placed in a dark box until tooth preparation was complete.
- Once the indirect bonding tray was fabricated and the brackets were prepared, the bovine teeth were prepared for bonding. The teeth were pumiced for 10 seconds, irrigated, and dried. 34% phosphoric acid etch (Dentsply) was placed on the facial surface for 15 seconds, then removed with air and water. The teeth were dried (but not desiccated), and then Optibond Solo (Kerr Corporation) was applied to the enamel surface for 15 seconds and air thinned for 3 seconds according to the manufacturer's instructions for use.
- The transfer tray with the flowable composite was positioned on the teeth and cured directly over top of the bracket according to the study group's curing duration specifications. The transfer tray was removed, and the sample was placed back in a black box to prevent any other light source from reaching the composite while preparing for the samples to be placed in the Instron Universal Testing machine.

Direct bonding preparation - Control

- The bovine teeth were mounted and prepared for direct bonding the same way as the teeth for indirect bonding.
- MBT Victory Twin series central incisor brackets were placed on the bovine teeth considering the limitations of the universal testing machine. The excess flash composite was removed around the bracket, and the brackets were cured directly over top of the bracket according to the study group's curing duration specifications. The sample was placed in a black box to prevent any other light

source from reaching the composite while preparing for the samples to be placed in the universal testing machine.

Data Collection

Bovine teeth with orthodontic brackets (directly or indirectly bonded) were placed in the universal testing machine 24 hours after bonding. The crosshead contacted the bracket where the bracket base was bonded to the enamel. The crosshead speed was 1mm/min. The force was applied to the base of the MBT Victory Twin series central incisor bracket until bond failure was reached. The result for each sample was recorded in Newtons (N) and converted to Megapascals (MPa) by dividing the max load (N) by the surface area of the bracket base (10.52 mm^2). This number represents the SBS of the bracket. Brackets were recovered, and Adhesive Remnant Index (ARI) was measured for each bracket. The amount of resin was observed on the bracket base and the amount remaining on the tooth. Two individuals were calibrated and scored each bracket. A score of 0 meant all of the adhesive was on the tooth, and a score of 3 meant that all of the adhesive was on the bracket. See Table 2.

Table 2: Adhesive Remnant Index (ARI)

Adhesive Remnant Index (ARI) Score	Observation based on percentage (%) of adhesive found on the bracket after bracket failure
0	0 (0% on bracket, 100% on tooth)
1	0<X<50 (<50% on bracket, >50% on tooth)
2	50≤X<100 (>50% on bracket, <50% on tooth)
3	100 (100% on bracket, 0% on tooth)

Data Analysis

The mean and standard deviation of SBS was calculated for each group. Data were analyzed with a 2-way ANOVA (α = 0.05) per power level (Standard and Xtra Power) and multiple 1-way ANOVAs (α = 0.007) per curing mode or time. Tukey Honest Significant Difference (HSD) post hoc tests were applied to determine differences between groups.

The median and interquartile range of adhesive remnant index (AHI) was calculated for each group. Data were analyzed with multiple Kruskal-Wallis tests (α = 0.007) per curing mode or time for both power levels.

A Bonferroni correction (α = 0.007) was completed due to multiple comparisons between groups. Tests were completed with statistical software (SPSS, Ver 25, IBM, Armonk, NY).

Results

The 2-way ANOVA for Standard power found significant differences in SBS based on time (p=0.004) but not on curing mode (p=0.063) with a significant interaction (p=0.017). The 2-way ANOVA for Xtra power found significant differences in SBS based on time (p<0.001) and curing mode (p<0.001) with no significant interaction (p=0.055).

The multiple 1-way ANOVAs and Tukey post hoc tests found significant differences in SBS based on time or curing mode with both power levels (p<0.007). See Table 3.

