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Original Research

Exploring Curing Distances and Their Influence on Orthodontic Bracket Bond Strength: In Vitro Research

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ABSTRACT

Background: The field of orthodontics has undergone significant changes, particularly with the development of bonding systems, which have revolutionized the way treatment is carried out. This study examines the remaining bonding and adhesive remnant index (ARI) of stainless steel and Radiance Plus ceramic brackets at different curing distances, which helps focus the curing protocol in orthodontics.

Methods: Throughout the research study, 120 extracted human premolar teeth were arranged randomly and classified into two groups consisting of 60 teeth each. Group A consisted of stainless-steel brackets, while Group B consisted of Radiance Plus ceramic brackets. These groups were split further in turns of different distances and curing brackets, which were 0 mm, 5 mm, and 10 mm distances. The Trumpbond XT bonding adhesive was used, and curing was accomplished utilizing the high-intensity 3M ESPE Elipar LED curing light. The shear bond strength was measured and assessed using the Instron Universal Testing Machine. The ARI was evaluated by a stereomicroscope that was 20x magnification.

Results: Radiance Plus ceramic brackets showed significantly higher bond strength at all distances compared to stainless steel brackets. As the distance curing brackets increased, bond strength decreased for both types of brackets, but ceramic brackets exhibited better bond strength at every single distance. The ARI scores indicated that, for failed bonds with stainless steel brackets, bond failure was more likely to occur at the bracket–adhesive interface. In contrast, for ceramic brackets, the majority of the adhesive remained on the tooth surface, suggesting failure at the enamel–adhesive interface.

Conclusion: The focus of this research is on how critical the proper distance for curing is, and the right materials for curing are to get the best results for orthodontics. Radiance Plus ceramic brackets achieve the best results for bond strength when compared to stainless steel brackets, and this is particularly true when curing is done at shorter distances.

Keywords: Condom use, Sexual health, youth, HIV, STI

BACKGROUND

In today's world, people have become increasingly concerned with their physical appearance and the pinnacle of one's physical beauty is thought to be facial perfection and perfect facial esthetics [1]. This change of attitude has resulted in a larger population of orthodontic patients being treated for their facial appearance. Patients believe that treatments can positively or negatively affect one's psychology and social acceptance outcomes, either directly or indirectly [2]. Perfection is the pursuit of making something perfect, followed by revisiting it and consistently working on it until there's nothing to change or improve for many people, a friendly smile is part of what defines us as 'perfect' [3].

Over time, orthodontics as a specialty has undergone significant development, not only providing us with excellent treatment results but also with increasingly advanced materials for clinical use in orthodontic therapy [4]. Practitioners get more and more requests for cosmetic procedures every day. Patients seek treatments that have both functional and aesthetic value. As orthodontic treatments 'braces' initially went to metal and braces progressed to more esthetically viable products that matched tooth color to meet the demand [5]. Ceramic brackets were created as an improvement to address patient concerns about the visibility of metal, providing an aesthetically superior product [6]. These ceramic brackets, however, suffered criticism due to their excessive bulk, friability, increased friction with consequent poor sliding mechanics, and also breakage during debonding [7]. In addition, when debonding occurred, some distortion was evident, indicating that the material and design could be improved [8].

In an attempt to overcome these limitations, Radiance Plus brackets were developed as a second-generation monocrystalline ceramic bracket. True Innovation Radiance Plus brackets are the next step in passive self-ligation [9]. Radiance Plus brackets are manufactured from a single crystal of pure-grown sapphire, which is second only to diamond in hardness. The sapphire out performs other crystals in design attributes. This sapphire is precision-ground and biomechanically designed to form a consistent solid core shape. Then its heat-polished using our own proprietary process to remove all micro-voids or flaws that could weaken the bracket [10].

This technique increases the strength of the bracket and esthetics, resulting in a more translucent and less synthetic appearance when compared to other monocrystalline brackets. Furthermore, the McNamara Radiance Plus Bracket has a patented quad matte base ensures superior bonding to the tooth [11].

The bond strength between the bracket and the tooth plays a vital role in orthodontic treatment. Optimal treatment outcomes are achieved not when the initial bond strength is high, but when it is consistent throughout the entire treatment. The firmness of the bond is affected by the bracket material, bracket size, and base design, as well as the etchant form and type of primer, the composition of the composite resin, the translucency factor for the bonding area, the intensity and duration of the curing light [12]. The light-curing of bonding systems is a crucial factor in determining bond strength. In the present study, the 3M ESPE Elipar LED Curing Light is employed due to its high output (1200 mW/cm^2) and clinically relevant curing distances for bond strength testing, as varying irradiation distances are used [13].

