CLINICAL COMPARISON OF TWO INDIRECT BONDING SYSTEMS ON RETENTION RATES OF ORTHODONTIC BRACKETS: CHEMICAL CURED CUSTOM BASE VS. LIGHT-CURED NON-CUSTOM BASE

by

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The aim of this study was to compare and evaluate the clinical failure rates of a light-cured non-custom base indirect bonding technique and a chemically cured custom base indirect bonding technique. The orthodontic records of 44 patients were selected for this retrospective study, and a total of 682 brackets were indirect bonded. A record of the site of failure and the time point of failure (immediately or six months following initial bonding) for each tooth and each patient was noted. During the immediate time point, 3 failed with the light-cured non-custom base indirect technique (0.85% failure rate) and 13 failed with the chemically cured custom base indirect technique (3.9% failure rate). During the six months following the initial indirect bonding, 16 failed with the light-cured non-custom base indirect bonding technique (4.6% failure rate) and 13 failed with the chemically cured custom base indirect bonding technique (3.9% failure rate). When the failures of the immediate time point and the six month time point were combined, 19 failed with the light-cured non-custom base indirect technique (5.4% failure rate) and 26 failed with the chemically cured custom base indirect technique (7.9% failure rate). There were no significant differences found between the failure rates of the light-cured non-custom base indirect technique and the chemically cured custom base indirect technique during any of the time points analyzed.
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LITERATURE REVIEW

Direct Bonding History

Advancements in restorative dentistry have significantly influenced the evolution of bonding techniques utilized in orthodontics. Buonocore\(^1\), in 1955, noted that a major downfall of dental filling materials was their inability to adhere to tooth structure. Buonocore observed an improvement in the adhesion of acrylic resins to enamel with the application of an 85% phosphoric acid solution.

Patented in 1962 by Bowen, bisphenol A-glycidyl dimethacrylate (bis-GMA) resins embodied characteristics which overcame many of the shortcomings found in the acrylic and epoxy resins used during that time\(^2\),\(^3\). Dimethacrylate resins comprise the majority of composite resins used clinically, with bis-GMA being one of the most common types of dimethacrylate resins\(^4\).

Newman\(^5\), in 1965, suggested direct bonding of orthodontic attachments to teeth as an alternative to cementing orthodontic bands. Newman used an epoxy resin adhesive to direct bond plastic brackets to enamel surfaces etched with 40% phosphoric acid. Another method of direct bonding orthodontic brackets was developed in the Orthodontic Department of the Eastman Dental Center in 1966. The adhesive resin was the same type used in research performed by Cueto and Buonocore for sealing pits and fissures. Only a small percentage of bracket failures recorded over an 8 to 18 month period was reported\(^6\). Retief and Dreyer\(^7\) utilized an epoxy resin for the direct bonding of orthodontic attachments. Clinical trials by Retief and Sadowsky\(^8\) reported an 18.8% failure rate using
the epoxy resin adhesive to bond 123 attachments to etched enamel teeth. Retief and Sadowsky concluded that the use of the acid etch technique and the epoxy resin adhesive were acceptable for clinical use.

Indirect Bonding History

The indirect bonding technique incorporates two distinct steps – a laboratory step and a clinical step. The laboratory process involves proper positioning of the brackets onto the dental stone casts using some type of adhesive material. A transfer tray is adapted over the cast and brackets to preserve the position of the brackets while also serving as a vehicle to carry the brackets to the patient’s mouth. The clinical step involves preparing both the brackets and the teeth for bonding, placement of the transfer tray with subsequent removal of the tray.

The continued success of direct bonding attachments helped pave the way for the development of indirect bonding in orthodontics. Silverman, Cohen, Gianelly and Dietz\(^9\) were the first to discuss an indirect bonding technique in 1972. Their technique required a second set of dental casts used to position the brackets by means of a temporary bracket adhesive cement. A clear plastic tray, adapted to the casts and brackets, was used to carry the brackets to the patient’s mouth while maintaining the brackets’ position as predetermined on the casts. Prior to intra-oral bonding, the temporary bracket adhesive cement was replaced with an adhesive system consisting of two parts – the pit and fissure sealant developed by Buonocore and a “new experimental adhesive”. As compared to the full-banded technique, the authors discussed multiple advantages of this method including improved precision of attachment positioning, more
patient comfort, less doctor stress and better esthetics. Even though this method was technique sensitive, the authors believed that with time a success rate of 90 to 100% would be achieved.

Silverman and Cohen\textsuperscript{10} discussed improvements to their indirect bonding technique, including a new adhesive cured by ultraviolet light. The authors stated that a complete indirect bonding procedure should take only half the time as compared to a full banding procedure. Newman, in 1974, reported a modified version of the indirect bonding technique described by Silverman and Cohen\textsuperscript{10} earlier that same year. Newman advocated the use of an acrylated epoxy adhesive with this indirect bonding method\textsuperscript{11}.

Thomas, in 1979, was the first to describe an indirect bonding technique involving a customized resin pad on the bracket base. The brackets were attached to the dental cast using a filled two paste self-curing composite system, all excess composite was removed around the bracket base and the composite was allowed to fully cure. The transfer tray, adapted from Silverman and Cohen\textsuperscript{9, 10}, was fabricated from a dental mouthguard material. The chairside procedure involved placing the liquid catalyst resin to the cured resin pad on the bracket base, the liquid base resin to the teeth and then firmly seating the transfer tray onto the patient’s teeth to allow polymerization of the unfilled resins. Thomas noted that this technique extended the working time because the unfilled resins were not pre-mixed. One of the main advantages of this technique was that any excess material around the bracket consisted of an unfilled liquid sealant which could be easily removed\textsuperscript{12}. A modification to this technique, involving mixing the sealant prior to application, was developed to help ensure complete mixing of the sealant’s two components\textsuperscript{13-16}.
Factors Influencing Bond Strength

The bond strength of the adhesive and attachments must be able to resist forces of mastication, stresses exerted by the arch wire and allow for control of tooth movement in all three planes of space. While at the same time, the bond strength has to be at a level to allow for bracket removal without causing damage to the enamel surface. According to Newman\textsuperscript{17}, the orthodontic force applied to brackets during treatment is about 1 MPa, with a maximum of about 3 MPa probably occurring under certain clinical conditions. Reynolds\textsuperscript{18} indicated that brackets should be able to withstand loads of 5.9 to 7.8 MPa to be considered clinically successful, while McCourt, Cooley, and Barnwell\textsuperscript{19} suggested a minimal clinical bond strength of 10 MPa. Reporting on a two year clinical study, Miura, Nakagawa, and Masuhara\textsuperscript{20} indicated that the required bracket bond strength was 5.1 MPa.

Retief\textsuperscript{21} stated that one of the main requirements for good bonding was intimate interfacial contact between the cement and the substrate. Ten Cate\textsuperscript{22} stated that the bond strength is influenced by chemical and mechanical properties of the adhesive and bracket material, as well as the adhesive forces at the enamel-adhesive and adhesive-bracket interfaces. Even though physical and chemical forces play a crucial role in the attachment of a bracket-adhesive system to the enamel surface, the mechanical retention represents the predominant mechanism in the bracket-bonding technique used today\textsuperscript{23, 24}. The strength of a cured adhesive depends on its composition, the degree of conversion and the length of the polymer chain. Any residual resin monomer remaining in the adhesive might alter its mechanical properties\textsuperscript{25}. 
The minimum bond strength required for clinical reliability of orthodontic bonding is still unknown and will vary, depending on factors such as the adhesive system used, bracket base design, morphology of the enamel, and appliance force. Individual clinician technique and patient treatment of the appliances may also influence the degree of clinical retention obtained.

Indirect Bonding vs. Direct Bonding

**Accuracy**

In order to obtain the full potential of a pre-adjusted edgewise appliance, Andrews stressed the importance of accurate bracket positioning. Indirect bonding affords the practitioner improved vision and access for bracket positioning, because the brackets are positioned on the patient’s dental casts. Many authors have suggested that indirect bonding is more accurate as a result of the improved vision and access for bracket positioning.