Table 3: Shear Bond Strength

Shear Bond Strength (Mean, St Dev)				
Time	5 sec	10 sec	15 sec	20 sec
Standard – No tray/no cure after	26.5 (8.2) Aab	25.4 (10.3) Aa	27.0 (7.6) Aa	35.9 (7.8) Aa
Standard – Tray/cure after	34.2 (9.2) Ab	35.8 (13.0) Aa	30.4 (12.4) Aa	33.1 (12.1) Aa
Standard – Tray/no cure after	17.8 (10.5) Aa	32.5 (7.6) Ba	29.8 (11.3) ABa	36.6 (12.5) Ba
Shear Bond Strength (Mean, St Dev)				
Time	1 sec	3 sec	6 sec	12 sec
Xtra – No tray/no cure after	25.0 (8.5) Ab	35.9 (5.6) Bb	39.3 (6.7) Bb	36.6 (8.6) Ba
Xtra – Tray/cure after	24.5 (7.9) Aab	30.4 (8.9) Aab	35.9 (12.2) Aab	30.5 (10.7) Aa
Xtra – Tray/no cure after	13.8 (8.4) Aa	24.5 (9.5) ABa	23.8 (10.8) ABa	34.9 (13.8) Ba
Groups with same upper-case letter by row or lower-case letter by column are not significantly different. p>0.007				

The multiple Kruskal-Wallis tests found no significant differences in adhesive remnant index based on time or curing mode with Xtra power levels (p>0.007). With Standard power, the Kruskal-Wallis tests only found a significant difference at 20 seconds based on curing mode (p=0.002). See Table 4.

Table 4: Adhesive Remnant Index

Adhesive Remnant Index (Median, IQR)				
Time	5 sec	10 sec	15 sec	20 sec
Standard – No tray/no cure after	3 (3) Aa	2 (2) Aa	2.5 (2) Aa	3 (0) Ab
Standard – Tray/cure after	1 (1) Aa	2 (1) Aa	3 (2) Aa	1 (1) Aa
Standard – Tray/no cure after	2(1) Aa	2 (2) Aa	1.5 (2) Aa	2 (1.75) Aab
Adhesive Remnant Index (Median, IQR)				
Time	1 sec	3 sec	6 sec	12 sec
Xtra – No tray/no cure after	2.5 (2) Aa	3 (1) Aa	3 (1) Aa	3 (0) Aa
Xtra – Tray/cure after	1 (1) Aa	3 (2) Aa	1 (1) Aa	1.5 (2) Aa
Xtra – Tray/no cure after	2 (1) Aa	1 (1) Aa	2 (3) Aa	1.5 (2) Aa
Groups with same upper-case letter by row or lower-case letter by column are not significantly different. p>0.007				

Discussion

This study was designed to determine the effect on shear bond strength when curing through an indirect bonding tray and investigate which curing light setting is the most efficient at achieving clinically acceptable bond strength of the orthodontic bracket to the enamel surface. The null hypothesis that no increase in curing light duration is needed to achieve the same SBS of orthodontic brackets when curing through an indirect bonding tray as compared to direct bonding was rejected, since there were significant differences found when curing through an indirect bonding tray.

In a study by Reynolds and von Fraunhofer, they stated that the ideal orthodontic adhesive SBS should be between 5.9 to 7.8 MPa. [16] This range should allow for brackets to remain bonded throughout treatment, yet also allow for easy removal when treatment is completed. Most SBS studies cite this paper for ideal bond strength. In a 2003 paper by Yi et al. comparing SBS between direct and indirect bonding, all of their results were higher than those stated by Reynolds and von Fraunhofer. [17] The *in vitro* study by Shimizu et al. also found SBS values higher than Reynolds and von Fraunhofer's recommendations for direct and indirect bonding. [18] In a 2010 study, Magno et al. reported SBS higher than Reynolds and von Fraunhofer, but they also stated that no enamel damage was observed on any of the samples. [19] Additionally, Almeida et al. stated that the values by Reynolds and von Fraunhofer were a personal opinion published in 1975, and they recommended estimating SBS from maximal biting force and the size of the bracket base, which would give a range of 22.99-25.8 MPa. [13] All of the groups in this study had an SBS higher than the ideal values determined by Reynolds and von Fraunhofer. The lowest mean SBS in this study was 13.8 MPa, and the highest mean was 39.3 MPa. However, there was still variability in the SBS among the different groups. When comparing the SBS values for the recommended curing durations, the lowest value was the standard direct bonding (5 seconds), and the rest of the values were in a similar range (30.4-35.9 MPa).

