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ORIGINAL ARTICLE

Comparative Study of the Shear Bond Strengths and Bracket Failure Rates of Two Orthodontic Adhesive Systems

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ABSTRACT
Objective: To evaluate and compare the shear bond strengths (SBS) and bracket failure rates (BFR) of orthodontic brackets bonded with Light Cure adhesive against those bonded with Self Cure adhesive. **Material and Methods:** The study had *in vitro* and *in vivo* parts. In the *in vitro* part to determine SBS of Light Bond(LB)(R) and Rely.a.Bond(RB)(R) adhesives used in bonding brackets to 88 extracted teeth, each adhesive type was used to bond 44 brackets. The clinical study was conducted to determine the BFR of the LB(R) and RB(R) adhesives by bonding 256 teeth using each adhesive type. A standardized bonding procedure was followed in both the *in vitro* and *in vivo* parts of the study. Data were analyzed using frequency, percentage, mean, independent t-test, chi-square, and Pearson Correlation statistics. A p-value of ≤ 0.05 was considered significant. SPSS version 21.0 was used to analyze the data generated. **Results:** There was a significantly higher mean SBS 10.6MPa for LB(R) adhesive than the 7.0MPa of the RB(R) adhesive. In the *in vivo* study, (LB)(R) had a greater but not significant BFR of 9.0% than RB(R) (8.0%). No significant relationship existed between the SBS of either adhesive type (as determined *in vitro*) and their BFR *in vivo*. **Conclusion:** Higher SBS of LB(R) did not translate to less BFR in the clinic, nor did a lower SBS of RB(R) translate to more BFR in the clinic.

Keywords: Orthodontic Brackets; Patients; Dental Bonding; Dental Materials.

Introduction

In contemporary times, orthodontic brackets, which act as both channel and source of delivering force from the archwire to the teeth are bonded to teeth using the "acid etch technique" introduced by Buonocore in 1955 [1]. In this technique, Buonocore used 85% Phosphoric acid and etched the enamel surfaces for 80 seconds [1]. The technique was an advancement to the previous method of banding. It allows the direct bonding of brackets to the teeth without the use of bands making treatment more acceptable to the patients [2,3].

However, the acid etch technique also has its limitations. It is technique sensitive and predisposes the teeth to decalcification and forming white spot lesions on the enamel surface [3,4]. Enamel fractures may also occur during debonding of brackets with associated enamel discoloration resulting from retention of resin tags in the enamel [5,6]. The major challenge with the use of the acid etch technique in orthodontics is the occurrence of orthodontic bracket bond failures in the course of treatment [7]. An orthodontic bracket bond failure is said to have occurred when the bracket attachment to the enamel surface of teeth ceases to be attached by the adhesive bond [7]. Unfortunately, these orthodontic bracket failures are relatively frequent with attendant consequences [8-10]. First, a niche may form between the bracket and enamel surface, which will encourage plaque accumulation resulting in periodontal compromise [3]. Secondly, the tooth from which this detachment has occurred ceases to be influenced by the active component; as such, no further movement of that tooth occurs in the meantime. Enamel fractures may also occur when orthodontic brackets fail [5].

Furthermore, to replace a failed bracket, the orthodontist will remove the archwires, clean the tooth again of adhesive remnants, re-etch, and replace it with another bracket before re-adapting the archwire. Bracket failures also cost time and finance to both the patient and the orthodontist [8-10]. One important factor that may influence bracket failure rates is the shear bond strength of the orthodontic adhesive, described as the peak force required to cause detachment of the bracket from the tooth using a shear force divided by the contact area between the bracket and the tooth [11,12]. Optimal bond strength is, therefore, necessary for every orthodontic adhesive [13].