A clinical trial compared the accuracy of bracket positioning between direct and indirect bonding with regards to linear and angular measurements. Even though the molars were not bonded, no statistically significant differences were found except on certain teeth in which indirect bonding indicated more accurate results in the vertical bracket height on maxillary canines and angular measurements on maxillary and mandibular canines.

Koo, Chun, and Vanarsdall assessed the accuracy of bonding brackets from second premolar to second premolar on maxillary and mandibular patient models between direct and indirect bonding techniques. No statistically significant differences
were noted with respect to angulation or mesiodistal positioning; however, the indirect bonding technique yielded better results in bracket height locations. The authors acknowledged that performing their study in an actual clinical setting might have altered the results. Hodge, Dhapatkar, Rock, and Spary\textsuperscript{33} carried out a clinical trial to compare the accuracy of direct and indirect bonding techniques when positioning brackets canine to canine. Even though the indirect bonding technique did not exhibit superiority relative to accuracy in a vertical, horizontal or angular dimension, indirect bonding was able to limit the range in which positional errors were made.

\textit{Bond Strength}

Hocevar and Vincent\textsuperscript{34} compared the shear bond strength of a direct bonding technique with an indirect bonding technique. No significant difference in shear bond strength was found between the direct ($68.2 \pm 9.37$ kg) and the void-free indirect bonding groups ($65.3 \pm 8.84$ kg); however, if voids were present between the bracket and enamel interface, the bond strength of the indirect bonding group decreased approximately 50%.

Sinha, Nanda, Duncanson, and Hosier\textsuperscript{16} used seven different chemically cured resins to compare the bond strengths of a direct bonding technique to two different indirect bonding techniques. The first indirect group was modeled after Silverman’s indirect technique\textsuperscript{9}, while the second indirect group followed the technique described by Thomas\textsuperscript{12} in 1979. In four of the seven composite groups evaluated, the results showed significantly higher bond strengths for the direct bonding group\textsuperscript{16}. Another study\textsuperscript{35} tested the shear bond strength of an indirect bonding technique modeled after Thomas\textsuperscript{12} to a direct bonding technique. Even though the findings showed no significant differences for
the shear bond strength of either group, the indirect group was slightly higher than the
direct group (11.2 ± 2.6 MPa vs. 10.9 ± 2.9 MPa, respectively).

One study\textsuperscript{14} compared a light-cured direct bonding technique with a modified
Thomas indirect bonding method using three different types of resins for the custom base
– thermally cured, light-cured and chemically cured. The light-cured and the chemically
cured composite groups showed similar bond strengths to the direct bonding group (14.99
± 2.85 MPa, 15.41 ± 3.21 MPa, and 13.88 ± 2.33 MPa, respectively), while the shear
bond strength of the thermally cured groups was significantly lower than the direct
bonding group (7.28 ± 4.88 MPa, 7.07 ± 4.11 MPa vs. 13.88 ± 2.33 MPa, respectively).
A recent study by Linn, Berzins, Dhuru, and Bradley\textsuperscript{36} compared the shear bond strengths
of a chemically cured and a light-cured indirect bonding technique with a light-cured
direct bonding technique in vitro. No statistically significant difference in shear bond
strengths between the direct and the two indirect groups was found (16.27 ± 4.74 MPa vs.
13.83 ± 4.27 MPa, 14.76 ± 4.06 MPa, respectively).

\textbf{Failure Rates}

Zachrisson and Brobakken\textsuperscript{37} reported a statistically significant difference with
regards to failure rates over a six month period between direct bonding (2.5%) and
indirect bonding techniques (13.9%). Aguirre, King, and Waldron\textsuperscript{31} analyzed the failure
rate of a modified Silverman indirect bonding group to a direct bonding group. The study
showed a similar failure rate for both groups over a three month period – 4.5% for the
indirect group and 5.3% for the direct group.
Thiyagarajah, Spary, and Rock\textsuperscript{38} analyzed the failure rates of 32 patients bonded with a split-mouth protocol comparing two light-cured techniques – direct vs. indirect. Over a one year period, only 2.9% (8 of 274 brackets) of the direct group and 2.2% (6 of 279 brackets) of the indirect group failed with 66% of the indirect group failures occurring during the first six months. A 2007 practice-based study\textsuperscript{39} analyzed the bond failure rates between five orthodontic offices performing direct bonding to six orthodontic offices using indirect bonding. The failure rates were recorded during 10 consecutive practice days for 772 patients in the direct group and 596 patients in the indirect group. No significant difference was found between the direct and indirect bonding groups. The study found an average per-patient debond prevalence of 1.17% for the direct group and 1.21% for the indirect group.

**Light-Cured vs. Chemically Cured**

Light-cured, chemically cured as well as thermally cured adhesive systems have been utilized for the bonding of orthodontic attachments. The majority of published articles describing direct and indirect bonding techniques involve the use of light-cured and chemically cured bonding systems. The physical and mechanical characteristics of an adhesive, including the solubility and degradation, are influenced by the degree of cure\textsuperscript{40}. The release of monomers from bonding adhesives has been associated with adverse biologic effects\textsuperscript{41}. A recent study by Gioka, Bourauel, Hiskia, Kletsas, Eliades, and Eliades\textsuperscript{42} investigated the degree of cure and monomer leaching of a light-cured and a chemically cured adhesive. Even though no significant difference was found for the degree of cure or the amount of monomer leaching between the two systems, a moderate
cytostatic effect was observed in vitro on normal human gingival fibroblasts for both systems.

A recent study by Thiyagarajah et al.\textsuperscript{38} argued that with the advent of chemically cured adhesives specifically designed for indirect bonding, the unlimited working time offered by light-cured adhesive systems is not necessary. If the tray is disturbed during the initial set of the adhesive, a weaker bond may occur\textsuperscript{43}. The shortened working time of the specialized indirect adhesives decreases the risk of the clinician disrupting the setting of the adhesive. The inclusion of air may occur during the mixing of the two components of a chemically cured system. As a result of the uneven rate of polymerization produced when loading the chemically cured adhesive onto the bracket bases from one side of the indirect transfer tray to the opposite side, air may also be introduced into the adhesive\textsuperscript{38, 44}. The incorporation of oxygen into the adhesive has been shown to inhibit the adhesive’s process of polymerization\textsuperscript{4}. The bond strength of brackets may be negatively affected by an incomplete polymerization of the adhesive\textsuperscript{45}. No-mix adhesives help decrease the risk of air inclusions and these adhesives have been advocated for use in chemically cured indirect bonding techniques\textsuperscript{43, 46}.

The original indirect bonding technique described by Silverman and associates in 1972 utilized light-cured materials. As reported by multiple authors, one of the main advantages of a light-cured adhesive system is the ability to manipulate the setting time of the adhesive, which ultimately allows for unlimited working time\textsuperscript{47-49}. When compared with chemically cured indirect bonding adhesives, Miles\textsuperscript{50} observed less staining over time with light-cured indirect bonding materials. Since no mixing is required with light cured adhesive systems, the risk of incorporating air into the adhesive is greatly reduced.
The transparent tray used with light-cured indirect bonding systems not only increases the distance between the light source and the bracket, but the tray may also act as a filter to reduce light intensity\(^{51}\). Since the degree of polymerization is affected by light intensity, the bond strength of light-cured indirect bonding adhesives may be negatively affected\(^{52}\).

**Bond Strength**

A laboratory study by Sinha et al.\(^{16}\) used two indirect bonding techniques to assess the bond strengths of seven different two-paste chemically cured resin systems and found a range of \(13.19 \pm 6.47\) MPa to \(26.12 \pm 6.58\) MPa. An in vitro study by Thompson, Drummond, and BeGole\(^{53}\) showed shear bond strengths from \(15.0 \pm 6.4\) MPa to \(23.4 \pm 7.6\) MPa, when various preparations of the cured composite-adhesive interface were performed with a light-cured indirect bonding technique. An in vitro study by Klocke et al.\(^{14}\) showed shear bond strengths of \(7.07 \pm 4.11\) MPa to \(15.41 \pm 3.21\) MPa for two indirect bonding techniques using three chemically cured adhesive systems.