The purpose of this study was to evaluate and compare the shear bond strength between stainless steel brackets as well as Radiance Plus ceramic brackets cured at different distances (0 mm, 5 mm, or 10 mm) from the center position using a 3M ESPE light-cure unit. The brackets, when cured, are tested in shear on the Instron Universal Tester. The adhesive remnant index (ARI) will also be assessed to determine whether the bond failure occurred at the bracket or at the tooth surface. Understanding how curing distance affects bond strength and evaluate the shear bond strength of stainless steel and Radiance Plus brackets are the goals of this study.

This study will build on the understanding of adhesion strength and material efficacy which could improve the clinical orthodontic treatment protocols that use metal and ceramic brackets.

METHODOLOGY

This study was conducted to compare the shear bond strength and ARI between stainless steel and Radiance Plus brackets in the Department of Orthodontics & Dentofacial Orthopedics, Vanachal Dental College and Hospital, Garhwa, Jharkhand, India. The study received approval from the Institutional Review Board.

A total of 120 therapeutically extracted maxillary and mandibular first and second premolars were collected from the Department of Oral & Maxillofacial Surgery, Vanachal Dental College and Hospital, Garhwa, Jharkhand, India. Additionally, 60 Stainless Steel pre-adjusted edgewise brackets (American Orthodontics, Sheboygan, WI, USA)

[Table 1] d 60 Radiance Plus pre-adjusted edgewise brackets (American Orthodontics, Sheboygan, WI, USA) [Table 2] were procured for this study. The premolars selected met the inclusion criteria: intact enamel on the buccal surface, no pretreatment with chemical agents (e.g., hydrogen peroxide), no cracks caused by extraction forceps, and no caries. The age range of the patients was between 15 and 30 years, and the geographical location of the extracted teeth was Garhwa. Patients affected by fluorosis were excluded from the study.

Table 1: Samples of Group A - Stainless Steel Brackets

S.NO	Sample (Group A)	Distance	No. of Brackets	Manufacturer
1	Stainless Steel Brackets (GROUP A1)	0 mm	20	American Orthodontics, Sheboygan, WI, USA
2	Stainless Steel Brackets (GROUP A2)	5 mm	20	American Orthodontics, Sheboygan, WI, USA
3	Stainless Steel Brackets (GROUP A3)	10 mm	20	American Orthodontics, Sheboygan, WI, USA

Table 2: Samples of Group B - Radiance Plus Ceramic Brackets

S.NO	Sample (Group B)	Distance	No. of Brackets	Manufacturer
1	Radiance Plus Ceramic Brackets (GROUP B1)	0 mm	20	American Orthodontics, Sheboygan, WI, USA
2	Radiance Plus Ceramic Brackets (GROUP B2)	5 mm	20	American Orthodontics, Sheboygan, WI, USA
3	Radiance Plus Ceramic Brackets (GROUP B3)	10 mm	20	American Orthodontics, Sheboygan, WI, USA

The 120 premolar teeth were randomly divided into two main groups, each containing 60 teeth: Group A (Stainless Steel Brackets) and Group B (Radiance Plus Brackets). Both groups were subdivided into three further groups based on the curing distance, as follows:

- **Group A1:** Stainless Steel brackets with a 0 mm distance (Color-coded: Maroon)
- **Group A2:** Stainless Steel brackets with a 5 mm distance (Color-coded: Pink)
- **Group Stainless** Steel brackets with a 10 mm distance (Color-coded: Yellow)
- **Group Radiance** Plus brackets with a 0 mm distance (Color-coded: White)
- **Group Radiance** Plus brackets with a 5 mm distance (Color-coded: Green)
- **Group Radiance** Plus brackets with a 10 mm distance (Color-coded: Rose)

Once the teeth were extracted, they were cleaned under running water to remove blood and other soft tissues. For the ultrasonic scaler, calculus was removed from the buccal surface and the teeth were also polished using the ICPA Smile and Shine Polishing kit. For permanent storage, the teeth were kept in 10% formalin.

To make it easier to work with, each tooth was mounted on a holder made out of acrylic. The crown section was kept exposed and was parallel to the holder's base. The polishing of the labial surface, which is to be bonded, was done in advance using fluoride-free pumice, and then the surface was rinsed with distilled water for 10 seconds. The teeth were etched with 37% phosphoric acid (D Tech) for 10 seconds, and then rinsed for 15 seconds with deionized water, and air-dried for an additional 5 seconds for the desired chalky white presentation.