The light-cure adhesive was introduced to achieve improved bonding, and it offers a few advantages over the older self-cure adhesives. They have unlimited working time during bracket placement, less patient discomfort because of accelerated setting time, and significant less chair side time, since the archwire can be placed immediately without having to wait 8-10 minutes for the adhesive to bond completely [14,15]. In addition, bracket placement and flash removal are easier with light-activated composites [14,15]. However, one key advantage of the self-cure adhesive is that it does not require curing light, making it versatile even in rural areas with no power supply.

An orthodontic adhesive should enable the bracket to stay bonded to the enamel for the entire treatment while also permitting easy removal of brackets when the need arises without damage to enamel surface and with the least discomfort to the patient [16]. The success of these adhesives in fixed appliance therapy largely depends on their capability to resist failure from a large number of forces directed to bracket-adhesive-enamel junction as well as various factors in the mouth [12].

Though the exact simulation of clinical conditions *in vitro* is yet to be achieved, manufacturers of orthodontic adhesives claim to have made great advancements in clinical performance to reduce bracket failures [12]. The best way to evaluate performance is still via *in-vivo* studies because all the factors that can contribute to bond failure would be present [12]. However, *in vitro* studies are useful because of the controlled testing environment they can offer for investigating the chemical and physical properties of adhesives. Thus, they provide valuable information on the amount of controlled force responsible for failure in bracket-adhesive-enamel system and give directions for clinical practice and *in vivo* investigations [17]. Since an adequate bond strength is necessary to prevent bracket failure, there is a need to determine if the shear bond strength of light-cure and self-cure adhesives determined *in vitro* translates to more or less bracket bond failure rates determined *in vivo*.

A previous study by Sharma et al. [18] compared the relationship between the bond strength of different adhesives and reported higher bond strength with light-cure than with self-cure adhesives. Other investigators [8,19] also studied failure rates of light-cure and self-cure adhesives, with varying reports including different failure rates [1] and similar bond failure rates [19]. However, not much literature has attempted to relate the shear bond strength determined *in vitro* to bracket failure rate determined in the clinic when similar adhesive types are used. This study, based in Nigeria with the possible influence of diet on bracket failure, sought to obtain information on the shear bond strength and bond failure rates of light-cure and self-cure composite adhesive systems and to determine whether a relationship exists between the shear bond strength as determined in the laboratory and the bond failure rates as observed in the clinic. The study findings will aid the orthodontists and the orthodontic trainees in making the right choice of adhesives to reduce the incidence of bracket failures during treatment.

Material and Methods

Determination of Sample Size

The sample size determination applies to both the clinical and laboratory parts of the study.

The calculation of the sample size was done using the formula for comparison of two independent groups using mean as shown by Shukla et al. [20], in which "n" = $2(Z_\alpha + Z_\beta)^2$ Sd ÷ d^2. Where,

n= Minimum sample size for each group

Z_α=Standard normal deviate corresponding to the level of significance at 95% confidence interval= 1.96

Z_β = Standard normal deviate corresponding with 1 minus power at 80%=0.84

S_d = Average from mean of shear bond strength for the light-cure adhesive (10.34) and the self-cure adhesive (9.03) = 9.7 (from the study by Shukla et al. [20])

d = Expected difference = 2

Therefore, "n" = $2(Z_\alpha + Z_\beta)^2$ Sd ÷d^2

$= 2(1.96+0.84)^2\ 9.7 \div 2^2$

$= 2(2.80)^2\ 9.7 \div 2^2$

$= 2 \times 7.84 \times 9.7 \div 4$

$= 15.68 \times 2.425 = 38.024 \approx 38$

To accommodate a possible 10% attrition, the minimum sample size; n of 38, was increased by 4. Therefore, the minimum sample size was 42 teeth for each adhesive system.