Yi et al.\(^{35}\) used extracted premolars to investigate the shear bond strength of a chemically cured bonding resin designed specifically for indirect bonding. Their study showed an average shear bond strength of \(11.2 \pm 2.6\) MPa. Linn et al.\(^{36}\) compared two modified Thomas indirect bonding techniques. The first indirect bonding technique used a light-cured resin and a chemically cured primer, while the second indirect technique used a light-cured resin and a light-cured primer. The results showed no statistically significant difference between the two indirect techniques – \(13.83 \pm 4.27\) MPa for the chemically cured and \(14.76 \pm 4.06\) MPa for the light-cured.
Failure Rates

In a 1983 report describing an indirect bonding technique using a no-mix adhesive system, Scholz\textsuperscript{43} noted a failure rate of 3.1\% from an earlier study of his in which 595 brackets were indirect bonded in 35 patients using a no-mix chemically cured adhesive system. Over a 24 hour observation period, only 15 of the 1090 brackets indirect bonded by Cooper and Sorenson\textsuperscript{13} utilizing a light-cured system failed during the bonding procedure. The authors attributed the 1.4\% rate of failure to moisture contamination during the bonding procedure. Polat, Karaman, and Buyukyilmaz\textsuperscript{54} used a nine month observation period to analyze the failure rate of 295 brackets indirect bonded with two chemically cured resins. The authors found no significant difference between the two techniques. The 13 failures occurred almost evenly between the two groups and all failures happened within the first month. Krug and Conley\textsuperscript{51} reported 18 out of 554 brackets failed during a three month observation period in which different light sources were analyzed for their effect on a light-cured indirect bonding technique.

A clinical trial by Miles and Weyant\textsuperscript{55} compared the failure rates of two chemically cured bonding resins used in an indirect bonding technique. During the six month observation period, a total of 726 brackets were indirect bonded – 363 in each group. The results showed a statistically significant difference between the failure rate of the two groups, 9.9\% vs. 1.4\%. A six month observation period was used by Read and O’Brien\textsuperscript{49} to evaluate the failure rate of 397 brackets indirect bonded with an experimental light-cured adhesive. In addition to an overall failure rate of 6.5\%, the results showed no significant difference between the failure rates for either the maxillary or mandibular arches or for the anterior and posterior segments of the arches. Miles and
Weyant conducted a clinical study evaluating the failure rates of 2468 brackets indirect bonded with either a chemically cured bonding resin or a flowable light-cured bonding resin. During the six month period of observation, the results indicated failure rates of 2.9% for the chemically cured group and 2.4% for the light-cured group.

**Custom Base vs. Non-Custom Base**

The first indirect bonding technique, introduced by Silverman et al. in 1972, advocated the use of a temporary adhesive for bracket attachment to the stone models. The temporary adhesive was then replaced with an adhesive resin prior to intra-oral bonding. This technique is often described as a clean base or a non-custom base technique. As a result of the guesswork involved with determining the correct amount of composite to apply to the bracket base, this non-custom base technique often resulted in voids or flash.

Thomas introduced the first indirect bonding technique that used a layer of cured composite resin attached to the bracket base, known as the custom base. The custom base was formed when the brackets were attached to the stone models with a filled composite resin. An unfilled sealant was used to bond the brackets to the teeth in the clinic. Even though the amount of flash was reduced with Thomas’ technique, the bond strength may be compromised if the custom base does not have intimate contact with the enamel surface. Since the introduction of both techniques, there have been many modifications and refinements to both the non-custom base and the custom base indirect bonding methods.
The majority of the indirect bonding studies reported in the literature describe techniques utilizing a custom pad. Depending on the time between bracket attachment to the stone cast and bracket placement intra-orally, the age of the bracket composite can range from minutes to weeks. The custom base creates a unique situation in which an interface exists between an aged composite and the sealant. The bond strength may be compromised as a result of this interface being a potential weak link. This interface is very similar to the interface found in restorative dentistry during the repair of composite restorations. Multiple studies analyzing the repair of composite restorations have shown that bond strengths can be significantly reduced when the interface involves an aged composite.

Various mechanisms of adhesion have been used to describe the bonding between layers of resins. The bonding of resin layers within 24 hours occurs primarily by a chemical reaction with the unreacted methacrylate groups on the surface of the substrate offering a foundation for chemical adhesion of the freshly applied polymerizing material. The process of polymerization has been shown to occur for at least 24 hours after initiation; however, the amount of unreacted methacrylate groups decreases as polymerization continues. Since the number of unreacted methacrylate groups is less with aged composite resins, the resulting bond depends less on chemical bonding and more on mechanical forms of attachment. The use of an unfilled intermediate resin helps achieve better wetting of the substrate surface, and to some degree dissolve and swell the polymer surface of the aged composite resin. Sandblasting the aged composite resin surface has been shown to increase the shear bond strength by producing a more reactive surface through exposure of glass filler particles.
Boyer et al.\textsuperscript{63} analyzed the interfacial bond strengths between layers of light-cured composites as a function of age of the initial layer. Their study simulated both the build-up as well as the repair of a composite restoration by aging the composites 2 to 20 minutes, 24 hours and 7 days. While their results showed that the use of a bonding agent improved the bond strength, the bond strength of the interfacial layers of composite decreased as the original layer of composite aged. The results of their study also indicated that the mean repair strengths of the light-cured composites were similar to the self curing composites. A study\textsuperscript{61} in 1993 analyzed the effects of various pretreatments on composite surfaces aged for seven days. The pretreatments included no treatment, cleaned [with water, a toothbrush and air dried], cleaned and roughened with a green stone bur, cleaned and placement of acetone, cleaned and placement of a plastic bracket primer, cleaned and placement of a universal resin or cleaned and placement of a catalyst resin. Of all the surface pretreatments tested, acetone was the only pretreatment likely to produce consistently high bond strengths.

\textit{Bond Strength}

A 2004 in vitro study\textsuperscript{59} investigated the effect on the bond strength of custom bases aged for 24 hours and for 7, 15, 30 and 100 days prior to indirect bonding. The results showed that up to 30 days of aging did not affect the shear bond strength with the mean bond strength values exceeding 15 MPa in these groups. The custom base group aged for 100 days showed significantly lower bond strengths. The authors suggested that indirect bonding may be performed safely when using custom bases aged up to 30 days. Shaiu et al.\textsuperscript{60} reported no significant difference between the bond strength of an indirect
bonding technique using custom bases aged for seven days and brackets placed by a direct method. The results suggested that a custom base aged for seven days will produce a sealant-composite interface with sufficient strength that this interface will not be the weak link for metal brackets placed by the indirect technique.

A recent study by Linn et al. compared two indirect bonding techniques, one chemically cured and the other light-cured, utilizing custom bases with each other as well as with a direct bonding method. No statistically significant difference was reported between the shear bond strengths of all three groups. One study in 2004 involved a direct bonding method and two chemically cured indirect bonding methods using custom bases. The results showed a statistically lower bond strength for one of the indirect bonding techniques (6.1 ± 1.6 MPa) compared with the other indirect group (10.3 ± 4.1 MPa) and the direct group (12.8 ± 5.4 MPa).

A report was published in 1988 comparing the shear bond strength of a direct bonding technique and a custom base indirect bonding technique. Both bonding techniques involved chemically cured bonding systems. No significant difference in shear bond strength was found between the direct (68.2 ± 9.37 kg) and the indirect bonding groups (65.3 ± 8.84 kg). Voids present between the bracket and enamel interface reduced the bond strength of the indirect bonding group approximately 50%; however, if the voids were sealed with an unfilled resin, the bond strength approached that of the direct and void-free indirect groups. Since almost 72% of the indirect bonding group debonded at the enamel-resin interface, the authors suggested that cleanup would be easier.