The current literature does not address the appropriate amount of time needed to achieve ideal SBS when curing through an indirect bonding tray. When analyzing SBS with Standard power in this study, there was no statistical difference to cure longer than 5 seconds with direct bonding. This is actually 5 seconds less than recommended by the manufacturer [20]. However, when indirect bonding, in order to achieve similar SBS to direct bonding and considering efficiency with Standard power, the provider must decide if they would rather cure each bracket for 5 seconds through the tray followed by a 3 second cure after tray removal or cure 10 seconds through the tray initially. The difference is 2 seconds per bracket. While it is only a difference of 24 seconds per arch, there is additional time needed to position the curing light on each bracket after tray removal, so 10 seconds directly over the bracket while the tray is still in place might be the more efficient option. The 10 seconds directly on the bracket is consistent with Valo's recommendation for curing time for direct bonding.

Additionally, there were statistically significant differences seen in SBS when using the Xtra power. The lowest mean for SBS in this study was when the bracket was cured for only 1 second through the indirect bonding tray. Based on the results of this study, the bracket should be cured for at least 3 seconds when curing for direct bonding. This was also half the time recommended by the manufacturer [20]. To achieve SBS similar to the recommended direct bonding setting, the provider should cure for 3 seconds through the tray with the 3 second cure afterwards or 12 seconds through the tray only. This results in a difference of 6 seconds per bracket or 72 seconds per arch depending on the curing protocol chosen. This study's finding with the 3 second cure through the tray followed by a 3 second cure after tray removal is consistent with the curing time duration recommended by the manufacturer for direct bonding.

Ideally, when bonding failures occur, this takes place at the bracket-adhesive interface to prevent damaging the tooth. [21] In this study, an ARI score of 3 meant that all of the adhesive was on the bracket base and none was remaining on the tooth. This indicates that there would be a higher likelihood that enamel fracture could occur when the bracket is removed. A more ideal situation is an ARI score of 0 where all of the adhesive is remaining on the tooth and none on the bracket base. ARI was measured to see if there was a difference when changing the curing light duration. For standard power, the only significant difference was seen when the bracket was cured for 20 seconds with the additional cure afterwards. For Xtra power, there was no significant difference between any of the groups. The majority of the groups that had a median score of 3 were the brackets cured without a tray. Additionally, none of the groups that were only cured through the tray achieved an ARI median score of 3. There was no enamel fracture observed on any sample in this study. The results of this study indicate that the ARI score or risk of causing enamel fracture at debond should not be a concern when determining the preferred curing protocol with indirect bonding.

There were a few limitations to this study. Some studies have shown that there is a difference in SBS from bovine enamel to human enamel, but this is an accepted method for SBS studies. A systematic review and meta-analysis by Soares et al. in 2016 concluded that no significant difference was found between human and bovine teeth, either for enamel or dentin substrates. Therefore, bovine teeth can be a reliable substitute for human ones on bond strength studies of adhesive systems to both enamel and dentin substrates. [22] This is an *in vitro* study, so the ability to cure directly over the bracket is easier in a laboratory setting as opposed to working in the patient's mouth. These teeth were kept in a dark box for 24 hours before SBS was tested, which is a much more controlled environment than inside a patient's mouth. Another factor of curing in the mouth is the effect of the curing light on the surrounding brackets. Human teeth are closer together than the bovine incisors in this study, so there could be additional curing intraorally when the adjacent bracket is being cured. For the study design, flash can interfere with the ability of the universal testing machine to shear the bracket. Some flash was removed with a hand scaler, but several brackets had to be retested because of the interference. The second attempt to debond might have resulted in a lower SBS, since an initial force was already applied during the first attempt. The acrylic blocks were adapted to hold only 4 teeth so that the force was applied through the middle of the block for each sample. Initial trial attempts with bovine incisors further from the center of the acrylic block resulted in failed attempts to debond due to the lack of stability of the acrylic block in the machine. Another limitation was recapturing the brackets after the SBS was determined. A barrier was in place around the machine, but due to the ricocheting force, 2 brackets were unable to be recovered to determine how much adhesive was remaining on the bracket base.

For this study, brackets were cured directly over the labial surface per the manufacturer's instructions. Future studies would be necessary to determine if curing from different angles (mesial/distal or incisal/gingival) through the indirect bonding tray affects SBS. Additionally, does the color of the tray material or the rigidity of a plastic transfer jig affect the depth of cure and SBS?

Conclusions

- There is a difference in shear bond strength when light curing through an indirect bonding tray.
- The provider must decide if it is more efficient in the practice workflow to cure through the indirect bonding tray for a longer duration or do an additional cure once the indirect bonding tray is removed to achieve results similar to direct bonding.
- The adhesive remnant index does not change significantly based on curing protocol.

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