The *In Vitro* Part (Laboratory)

The study was carried out at the laboratory of the Standards Organization of Nigeria (S.O.N) after ethical approval was obtained from the Ethics and Research Committee of the University of Nigeria Teaching Hospital (UNTH), Enugu, with approval number: FWA00002458-1RB00002323. It was a cross-sectional study in which the shear bond strengths of light Bond(R) light-cure and Rely.a.Bond(R) self-cure adhesives were determined in the laboratory. These adhesives were used to bond 88 Azdent brackets (Azdent Dental Manufacturer, Henan, China) on 88 consecutive teeth extracted from 28 consecutive patients (needing extraction as part of their orthodontic treatment plan) who presented at the orthodontic clinic of the UNTH and also took part in the clinic part of the study. Microdonts, teeth with enamel hypoplasia, and fracture or restorations on their buccal surfaces were excluded from the study.

In the determination of shear bond strength of the light-cure (Light Bond(R), Reliance Orthodontic Products, Itaska, Illinois, USA) and the Self-cure (Rely.a.Bond(R), Reliance Orthodontic Products, Itaska, Illinois, USA) composite adhesive systems, each of the eighty-eight extracted teeth were put into a container which contained 10% formalin and left for seven days as was done in a similar study [14]. Irrespective of the tooth type, the first tooth extracted was numbered as "1", the next as "2" and progressing in that pattern until the 88th tooth was extracted. The teeth labeled with odd numbers had orthodontic brackets bonded on them using the self-cure adhesive, while those labeled with even numbers had brackets bonded on them using the light-cure adhesive. Forty-four brackets were bonded using each adhesive type. The detailed steps followed in the study are summarized below.

The tooth was brought out of the formalin, rinsed in water, and dried with a stream of air. In order of extraction, each tooth was separately mounted on a cold cure acrylic block (up to the neck of the tooth) (Figure 3). The tooth was scaled using manual scalers and subsequently polished using a fluoride and an oil free prophylactic paste. They were then washed with water and dried in a stream of oil-free compressed air [14]. A bracket was then bonded on the buccal surface of each tooth before taking it (singly or in groups of teeth extracted the same day) to the laboratory for shear bond strength testing, which was done 24 hours after bonding, as reported for previous studies [9,15].

Bonding brackets with the self-cure adhesive on the 44 teeth labeled with odd numbers were done according to the manufacturer's recommendation as follows: A brush applicator was used to apply 37% Phosphoric acid gel (Reliance Orthodontic Products, Itaska, Illinois, USA) to the mid-buccal enamel surface of each tooth from Group "A" and left for 15 seconds [16]. Each tooth was rinsed with water and dried with oil free compressed air until the enamel surface became frosty white. The primer was applied onto the etched tooth surface and the mesh surface of the bracket. The self-cure adhesive was syringed onto the bracket base. The bracket was firmly placed in position on the buccal tooth surface. Thirty seconds allowed the bonded bracket to become reasonably stable before excess adhesive was removed using a sharp probe [14].

For the bonding with the light-cure (Light Bond(R)) Adhesive, similar steps were followed as with the self-cure adhesive until the application of the primer. The light-cure adhesive was syringed onto the bracket base and placed in position on the buccal tooth surface. The excess resin was removed by running a dental probe around the base of the bracket. The resin was polymerized by pointing a Woodpecker LED-b curing light source (Woodpecker, China) with a wavelength of 480nm on the tooth (20 seconds for each bracket-adhesive interface: 10 seconds on the mesial and 10 seconds on the distal) and polymerization occurred immediately [17]. A total of 44 teeth were bonded (singly or in groups of teeth extracted the same day) using the light-cure adhesive.

To determine the shear bond strength of adhesive per tooth, de-bonding of the bracket from the tooth was carried out after 24 hours [9,15], using the TUE-C-100 Universal Testing Machine (Fine Spavy Associates & Engineers P. Ltd., Miraj, India), as in previous studies. [17-19] To facilitate the application of a vertical debonding force, the tooth surface was positioned perpendicular to the horizontal plane. An occluso-gingival load was applied to produce a shear force at the bracket-tooth interface (this was accomplished with the flattened end of a steel rod attached to the crosshead of the universal testing machine [18]). The bond strengths were determined at a crosshead speed of 1mm per minute (crosshead speed being the time rate at which the crosshead descends vertically). The force applied at the time of fracture/de-bonding was recorded in Newtons and then divided by the area of the bracket base (which is 12.0mm²) to convert to megapascals (MPa) [11].