Klocke et al. showed significantly lower bond strengths when indirect bonding with a thermally cured custom base as compared with the indirect bonding groups with
chemically or light-cured custom bases as well as the direct bonding group. The study also reported that both the original and the modified Thomas technique were able to achieve bond strengths comparable with direct bonding techniques. Another indirect bonding study\textsuperscript{15} analyzed the shear bond strength of three composite base-sealant combinations at three different debonding time intervals – time of transfer tray removal, 30 minutes after bonding of the sealant and 24 hours after bonding of the sealant. All three composite base-sealant groups were indirect bonded using chemically cured sealants. Even though a significantly lower bond strength was found for one composite base-sealant group at transfer tray removal, all three composite base-sealant combinations displayed acceptable bond strengths at 30 minutes and 24 hours after bonding the sealant.

A study\textsuperscript{16} published in 1995 used seven different chemically cured resins to compare a non-custom base indirect bonding technique with a custom base indirect bonding technique. When six of the seven groups were tested for bond strength, no significant difference was found between the two indirect techniques. As a result of having a significantly lower amount of composite remaining on the tooth surface after debonding, the study suggested that the custom base technique would be easier to clean-up during a clinical debonding procedure. A 2003 in vitro study\textsuperscript{58} analyzed the bond strengths of a custom base indirect bonding technique and a non-custom base indirect bonding technique at two different time points – 30 minutes and 24 hours after bonding. Even though the bond strength was not significantly different for the two debonding times within each group, the non-custom base showed significantly lower bond strengths when compared with the custom base group.
Failure Rates

During a 24 hour observation period, Cooper and Sorenson\textsuperscript{13} investigated the failure rate of 1090 brackets placed by a custom base indirect bonding technique and found a 1.4\% failure rate. A 1978 report published by Zachrisson and Brobakken\textsuperscript{37} showed a failure rate of 13.9\% for brackets attached with a non-custom base indirect bonding technique. The results of a clinical trial\textsuperscript{51} over a three month observation period revealed that 18 of 554 brackets failed when placed by a custom base indirect bonding technique. In a clinical study evaluating the failure rate of a light-cured non-custom base indirect bonding technique, Thiyagarajah et al.\textsuperscript{38} reported a failure rate of 2.2\%. Bracket failures, analyzed over a three month period following appliance placement, were reported to be 4.5\% for a non-custom base indirect bonding technique\textsuperscript{31}.

Miles and colleagues\textsuperscript{56} observed a 2.4\% and a 2.9\% rate of failure for two indirect bonding techniques using custom bases during a six month observation period. After six months of observation, Read and O’Brien\textsuperscript{49} reported a failure rate of 6.5\% for 397 brackets placed with a custom base indirect bonding technique. Scholz\textsuperscript{43} commented on a recent study where he tested the rate of bond failure of 595 brackets positioned by a non-custom base indirect bonding technique. Scholz noted that 19 failed resulting in a failure rate of 3.1\%. A clinical study by Miles and Weyant\textsuperscript{55} evaluated the bond failures for two custom base indirect bonding techniques over a six month period following the bonding of brackets. A 1.4\% failure rate and a 9.9\% failure rate were observed – indicating a significant difference between the two methods.
Transfer Tray

By using the occlusal surfaces of teeth as reference points, transfer trays must transport as well as maintain the predetermined position of the brackets from the working models to the patient’s mouth. Transfer trays must provide rigidity to maintain close adaptation of the brackets during composite polymerization as well as be flexible enough to permit easy removal following polymerization. Transfer trays can be divided into full-arch and single-tooth categories. Echarri and Kim \(^{68}\) reported that single-tooth trays provide more accurate positioning and have the ability to be saved for future rebonding, while full-mouth trays have the advantage of decreasing the amount of chairside time. The inability to apply pressure to each individual bracket with full-arch trays may influence the adhesive thickness and the bond strength on indirect bonded brackets\(^{54}\). The increased adhesive thickness resulting from the difficulty keeping a uniform and steady pressure on all brackets, particularly the posterior, was indicated by Zachrisson and Brobakken\(^{37}\) to be one of the main reasons for higher failure rates with indirect bonding.

Various forms of materials and techniques have been involved in the fabrication of transfer trays. While opaque trays are limited to use with chemically cured bonding systems, clear transfer trays have been used for both chemically cured and light-cured indirect bonding systems. Clear transfer trays have been advocated to provide better visualization of the brackets during bonding; however, the patient’s cheeks and lips as well as the clinician’s hands may negate this proposed advantage\(^{69}\). Sheridan\(^{70}\) reported that the preferred tray material among respondents was either a silicone-based impression material or a vacuum-formed plastic. The report also noted that accurate placement of the transfer tray with the least chance of distortion was one of the principal reasons for
choosing a particular indirect bonding system. Scholz\textsuperscript{43} advocated the use of adhesive reservoirs within the transfer tray to facilitate excess adhesive cleanup. Cooper and Sorenson\textsuperscript{13} indicated that modifications to transfer trays will help prevent moisture contamination, which the authors suggested as being the main reason for bracket failure in indirect bonding.
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Format adapted for thesis
ABSTRACT

The aim of this study was to compare and evaluate the clinical failure rates of a light-cured non-custom base indirect bonding technique and a chemically cured custom base indirect bonding technique. The orthodontic records of 44 patients were selected for this retrospective study, and a total of 682 brackets were indirectly bonded. A record of the site of failure and the time point of failure (immediately or within six months following initial bonding) for each tooth and each patient was noted. During the immediate time point, 3 failed with the light-cured non-custom base indirect technique (0.85% failure rate) and 13 failed with the chemically cured custom base indirect technique (3.9% failure rate). During the six months following the initial indirect bonding, 16 failed with the light-cured non-custom base indirect bonding technique (4.6% failure rate) and 13 failed with the chemically cured custom base indirect bonding technique (3.9% failure rate). When the failures of the immediate time point and the six month time point were combined, 19 failed with the light-cured non-custom base indirect technique (5.4% failure rate) and 26 failed with the chemically cured custom base indirect technique (7.9% failure rate). There were no significant differences found between the failure rates of the light-cured non-custom base indirect technique and the chemically cured custom base indirect technique during any of the time points analyzed.
INTRODUCTION

The bonding of orthodontic brackets has become a routine in clinical practice. As a larger percentage of orthodontic offices begin to bond the posterior teeth instead of banding them, an efficient and reliable bonding system which allows for accurate placement of orthodontic brackets throughout the entire arch becomes even more important. A nation-wide survey in the United States conducted in 2008 indicated an increase in the number of orthodontists using indirect bonding\(^1\). By limiting the envelope of error made during bracket positioning\(^2\), indirect bonding improves the clinician’s opportunity to take advantage of the full potential of the pre-adjusted orthodontic appliance.

Indirect bonding incorporates two distinct steps, a laboratory step and a clinical step. The laboratory process involves placement of the brackets in their optimal position onto the teeth of the patient’s stone models. Following the placement of the brackets on the stone models, a transfer tray is made to transfer the brackets to the mouth while maintaining the exact position of the brackets as located on the stone models. The clinical step uses the transfer tray containing the brackets as a vehicle to carry the brackets to the patient’s mouth for bonding onto the teeth.

The majority of indirect bonding techniques used today are modeled after Thomas’ original method\(^3\) in 1979 which involved the fabrication of a cured custom composite pad attached to the bracket base\(^4\)-\(^18\). The custom base was formed when the brackets were attached to the stone models with a filled resin adhesive. A two-part
unfilled sealant was used to bond the brackets in the mouth. The first indirect bonding technique introduced to the orthodontic profession by Silverman, Cohen, Gianelly and Dietz did not describe the use of a custom base. Their technique applied adhesive resin to the bracket base immediately prior to intra-oral bonding. As a result of the inaccuracy involved with determining the correct amount of adhesive resin to apply to the bracket base, this non-custom base technique often resulted in voids or flash of bonding material.