Finally, the teeth were coated with Transbond XT primer, which was then light-cured. Adjacent to the light-cured bonded brackets, Transbond orthodontic adhesive was placed, and then excess adhesive was stripped off with an explorer tip. A custom-made wooden jig calibrated with a fixed metal scale, and a digital vernier caliper was used to standardize the distance from the light-cure tip to the base of the bracket.

Brackets were cured using a 3M ESPE Elipar™ LED light and intensity of 1200mW/cm² for 15 seconds at 3 distances (0 mm, 5 mm, and 10 mm). After curing, specimens were stored for 24 hours.

An Instron Universal Testing Machine (ABS INSTRON 338266216) evaluates the shear bond strength of the

brackets at 1 kN. The bond failure mode is determined by the ARI, proposed by Alper OZ et al. (2013), while brackets are inspected under a stereomicroscope at 20x magnification.

RESULTS

This study aimed to analyze the shear bond strength and ARI of stainless steel and Radiance Plus ceramic brackets with 3 different curing distances (0 mm, 5 mm, and 10 mm). The results are as follows:

With 0 mm curing distance, the mean shear bond strength and standard deviation were 23.07±1.83 and 31.38±1.55 for Group A (Stainless Steel brackets) and Group B (Radiance Plus ceramic brackets) respectively. Between the two groups, the difference was considerable with t=-15.51 and p=0.0001 [Table 3]. This indicates that at 3 mm, Radiance Plus brackets had considerably stronger bonds compared to stainless steel brackets.

When the curing distance was 5 mm, the mean shear bond strength of Group A was 20.57 MPa with a standard deviation of 2.13 MPa, and that of Group B was 28.30 MPa with a standard deviation of 1.37 MPa. The statistical analysis showed a significant difference between the two groups with a t-value of -13.65 and a p-value of 0.0001, favoring the Radiance Plus brackets [Table 4].

At a 10 mm curing distance, Group A's mean shear bond strength was 14.09 MPa with a standard deviation of 2.52 MPa, and Group B's mean shear bond strength was 24.47 MPa with a standard deviation of 2.03 MPa. The t-value of -14.33 and the p-value of 0.0001 indicated statistically significantly higher bond strength for Radiance Plus brackets at this curing distance as well [Table 5].

Regarding the ARI, most of the stainless-steel bracket samples (Group A) exhibited a greater amount of adhesive remaining on the bracket base at higher curing distances. Specifically, Group A3 (10 mm distance) showed the highest occurrence of adhesive left on the bracket base.ARI score of 3, with five samples exhibiting this score in Group A1. In contrast, the Radiance Plus ceramic brackets (Group B) generally demonstrated lower ARI scores, indicating that less adhesive remained on the tooth surface after debonding. This was particularly evident in Group B3 (10 mm distance), where one sample showed no adhesive remaining [Table 6].

Overall, the results indicate that Radiance Plus ceramic brackets consistently demonstrated superior shear bond strength compared to stainless steel brackets, with bond strength decreasing as the curing distance increased. The ARI scores suggest that Radiance Plus brackets also resulted in cleaner debonding with less adhesive remaining on the tooth surface. These findings provide valuable insights into optimizing curing distance for improved orthodontic bond strength [Figure 1-6].

Table 3: Comparison of Shear Bond Strength Between Group A and Group B at 0 mm Distance

Group	Sample size (n)	Mean	Std. Deviation	t	df	P value	95% Confidence Interval
A1	20	23.07	1.83	-15.51	38	0.0001	-9.41 to -7.23
B1	20	31.38	1.55		38	0.001	-9.41 to -7.23

Table 4: Comparison of Shear Bond Strength Between Group A and Group B at 5 mm Distance

Group	Sample size (n)	Mean	Std. Deviation	t	df	P value	95% Confidence Interval
A2	20	20.57	2.13	-13.65	38	0.0001	-8.87 to -6.58
B2	20	28.30	1.37		38	0.001	-8.87 to -6.58

Table 5: Comparison of Shear Bond Strength Between Group A and Group B at 10 mm Distance

Group	Sample size (n)	Mean	Std. Deviation	t	df	P value	95% Confidence Interval
A3	20	14.09	2.52	-14.33	38	0.0001	-11.84 to -8.91
B3	20	24.47	2.03		38	0.0001	-11.84 to -8.91