The *In Vivo* Part (Clinical)

This was carried out at the Orthodontic unit of the University of Nigeria Teaching Hospital, Enugu. It was a prospective six-month, randomized, single-blinded split-mouth design clinical trial involving a within-subject comparison of the rates of orthodontic bracket failure of Light Bond(R) light-cure and Rely.a.Bond(R) self-cure adhesives after using them to bond brackets on a total of five hundred and twelve (512) teeth, with two hundred and fifty-six (256) brackets bonded using each adhesive type in 30 consecutive patients whose treatment with upper and lower fixed appliance therapy required or did not require tooth/teeth extractions (sample size calculation is shown above). The study was not limited to any type of malocclusion; however, patients who had teeth with fractured or restored buccal surface, microdonts, or enamel hypoplasia were excluded from the study.

The bonding procedure was performed by the same clinician to avoid possible procedural differences. The Battenburg design was used as in previous studies [1,21] in which, for a participant, when upper right/ lower left quadrants were bonded with one type of adhesive. Then the upper left/lower right quadrants were bonded with the other type of adhesive. This design had the advantage that both adhesive types were on each side of a participant's mouth, allowing both to simultaneously experience similar intra-oral conditions on both sides of the mouth.

While bonding with the Self-cure Adhesive, teeth were scaled, polished with pumice, and isolated using cotton pledgets and cheek retractor in readiness for bonding. Bonding was carried out from the Central Incisor to the 2nd Premolar (with buccal tubes bonded on the 1st Molars). The remaining teeth were prepared for bonding in participants who had teeth extracted as part of the treatment plan. The manufacturer's recommended protocol was followed with the enamel surface preparation carried out in the same way as for the *in vitro* study, and 256 teeth were bonded with Rely.a.Bond(R) Self-cure adhesive as described in the *in vitro* study. 0.014 Ortho Classic Nickel-Titanium archwire (Ortho Classic Inc., Oregon, USA) was ligated onto the brackets. The same wire sequence was used after bonding for all the patients.

With bonding using the Light-cure Adhesive, similar manufacturer's recommended protocol as with the Light Bond(R) light-cure adhesive used in the *in vitro* study was followed. 0.014 Ortho Classic Nickel-Titanium archwire was ligated onto the brackets. The same wire sequence (of 0.014 and 0.016 for the treatment duration of 6 months) was used after bonding for all the patients. Bracket failure rates were prospectively determined for each adhesive type.

Verbal and written oral hygiene and care of appliance instructions were given to each participant. They were to brush their teeth with a fluoride containing toothpaste after every meal. They should eat only soft food during the duration of the treatment because hard, large, and sticky pieces of food (nuts, crisps, chunky meat, and chewing gum) may damage the appliance. They were also to avoid taking a bite but to cut large pieces of food into smaller pieces before eating them. Weekly telephone calls were made to each participant throughout the research duration of six months, during which they came for review every six weeks, and a similar sequence of archwire and treatment approach was adopted for each patient.

To determine the bracket failure rate, each participant was given a diary in which to record the date and time of bracket failures during the six-month duration of the study for each patient. They visually inspected the appliance daily using a mirror and reported any loosening of bracket via telephone as soon they thought it occurred and, in such circumstances, were asked to report to the clinic as soon as possible for bracket replacement. The type of adhesive that was used to bond each tooth was also recorded. In case of failures were not detected and not recorded by the patient, the date of the review appointment during which the clinician detected the failure was taken as the date of failure. No second recording of the same tooth was made, even if a second bracket failure results for that tooth. After six months of observation for each participant, the rate of bracket failure with the Self-cure adhesive and the Light-cure adhesive was recorded.