Despite the proposed advantages of indirect bonding over direct bonding, the number of orthodontists incorporating indirect bonding in their practice is less than 10%. In addition to the added expense of material and training office personnel, practitioners reported difficulty in achieving consistent and predictable attachment of the brackets to the teeth with indirect bonding. Reynolds indicated that brackets should be able to withstand loads of 5.9 to 7.8 MPa to be considered clinically successful, while McCourt, Cooley, and Barnwell suggested a minimal clinical bond strength of 10 MPa. Multiple in vitro bond strength studies have reported similar bond strengths between direct and indirect bonding methods. In vivo studies by Aguirre, King, and Waldron, Thiyagarajah, Sparry, and Rock as well as a practice-based study by Deahl, Salome, Hatch, and Rugh reported no significant differences between the failure rates of direct and indirect bonding.

Indirect bonding studies evaluating light-cured and chemically cured indirect bonding techniques have been performed both in vitro and in vivo to compare bond strengths and bond failure rates. In vitro studies have demonstrated that bond strengths following indirect bonding methods using either chemically cured adhesive
systems or light-cured adhesive systems were similar\textsuperscript{11, 16, 31}. Excluding two clinical trials\textsuperscript{12, 32}, the majority of indirect bonding studies have shown that failure rates using either adhesive system were under 7.0\%\textsuperscript{4, 10, 13, 15, 27, 28, 30}.

The custom base indirect bonding technique creates a unique situation in which an interface exists between an aged composite and the sealant\textsuperscript{9}. The bond strength may be compromised as a result of this interface being a potential weak link in the system\textsuperscript{5, 18, 19}. The two published bond strength studies comparing a custom base indirect technique to a non-custom base indirect technique have reported conflicting results\textsuperscript{7, 16}. In addition, clinical trials investigating bond failures of the custom base indirect technique and non-custom base indirect technique have shown varying rates of failure\textsuperscript{4, 10, 12, 13, 15, 27, 28, 30, 32}.

The purpose of the present retrospective indirect bonding study was to compare and evaluate the clinical performance over six months of two different indirect bonding techniques, a chemically cured custom base indirect technique and a light-cured non-custom base indirect technique.

**MATERIALS AND METHODS**

The orthodontic records of 44 patients of varying ages who had been scheduled to undergo comprehensive fixed orthodontic mechanotherapy were selected for this retrospective study. All of the laboratory and clinical procedures were performed by a single clinician employing one of the two indirect bonding techniques being evaluated. Twenty-two patients were assigned to each of the two indirect bonding groups. An approximately equal number of brackets were bonded in each group: 351 brackets bonded employing the light-cured non-custom base indirect technique and 331 brackets employing the chemically cured custom base indirect technique. Since the types of
malocclusion among the patients varied and the patients underwent varying biomechanical procedures, not every patient had an equal number of brackets bonded. An approximately equal number of brackets were bonded in the maxillary arch and the mandibular arch (350 in the maxilla vs. 332 in the mandible). In addition, an approximately equal number of brackets were bonded in the anterior and posterior segments (332 in the anterior segments vs. 350 in the posterior segments). Approval for this study was obtained from the Institutional Review Board (IRB) at the University of Alabama at Birmingham.

First and second molar teeth were bonded and were included in this study. A record of the site of failure (tooth number) and the time point of failure (immediately or six months following initial bonding) for each tooth and each patient was noted. No attempt was made to record the reason for bracket failure. Rebonded brackets were counted as only a single failure regardless of whether the same bracket failed again. Teeth with facial restorations or crowns were excluded from the study. An observation period of six months following the initial bonding of brackets was recorded from each patient’s orthodontic record.

**Light-cured Non-Custom Base Indirect Bonding Protocol**

*Laboratory Procedure*

Accurate alginate impressions (Jeltrate Fast Set, DENTSPLY International, Inc, York, PA) of each patient were poured immediately with Microstone (Whip Mix Corporation, Louisville, KY). After the stone models were trimmed, bubbles removed and voids repaired, the models were coated with two thin layers of Al-Cote (DENTSPLY)
separating medium (diluted one part to four parts water) and allowed to dry after the first and second coating. There were three different bracket types used on the patients in the light-cured non-custom base indirect bonding group. These were Victory Series brackets (APC, 3M/Unitek, Monrovia, CA), Innovation-R brackets (GAC International, Inc, Bohemia, NY) and Damon 3MX brackets (Ormco Corporation, Glendora, CA). The Innovation-R brackets (GAC) and Damon 3MX brackets (Ormco) were placed on stone models using Transbond XT adhesive (3M/Unitek). The Victory Series brackets (APC, 3M/Unitek) were pre-coated brackets from the company. The remaining protocol steps for the light-cured non-custom base indirect bonding technique were adapted from the Quest Indirect Bonding manual (OrthoQuest, Lubbock, TX). After the brackets were accurately positioned on the stone models, the brackets were briefly cured to obtain a light tacking to the models (~2-5 seconds). For fabrication of the transfer tray, the translucent Quest matrix material (OrthoQuest) was applied to the occlusal side of the brackets and teeth on the stone models. The opaque Quest matrix material (OrthoQuest) was then applied to the gingival side of the brackets and teeth on the same stone model. Excess matrix material was trimmed away from the brackets and the teeth using a scalpel. The hard portion of the transfer tray was fabricated using a Biostar (Great Lakes Orthodontics, Tonowanda, NY) unit to vacu-form a 1.0mm thick layer of Biocryl (Great Lakes Orthodontics). The hard portion of the transfer tray was trimmed on the facial surface to the margin of the Quest opaque matrix material and on the lingual surface to about 3-5mm apical to the gingival margin. To remove the entire transfer tray from the stone cast and maintain the brackets within the transfer tray, a scaler was inserted on the facial surface through both layers of the matrix material to access the brackets and gently
break the brackets’ bond from the stone models. The transfer tray was adjusted to relieve any facial and lingual undercuts. The resin adhesive which had been used to position the brackets to the stone models was completely removed from the bracket bases using 90-micron aluminum oxide (Henry Schein, Melville, NY). Dry compressed air was used to clean the entire tray containing the brackets.

Clinical Procedure

After the transfer tray had been fabricated, the patient’s dentition in the clinic was prepared for the indirect bonding of the brackets. All of the patient’s teeth were cleaned with pumice. Isolation was obtained with either the Quest Dry Field System (OrthoQuest) or the Nola Dry Field System (Great Lake Orthodontics). After rinsing and drying, the enamel surfaces of the teeth were etched with 37% phosphoric acid (Reliance Orthodontic Products, Itasca, IL) for 30 seconds and then rinsed with water, and dried with compressed air from a moisture free air supply. A thin coat of Assure Universal Bonding Resin (Reliance Orthodontic Products) was applied to each etched tooth, lightly air dried, and then light cured for 2-5 seconds. The latter coating was repeated twice. Following the double coating as described above, a thin coat of Assure Universal Bonding Resin (Reliance Orthodontic Products) was applied to the bracket base followed by a brief stream of moisture free air. An appropriate amount of Quest Indirect Bonding Adhesive (OrthoQuest) was placed onto the bracket bases. The transfer tray with the enclosed brackets was then firmly seated in the patient’s mouth. While applying finger pressure onto the transfer tray, the bonding material was light cured with an Ortholux LED curing light (3M/Unitek) for 20 seconds, starting with the most posterior teeth.
After completion of the light curing, the hard outer layer of the transfer tray was removed from the patient’s mouth and then the softer inner layer of the transfer tray was removed. A check was made to ensure the absence of any remaining tray and/or bonding material prior to the seating of the arch wire.