Statistical Analysis

To determine the shear bond strength for each adhesive system, mean statistics were used, while frequencies and percentages were used for bracket failure rates of the respective adhesive systems. Independent sample t-test was used to compare the shear bond strength of the two adhesives while chi-square was used to compare bracket failures and type of adhesives used. The relationship between the shear bond strengths and bracket failure rates was done using Pearson Correlation analysis. A p-value of 0.05 or less was considered statistically significant. Statistical Package of Social Science (SPSS), version 21.0 IBM Armonk, New York, USA, was used to analyze the data generated.

Results

In Vitro Results

Table 1 reveals that the mean shear bond strength of (Light Bond(R)) light-cure adhesive was 10.60MPa (ranging between 5.0 and 21.0) while the mean shear bond strength for (Rely.a.Bond(R)) self-cure adhesive system was 7.0MPa, which ranged between 4.60 and 13.00 MPa. There was a statistically significant difference between the mean shear bond strengths of Light-cure and Self-cure (p=0.001).

Table 1. Comparison of mean shear bond strengths of light-cure and self-cure adhesives.

Adhesive Type	Range		Mean	S.D.	t-value	p-value
	Minimum	Maximum				
Light-cure	5.00	21.00	10.60	3.80	-3.559	0.001
Self-cure	4.60	13.00	7.00	2.30		

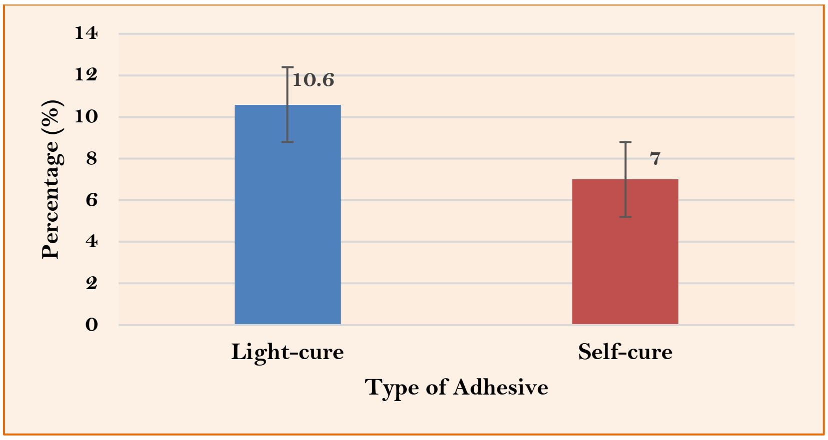

Figure 1. Percentage distribution of the mean shear bond strength among the two adhesives.

In Vivo Results

Table 2 shows that out of the 256 teeth bonded with the light-cure adhesive, 23 (9.0%) failed, while the remaining 233 (91.0%) did not. While 20 (8.0%) of the brackets bonded on 256 teeth using the self-cure adhesive failed, the remaining 236 (92.0%) did not fail. Therefore, 43 (8.0%) brackets (of the 512 bonded) failed. The test of association between bond failure and type of orthodontic adhesive used showed no significant association (p=0.624). That is, failure rate had no significant association with the type of orthodontic adhesive used.

Table 2. Relationship between bracket failure rate and adhesive type.

Type of adhesive	N	Number of Bracket Failures	Bracket Failure Rates	Chi-Square value	p-value
Light-Cure	256	23	9.0	0.240	0.624
Self-Cure	256	20	8.0		

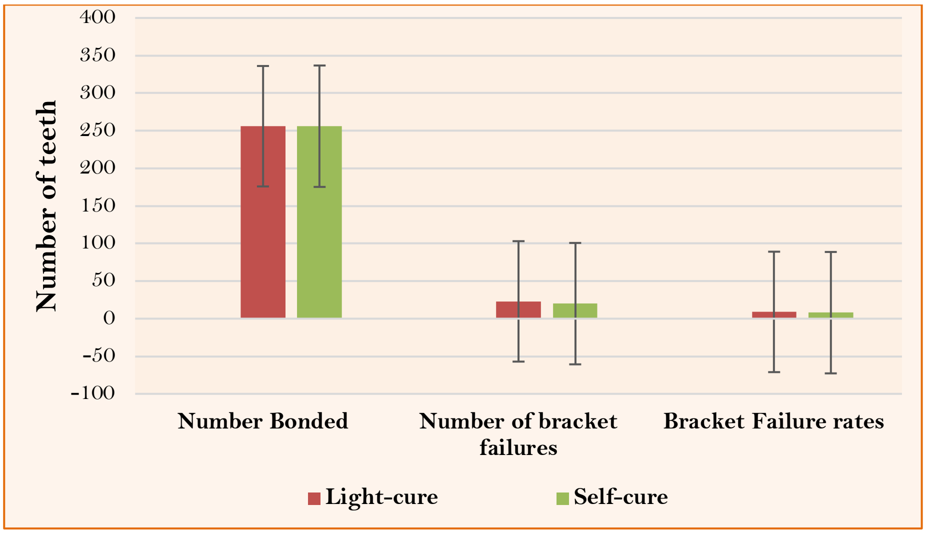

Figure 2. Distribution of bracket failure and failure rate according to adhesive type.

C. Comparison of Laboratory and Clinic Results

Table 3 demonstrates the relationship between the shear bond strengths of the two adhesive systems (light-cure and self-cure) and bracket failure rates of orthodontic brackets bonded using both systems.

Table 3. Pearson correlation coefficient analysis test of relationship between shear bond strength and bracket failure rate.

Types of Adhesives (Shear bond strength)		Types of Adhesives (Bracket Failure rate) Light-Cure	Self-Cure
Light-cure	Correlation Coefficient	-0.098	
	p-value	0.633	
Self-Cure	Correlation Coefficient		0.328
	p-value		0.110

The shear bond strengths and bracket failure rates were analysed based on each participant. The shear bond strength for each adhesive per participant was noted, and an average of the shear bond strength for those bonded with more than one tooth was used for that participant. In comparison, the shear bond strength for those with only one tooth bonded was used for that one. On the bracket failure rate, failure for each participant per adhesive type was determined by obtaining the number of teeth that failed per participant per adhesive out of the total number of bonded teeth. Using the Pearson correlation, no significant relationship was found between the bond strength of the light-cure adhesive (as determined in the laboratory) and their bracket failure rates in the clinic (Pearson Correlation Coefficient= -0.098, p-value=0.633). Similarly, the shear bond strength of the self-cure adhesive did not correlate with the failure rate in the clinic (Pearson Correlation Coefficient = 0.328, p-value=0.110). This meant that the higher bond strength of the light-cure adhesive in the laboratory did not automatically translate to less bracket failure rate.

Figure 3. Tooth mounted on Cold cure acrylic block (with bonded orthodontic bracket).