**Chemically Cured Custom Base Indirect Bonding Protocol**

**Laboratory Procedure**

Accurate alginate impressions (Jeltrate Fast Set, DENTSPLY International, Inc, York, PA) of each patient were poured immediately with Microstone (Whip Mix Corporation, Louisville, KY). After the stone models were trimmed, bubbles removed and voids repaired, the models were coated with two thin layers of Al-Cote (DENTSPLY) separating medium (diluted one part to four parts water) and allowed to dry after the first and second coating. The same three types of brackets used in the light-cured non-custom base indirect bonding group were also used for the chemically cured custom base indirect bonding group. These were Victory Series brackets (APC, 3M/Unitek, Monrovia, CA), Innovation-R brackets (GAC International, Inc, Bohemia, NY) and Damon 3MX brackets (Ormco Corporation, Glendora, CA). The Innovation-R brackets (GAC) and Damon 3MX brackets (Ormco) were placed on stone models using Transbond XT adhesive (3M/Unitek). The Victory Series brackets (APC, 3M/Unitek) were pre-coated brackets from the company. The remaining protocol steps for the chemically cured custom base indirect bonding protocol were adapted from the chemically cured custom base indirect bonding protocol described by Sondhi\textsuperscript{33}. After the brackets were accurately positioned on the stone models, the stone models with the attached brackets were placed in a TRIAD
curing unit (TRIAD 2000, DENTSPLY) for 10 minutes to cure the adhesive material that was used to attach the brackets to the stone models. Aquasil Ultra LV regular set impression material (DENTSPLY) was applied to block out any significant undercut areas around the brackets, such as the bracket hooks. In addition to the impression material used to block out any undercuts, the transfer tray for the chemically cured custom base indirect technique consisted of two layers of transparent vacu-form tray materials. The first layer was fabricated using a Biostar (Great Lakes Orthodontics) unit to vacu-form a 1.5mm thick layer of Bioplast (Great Lakes Orthodontics). This layer of Bioplast was trimmed to the level of the block-out impression material. One coat of cooking spray (PAM, ConAgra Foods, Omaha, NE) was applied over the Bioplast layer. The lead pellets of the Biostar unit were placed to the level of the gingival tie wings of the brackets. The second and final layer consisted of a 2.0mm thick layer of Biocryl (Great Lakes Orthodontics) that was vacu-formed over the first layer of Bioplast. The outer layer of Biocryl tray material was trimmed away from the height of contour of all the teeth of the stone cast. The stone cast along with the transfer tray containing the brackets was soaked in warm water for approximately 30 minutes. The transfer tray containing the brackets was gently removed from the stone cast, dried with compressed air, and any excess transfer tray material trimmed away. The transfer tray was placed in the TRIAD curing unit for one minute. The transfer tray was placed into an ultrasonic cleaner with dishwashing detergent for five minutes and then placed back into the ultrasonic cleaner with water only for an additional five minutes. The transfer tray was rinsed with water, and dried with compressed air. The custom base of each bracket, fabricated from the cured adhesive material used to position the brackets on the stone
models, was lightly microetched with 50-micron aluminum oxide (Henry Schein, Melville, NY) to help remove any contaminants.

Clinical Procedure

After the transfer tray had been fabricated, the patient’s dentition in the clinic was prepared for the indirect bonding of the brackets. All teeth were cleaned with pumice. Isolation was obtained with either the Quest Dry Field System (OrthoQuest) or the Nola Dry Field System (Great Lake Orthodontics). After rinsing and drying, the enamel surfaces of the teeth were etched with 37% phosphoric acid (Reliance Orthodontic Products) for 30 seconds and then rinsed with water, and dried with compressed air from a moisture free air supply. A thin coat of Assure Universal Bonding Resin (Reliance) was applied to each etched tooth, lightly air dried and then light cured for 2-5 seconds. The latter coating was repeated twice. Custom I.Q., an A & B indirect bonding sealant (Reliance Orthodontics Products), was used for the bonding of the brackets to the patient’s teeth. Following the double coating of Assure Universal Bonding Resin as described above, Part A of the Custom I.Q. was applied to the enamel surfaces of the patient’s teeth, while Part B was applied to the custom base on the bracket. The transfer tray with the enclosed brackets was firmly seated in the patient’s mouth. During seating of the transfer tray containing the brackets, finger pressure was evenly applied to the entire transfer tray for 60 seconds. The transfer tray was left undisturbed in the patient’s mouth for an additional four minutes. The two layers of transparent transfer tray material along with the block-out impression material were removed sequentially. A check was
made to ensure the absence of any remaining tray and/or bonding material prior to the seating of the arch wire.

RESULTS

Statistical differences in failures among categories were determined by using a logistic regression models adjusting for repeated measures of subjects. Significant statistical difference was determined at p<0.05. All analysis was done using SAS v 9.1 (Cary, NC).

The immediate time point evaluated those bond failures occurring while the patient was in the clinic on the day of the initial indirect bonding procedure. The number of bracket failures for the light-cured non-custom base and chemically cured custom base indirect bonding techniques combined during the immediate time point was 16 (2.4% failure rate). Of the 16 combined failures: 3 failed with the light-cured non-custom base indirect technique and 13 failed with the chemically cured custom base indirect technique (0.85% failure rate vs. 3.9% failure rate, respectively, P=0.06), 7 failed in the maxillary arch and 9 failed in the mandibular arch (2.0% failure rate vs. 2.7% failure rate, respectively, P=0.69), 1 failure in the anterior segments and 15 failures in the posterior segments (0.3% failure rate vs. 4.3% failure rate, respectively, P=0.0085). See Tables 1, 2, 3, 4.

The six month time point represented those failures occurring up to six months of treatment following the day of the initial indirect bonding procedure. The number of bracket failures for the light-cured non-custom base and chemically cured custom base indirect techniques combined during the six month time point was 29 (4.3% failure rate).
Of the 29 combined failures: 16 failed with the light-cured non-custom base indirect technique and 13 failed with the chemically cured custom base indirect technique (4.6% failure rate vs. 3.9% failure rate, respectively, \( P=0.76 \)), 15 failed in the maxillary arch and 14 failed in the mandibular arch (4.3% failure rate vs. 4.2% failure rate, respectively, \( P=0.95 \)), 10 failed in the anterior segments and 19 failed in the posterior segments (3.0% failure rate vs. 5.4% failure rate, respectively, \( P=0.14 \)). See Tables 1, 2, 3, 4.

The overall time period includes the failures occurring during the immediate and six month time points together. The overall number of bracket failures for the light-cured non-custom base and chemically cured custom base indirect techniques combined was 45 (6.6% failure rate). Of the 45 combined failures: 19 failed with the light-cured non-custom base indirect technique and 26 failed with the chemically cured custom base indirect technique (5.4% failure rate vs. 7.9% failure rate, respectively, \( P=0.35 \)), 22 failed in the maxillary arch and 23 failed in the mandibular arch (6.3% failure rate vs. 6.9% failure rate, respectively, \( P=0.77 \)), 11 failures in the anterior segments and 34 failures in the posterior segments (3.3% failure rate vs. 9.7% failure rate, respectively, \( P=0.0006 \)). See Tables 1, 2, 3, 4.