Discussion

The results of the present study showed that the mean shear bond strength of light-cure (Light Bond(R)) adhesive was significantly higher than that of the self-cure (Rely.a.Bond(R)) adhesive system. The finding in this study validates what was previously reported by Shukla et al. [20], who reported a higher mean shear bond strength of 10.34MPa for the light-cure and 9.03MPa for the self-cure adhesive. Similarly, a later study [18] reported higher shear bond strength of 15.49MPa for the light-cure adhesive, while that for the self-cure adhesive was 12.26MPa. This, however, differs from that reported in two other studies [22,23] in which lower bond strength was reported for the light-cure adhesives, with both reporting the bond strength of the light-cure adhesives to be nearly half of the self-cure. Toledano et al. [22] also reported a lower bond strength of 35.96MPa for the light-cure adhesive and 71.31MPa for the self-cure adhesive. This much lower bond strength of the light-cure adhesive is possibly due to incomplete polymerization [22-24]. However, bond strengths recorded for the light-cure (Light Bond(R)) and self-cure (Rely.a.Bond(R)) adhesive systems recorded in the present study show that both adhesive types meet the reported minimum clinically adequate shear bond strength of 6-8MPa reported in the literature [25]. Additionally, adhesion forces should not be too strong to avoid substrate loss after debonding (40–50 MPa). Therefore, the ideal orthodontic biomaterial should have bonding forces included in the interval of 5–50 MPa, even if these limits are mostly theoretical [26].

In the clinic study, the bracket failure rate for the light-cure adhesive was more than that for the self-cure adhesive, but the difference was not significant. The bracket failure rate for the light-cure adhesive is similar to that reported by Galindo et al. [27], in which the failure rate was 11.3% after a study duration of eleven months. Conversely, O'Brien et al. [28] and Millet et al. [29] reported a relatively lower bracket failure rate. Following a study duration that lasted through the entire treatment time, O'Brien et al. [28] reported a failure rate of 3.9%, while Millet et al. [29] reported a failure rate of 6% over a 48-month study period. The lower value reported in the previous studies [28,29] maybe as a result of dietary differences which have also been reported to affect bond failure rate [7]. The harder the diet, the greater the tendency for failure to occur [7].

With the self-cure adhesive used in the present study, the bracket failure rate was similar to the finding by O'Brien et al. [28], in which the bracket failure rate for the self-cure adhesive was 7.5%. However, in a Nigeria based study [30] which used a similar adhesive to the present study, Moninuola et al. [30] reported a higher failure rate of 24.1%. This higher value of the self-cure adhesive may be attributed to the longer study duration of 24 months as against 6 months in the present study. In the present study, when the bracket failure rates of the light and the self-cure adhesive systems in the clinic were compared within the study duration of 6 months, a greater bracket failure rate was recorded for the light-cure than for the self-cure adhesives. This higher failure rate for the light-cure adhesive has been reported in a previous study by Trimpeneers and Dermaut [19], who reported a significantly higher failure rate for light-cure (24.3%), being twice that for self-cure (12.4%). However, the higher bracket failure rate recorded for the light-cure adhesive in the present study was not statistically significant. Incomplete polymerization has been suggested as a possible reason for this higher bracket failure rate with the light-cure adhesives [31,32]. On the other hand, other studies reported higher failure rates for self-cure adhesives [8,28,27]. Galindo et al. [27] reported a 12% bracket failure rate for the self-cure and 11.3% for the light-cure. Likewise, in a separate study by O'Brien et al. [28], 7.5% and 5.5% failure rates were reported for self-cure and light-cure, respectively. However, Sonis et al. [14] and Artun et al. [33] reported no significant difference in bracket failure rate between the light and the self-cure adhesives. This is in agreement with the findings in the present study, which showed that despite the higher failure rate of the light-cure adhesive over the self-cure, the difference was not significant.

When the relationship between the shear bond strength of the two adhesive systems (light-cure and self-cure) determined in the laboratory and the bracket failure rates of orthodontic brackets bonded using the two systems (in the clinic) was assessed, there was no significant relationship between the shear bond strength as determined in the laboratory (*in vitro*) and the bracket failure rates as determined in the clinic (*in vivo*) for both the light-cure and the self-cure adhesives. Contrary to previous studies [18,20,34] (most of which did not compare shear bond strength and failure rate) in which teeth used to determine shear bond strength in the laboratory were extracted from any available participant, in the present study, the teeth used for the *in vitro* shear bond strength determination were from the same participants enrolled into the clinic study. This was to ensure that teeth with similar morphology and chemistry per participant were used in the comparison of bond strength and failure rate since the success of adhesion has also been linked to the characteristics of the interfacing surfaces [35]. Teeth surfaces with sub-clinical erosion from cola-based drinks have been reported as having significantly reduced bond strength [36].

There is a dearth of literature on this area of study. Using the Pearson correlation in the present study, no significant relationship was found between the bond strength of either adhesive type (as determined in the laboratory) and their bracket failure rates in the clinic. The light-cure adhesive had greater mean shear bond strength *in vitro*, but this did not translate to less failure rate *in vivo* as it was seen to have a higher failure rate in the clinic than the self-cure, although the difference in failure rate was not significant. This means that higher bond strength did not necessarily translate to a lower failure rate and vice versa. These results were similar to the finding in an earlier study by Eliades et al. [37], which though was not carried out using teeth from the same group of patients as was done in the present study, reported that bond strength values may not necessarily relate to failure rates because of the effect of mastication which is associated with the rate of loading. This factor, it claims, may explain the disagreement between clinical failure rates and *in vitro* bond strength data [37]. Pickett et al. [38] also compared bond strength *in vivo* against that *in vitro* using a debonding machine in both cases. Though they did not simulate the natural masticatory effect, they concluded that the mean bond strengths recorded *in vivo* following comprehensive orthodontic treatment were significantly lower than those recorded *in vitro*.

The lack of relationship between the shear bond strength determined in the laboratory and the failure rate determined in the clinic may result from several reasons. Firstly, the maximum time the bonded brackets remained on the teeth *in vitro* before debonding did not correspond with that of the teeth bonded in the patient's mouth. Secondly, the moist intra-oral environment, which contrasts with the dry environment in the *in-vitro* test, presented an unbalanced study environment. Another reason could be that the universal testing machine applied only shear force, while in the oral cavity, a combination of debonding forces exists, including shear, tensile, and peel. The rate of loading from mastication may also vary, whereas the rate is constant for the universal testing machine. Additionally, recent research by Butera et al. [39] showed the deposition of hydroxyapatite and casein phosphopeptide-amorphous calcium phosphate [40] on polymeric composite resin. This feature could also be tested with orthodontic composites in future studies to understand if it would influence the bond strength.

The limitations of the present study include that it only assessed failure rate *in vivo* within the 6 months study period. Changes beyond this period that may be different from the reported findings are possible. The moist intra-oral environment, which contrasts with the dry environment in the *in-vitro* test, also presented an unbalanced study environment. We suggest that future researches should aim at simulating the conditions within the oral environment in the *in vitro* studies.

Conclusion

The mean shear bond strength of light-cure (Light Bond(R)) adhesive was significantly higher than that of the self-cure (Rely.a.Bond(R)) adhesive system. The Light Bond(R) Light-cure adhesive and the Rely.a.Bond(R) Self-cure adhesive had acceptable clinical shear bond strength. The bracket failure rate of the light-cure adhesive was higher than that of the self-cure adhesive. There was no significant relationship between the shear bond strengths as determined in the laboratory (*in vitro*) and the bracket failure rates as determined in the clinic (*in vivo*) for both the light and the self-cure adhesives.

Authors' Contributions

ACO	https://orcid.org/0000-0003-0667-341X	Conceptualization, Methodology, Formal Analysis, Investigation, Resources, Data Curation.
IU	https://orcid.org/0000-0003-0602-1438	Conceptualization, Methodology, Formal Analysis, Investigation, Writing - Review and Editing, Supervision.
NF	https://orcid.org/0000-0003-1175-2171	Conceptualization, Methodology, Formal Analysis, Investigation, Data Curation, Writing - Review and Editing, Supervision.

All authors declare that they contributed to critical review of intellectual content and approval of the final version to be published.

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Conflict of Interest

The authors declare no conflicts of interest.

Data Availability

The data used to support the findings of this study can be made available upon request to the corresponding author.

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