**Table 1.** Bond failures according to indirect bonding technique and time point.
Overall time point refers to Immediate and 6 month time points combined.
(* statistically significant at \( p<0.05 \))

<table>
<thead>
<tr>
<th>Indirect Bonding Technique</th>
<th>Time Point</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Immediate</td>
<td>6 month</td>
</tr>
<tr>
<td>Light-Cured Non-Custom Base</td>
<td>3 (0.85%)</td>
<td>16 (4.6%)</td>
</tr>
<tr>
<td>Chemical Cured Custom Base</td>
<td>13 (3.9%)</td>
<td>13 (3.9%)</td>
</tr>
<tr>
<td>Total</td>
<td>16 (2.4%)</td>
<td>29 (4.3%)</td>
</tr>
</tbody>
</table>
Table 2. Bond failures according to site of failure and time point.
(* statistically significant at p<0.05)

<table>
<thead>
<tr>
<th>Site of Bond Failure</th>
<th>Time Point</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Immediate</td>
</tr>
<tr>
<td>Maxillary Arch</td>
<td>7 (2.0%)</td>
</tr>
<tr>
<td>Mandibular Arch</td>
<td>9 (2.7%)</td>
</tr>
<tr>
<td>Total</td>
<td>16 (2.4%)</td>
</tr>
</tbody>
</table>

Table 3. Bond failures according to site of failure and time point.
(* statistically significant at p<0.05)

<table>
<thead>
<tr>
<th>Site of Bond Failure</th>
<th>Time Point</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Immediate</td>
</tr>
<tr>
<td>Anterior Segments</td>
<td>1 (0.3%)</td>
</tr>
<tr>
<td>Posterior Segments</td>
<td>15 (4.3%)*</td>
</tr>
<tr>
<td>Total</td>
<td>16 (2.4%)</td>
</tr>
</tbody>
</table>

Table 4. Overall bond failure.
Overall bond failure refers to bond failures that occurred during the Immediate and 6 month time points combined. (* statistically significant at p<0.05)

<table>
<thead>
<tr>
<th></th>
<th>Number Placed</th>
<th>Failures</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light-Cured Non-Custom Base</td>
<td>351</td>
<td>19</td>
<td>5.4%</td>
</tr>
<tr>
<td>Chemical Cured Custom Base</td>
<td>331</td>
<td>26</td>
<td>7.9%</td>
</tr>
<tr>
<td>Maxillary Arch</td>
<td>350</td>
<td>22</td>
<td>6.3%</td>
</tr>
<tr>
<td>Mandibular Arch</td>
<td>332</td>
<td>23</td>
<td>6.9%</td>
</tr>
<tr>
<td>Anterior Segments</td>
<td>332</td>
<td>11</td>
<td>3.3%</td>
</tr>
<tr>
<td>Posterior Segments</td>
<td>350</td>
<td>34</td>
<td>9.7%*</td>
</tr>
</tbody>
</table>

Tables 5 and 6 illustrate the overall failures that occurred within the maxillary arch and the mandibular arch for both the light-cured non-custom base indirect technique and the chemically cured custom base indirect technique. The light-cured non-custom base indirect technique had a statistically significant difference between the anterior segments and posterior segments in the maxillary arch (4 anterior failures (4.4%))
vs. 9 posterior failures (9.9%), respectively, \( P=0.01 \), and the anterior segments and posterior segments in the mandibular arch [1 anterior failure (1.3%) vs. 5 posterior failures (5.6%), respectively, \( P=0.048 \)]. The chemically cured custom base indirect technique had a statistically significant difference between the anterior segments and posterior segments in the mandibular arch [2 anterior failures (2.5%) vs. 15 posterior failures (17.9%), respectively, \( P=0.01 \)]. When the maxillary arch and mandibular arch of the light-cured non-custom base indirect technique were compared with the maxillary arch and mandibular arch of the chemically cured custom base indirect technique, the only statistically significant difference was between the posterior segments of the mandibular arches [5 light-cured failures (5.9%) vs. 15 chemically cured failures (17.9%), respectively, \( P=0.045 \)].

**Table 5.** Light-cured non-custom base bond failures according to dental arch and dental segments. (* statistically significant at \( p<0.05 \))

<table>
<thead>
<tr>
<th>Position</th>
<th>Number Placed</th>
<th>Failures</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maxillary Arch</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anterior Segments</td>
<td>92</td>
<td>4</td>
<td>4.4%</td>
</tr>
<tr>
<td>Posterior Segments</td>
<td>91</td>
<td>9</td>
<td>9.9%*</td>
</tr>
<tr>
<td>Total</td>
<td>183</td>
<td>13</td>
<td>7.1%</td>
</tr>
<tr>
<td>Mandibular Arch</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anterior Segments</td>
<td>78</td>
<td>1</td>
<td>1.3%</td>
</tr>
<tr>
<td>Posterior Segments</td>
<td>90</td>
<td>5</td>
<td>5.6%*</td>
</tr>
<tr>
<td>Total</td>
<td>168</td>
<td>6</td>
<td>3.6%</td>
</tr>
<tr>
<td>Maxillary Arch and Mandibular Arch</td>
<td>351</td>
<td>19</td>
<td>5.4%</td>
</tr>
</tbody>
</table>
Table 6. Chemical cured custom base bond failures according to dental arch and dental segments. (* statistically significant at p<0.05)

<table>
<thead>
<tr>
<th>Position</th>
<th>Number Placed</th>
<th>Failures</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maxillary Arch</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anterior Segments</td>
<td>82</td>
<td>4</td>
<td>4.9%</td>
</tr>
<tr>
<td>Posterior Segments</td>
<td>85</td>
<td>5</td>
<td>5.9%</td>
</tr>
<tr>
<td>Total</td>
<td>167</td>
<td>9</td>
<td>5.4%</td>
</tr>
<tr>
<td>Mandibular Arch</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anterior Segments</td>
<td>80</td>
<td>2</td>
<td>2.5%</td>
</tr>
<tr>
<td>Posterior Segments</td>
<td>84</td>
<td>15</td>
<td>17.9%*</td>
</tr>
<tr>
<td>Total</td>
<td>164</td>
<td>17</td>
<td>10.4%</td>
</tr>
<tr>
<td>Maxillary Arch and Mandibular Arch</td>
<td>331</td>
<td>26</td>
<td>7.9%</td>
</tr>
</tbody>
</table>

DISCUSSION

In the present study, the failure rate of a light-cured non-custom base indirect bonding technique was compared with the failure rate of a chemically cured custom base indirect bonding technique over a six month observation period following initial bonding. The light-cured non-custom base indirect bonding technique was modeled after the indirect bonding technique introduced by Silverman and associates\(^{19}\) in 1972, while the chemically cured custom base indirect bonding technique closely followed Thomas’ indirect bonding technique\(^3\). Clinically acceptable failure rates have previously been demonstrated in studies investigating light-cured and chemically cured indirect bonding techniques\(^{12, 13, 15, 28}\). In addition, clinical indirect bonding studies have shown clinically acceptable failure rates for custom base and non-custom base indirect bonding techniques\(^{12, 13, 15, 27, 30}\).
Since various sources of stress are encountered on the brackets soon after bonding, the minimum bond strength that will allow the adhesive to withstand bond failure must be achieved\textsuperscript{34}. The ability to withstand immediate stress is even more important with indirect bonding, where the bracket is subjected to forces during the removal of the transfer tray shortly after the adhesive resin cures\textsuperscript{8}. Even though most clinical trials investigating the failure rate of indirect bonding techniques did not investigate the immediate bond failures\textsuperscript{10, 12, 13, 14, 15, 27, 28, 32}, the authors of the present study considered it was important to evaluate immediate bond failures. The results of the present study indicated an acceptable bond failure rate of 0.85\% for the light-cured non-custom base indirect technique and 3.9\% for the chemically cured custom base indirect technique at the immediate time point. While no statistically significant difference was found between the latter two groups, a clinically significant difference may be considered to exist by the increased number of failures with the 13 failures of the chemically cured custom base indirect technique when compared with the 3 failures of the light-cured non-custom base indirect technique.

The bond strength of an adhesive resin increases with time as a result of the continued process of polymerization\textsuperscript{35, 36}. If an insufficient amount of time has occurred prior to the application of stress to the bracket, the bond strength of the adhesive resin may be negatively affected due to the incomplete polymerization\textsuperscript{37}. Chamda and Stein\textsuperscript{38} compared the bond strength of a light-cured adhesive resin and a chemically cured adhesive resin during the first minutes after the initiation of polymerization. These authors reported higher bond strengths with the light-cured adhesive resin at two and five minutes after curing.
Several indirect bonding studies have indicated that the majority of bond failures occur during the first six months following initial bonding\textsuperscript{14,15,28}. The six month period of observation gave the researchers of the present study an opportunity to evaluate the performance of the light-cured non-custom base and chemically cured custom base indirect techniques over a period of time, and evaluate whether an increase or decrease in the bond failure rates occurred following the initial bonding. When compared with the immediate time point failure rate, the failure rate during the six month period following the initial bonding was higher with the light-cured non-custom indirect technique (4.6%), while the chemically cured custom base indirect technique showed no change in the bond failure rate (3.9%). Even though a higher bond failure rate was reported for the light-cured non-custom base indirect technique during the six months following the initial bonding, no statistically significant difference was found between the failure rates of the light-cured non-custom base and the chemically cured custom base indirect techniques during the six month time period.

The present study found a statistically significant difference between the overall failure rates of the anterior segments (4.4%) and the posterior segments (9.9%) in the maxillary arch of the light-cured non-custom base indirect technique as well as between the anterior segments (1.3%) and the posterior segments in the mandibular arch (5.6%) of the light-cured non-custom base indirect technique. The overall failure rates found in the present study represents the combined failure rates of the immediate time point and the six month time point. Read and O’Brien\textsuperscript{15} reported no significant difference between the failure rates of the anterior and posterior teeth for a light-cured indirect bonding technique. The present study found the mandibular posterior segments of the chemically
cured custom base indirect technique to have a statistically higher number of bond failures overall when compared with the mandibular anterior segments (17.9% vs. 1.3%, respectively.). A nation-wide survey in the United States conducted in 2008 reported a higher failure rate for posterior teeth when compared with the anterior teeth in both the maxilla and the mandible, with the mandibular posterior teeth having the largest reported percentage of failures\(^1\). When both indirect bonding techniques in the present study were analyzed together, a significantly higher failure rate was found for the posterior segments when compared with the anterior segments at the immediate time point (4.3% vs. 0.3%, respectively) and the overall time point (9.7% vs. 3.3%, respectively), while no statistically significant difference was found at the six month time point (5.4% vs. 3.0%, respectively).

Depending on the time between bracket attachment to the stone cast and bracket placement on the patient’s dentition, the age of the custom base attached to the bracket base can range from minutes to weeks\(^1\). The interface between an aged composite and the bonding sealant is very similar to the interface found in restorative dentistry during the repair of composite restorations\(^1\). Numerous studies analyzing the repair of composite restorations have shown that bond strengths can be significantly reduced when the interface involves an aged composite\(^3,9\). Sandblasting the aged composite resin surface\(^3,9\), as well as the application of an unfilled intermediate resin to the aged composite resin surface\(^4\) have been reported to improve the bond strength. One study reported that custom bases aged for seven days will produce an interface with sufficient strength\(^8\), while another study reported that indirect bonding may be performed safely when using custom bases aged up to 30 days\(^9\). The overall failure rate of 7.9% for the
chemically cured custom base indirect bonding technique of the present study was in the higher end of the range of 1.4 to 9.9% reported in previous indirect bonding studies investigating chemically cured custom base indirect techniques\textsuperscript{4, 12, 13, 15, 27}.

According to Krug and Conley\textsuperscript{10}, transparent transfer trays used with light-cured indirect bonding systems not only increases the distance between the light source and the bracket, but in addition may also act as a filter to reduce light intensity. Since the degree of polymerization is affected by light intensity, the bond strength of light-cured indirect bonding adhesives may be negatively affected by a reduced light intensity\textsuperscript{45}. In a clinical study evaluating the failure rate of a light-cured non-custom base indirect bonding technique, Thiyagarajah et al.\textsuperscript{28} reported a failure rate of 2.2%. The lower failure rate from the latter study may be partly attributed to the exclusion of taking into account immediate bond failures as well as the exclusion of molar teeth from their study.

The present study found no significant difference between the overall failure rate of the light-cured non-custom base indirect technique (5.4%) and the overall failure rate of the chemically cured custom base indirect technique (7.9%). This finding is similar to the finding of a clinical trial by Miles and Weyant\textsuperscript{13} who used a six month observation period to compare the failure rates of a light-cured indirect bonding technique to a chemically cured indirect bonding technique. The overall failure rates of the present study for both indirect bonding techniques used were within the range of 1.4% and 19.3% for failure rates of indirect bonding techniques\textsuperscript{4, 10, 12, 13, 15, 27, 28, 30, 32}. 

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CONCLUSIONS

- The present retrospective clinical study found failure rates for a light-cured non-custom base indirect bonding technique and a chemically cured custom base indirect bonding technique to be comparable with other documented studies evaluating failure rates of indirect bonding techniques.

- No statistically significant difference between the failure rates of the light-cured non-custom base and the chemically cured custom base indirect bonding techniques was shown during the immediate time point, within the six month time period as well as the overall time period.

- Although not statistically significantly different, failure rates may be significant for clinicians by the reported higher number of bond failures for the chemically cured custom base indirect bonding technique [13] when compared with the light-cured non-custom base indirect bonding technique [3] at the immediate time point.
REFERENCES


CONCLUSIONS

One of the major paradigm shifts in orthodontics involved the direct bonding of orthodontic attachments to the enamel surface. The decline in the placement of orthodontic bands has evolved to include the first and second molar teeth. In addition to helping overcome the limited vision and access that accompanies the direct bonding of the posterior dentition, indirect bonding has been indicated to limit the envelope of error made during bracket positioning. Since 1990, there has been a gradual increase in the popularity of indirect bonding. This increase in popularity may have resulted from further advancements in indirect bonding adhesives, simplified indirect bonding protocols, and published literature indicating similar failure rates and bond strengths between indirect bonding and direct bonding.

The present retrospective clinical study found failure rates for a light-cured non-custom base indirect bonding technique and a chemically cured custom base indirect bonding technique to be comparable with other documented studies evaluating failure rates of indirect bonding techniques. No statistically significant difference between the failure rates of the light-cured non-custom base and the chemically cured custom base indirect bonding techniques was shown during the immediate time point, within the six month time period as well as the overall time period. The results of the present study may provide orthodontic practitioners with an additional resource for evaluating current indirect bonding techniques.
GENERAL LIST OF REFERENCES


APPENDIX A

INSTITUTIONAL REVIEW BOARD FOR HUMAN USE APPROVAL FORM

THE UNIVERSITY OF ALABAMA AT BIRMINGHAM
Institutional Review Board for Human Use

Form 4: IRB Approval Form
Identification and Certification of Research
Projects Involving Human Subjects

UAB's Institutional Review Boards for Human Use (IRBs) have an approved Federalwide Assurance with the Office for Human Research Protections (OHRP). The UAB IRBs are also in compliance with 21 CFR Parts 50 and 56 and ICH GCP Guidelines. The Assurance became effective on November 24, 2003 and expires on October 26, 2010. The Assurance number is FWA00005960.

Principal Investigator: CRANFORD, ALEXANDER DAVIS
Co-Investigator(s):  
Protocol Number: X080905003
Protocol Title: Clinical comparison of two indirect bonding systems on retention rates of orthodontic brackets: Chemical-cured custom based vs. Light-cured non-custom base

The IRB reviewed and approved the above named project on 9/5/08. The review was conducted in accordance with UAB's Assurance of Compliance approved by the Department of Health and Human Services. This Project will be subject to Annual continuing review as provided in that Assurance.

This project received EXPEDITED review.
IRB Approval Date: 3/5/08
Date IRB Approval Issued: 9/5/08
HIPAA Waiver Approved?: Yes

Marilyn Doss, M.A.
Vice Chair of the Institutional Review Board for Human Use (IRB)

Investigators please note:

The IRB approved consent form used in the study must contain the IRB approval date and expiration date.

IRB approval is given for one year unless otherwise noted. For projects subject to annual review research activities may not continue past the one year anniversary of the IRB approval date.

Any modifications in the study methodology, protocol and/or consent form must be submitted for review and approval to the IRB prior to implementation.

Adverse Events and/or unanticipated risks to subjects or others at UAB or other participating institutions must be reported promptly to the IRB.