Table 6: ARI Scores

Value	Criteria	GP A1	GP A2	GP A3	GP B1	GP B2	GP B3
0	Entire adhesive left on bracket base	1	2	12	2	3	7
1	More than half of adhesive left on bracket base	4	12	4	3	11	9
2	Less than half of adhesive left on bracket base	10	4	3	11	2	3
3	No adhesive left on bracket base	5	2	1	4	4	1

Figure 1: ARI Group A1 at 0 mm

Figure 2: ARI Group A2 at 5 mm

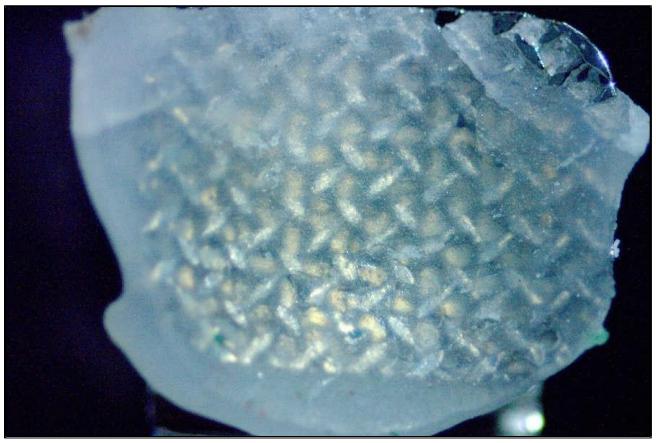

Figure 3: ARI Group A3 at 10 mm

Figure 4: ARI Group B1 at 0 mm

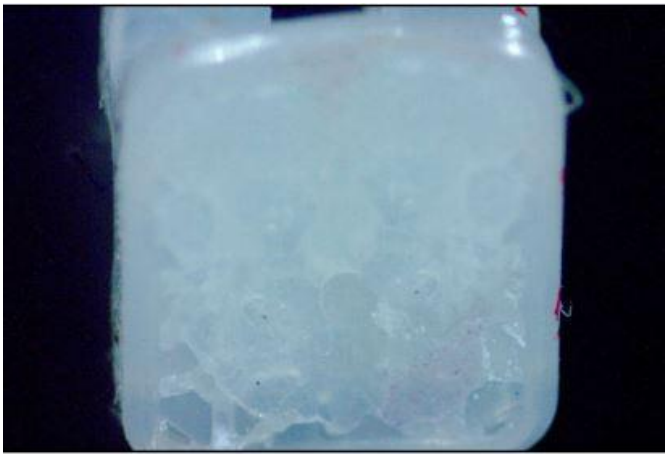

Figure 5: ARI Group B2 at 5 mm

Figure 6: ARI Group B3 at 10 mm

DISCUSSION

Orthodontics has made tremendous progress in recent years; the research and production of new materials (bonding agents) used in bonding systems have changed orthodontic treatment completely. In the past, brackets were welded onto bands that were then cemented to each tooth; this process involved additional work and preparation, during which esthetic problems could arise for patients [15, 16]. The introduction of bonding systems in the 1950s solved the issue via a simplified technique with less chairside time and also patients' satisfaction. These systems were initially of low bond strength but have progressed over several generations of resins with better clinical results [17].

The first generation of bonding agents, which were developed by Buonocore in 1956, had very low bond strengths (1–3 MPa). In the late 1970s phosphate and amino acid-based adhesives were developed to enhance bond strength up to about 5-6 MPa [18]. With the development of 3G and 4G adhesive systems in the 1990s, bonding became more predictable with stronger bonds and better clinical results. The Transbond XT adhesive, which was used in the present work, is a fourth-generation bonding system that boasts of total etch concept and moist bonding techniques to enhance enamel bond strength [19].

One of these important factors is the curing light, an essential element for bracket-tooth bond strength. Light emitting diode (LED) Curing lights, first introduced by Mills in 1995, are popular for their benefits like less heat generation, longer operating life and portability. The light that was used in this study, the 3M ESPE Elipar LED, has a power intensity of 1200 mW/cm^2 - high enough to allow bond strength at very great distances during curing [20].

The results of this study indicated that the monocrystalline ceramic brackets (Radiance Plus) presented significantly greater bond strength compared to stainless steel brackets, which is in line with previous studies. The mean shear bond strength at 0 mm for the Radiance Plus brackets was 31.38 MPa, and for the stainless-steel brackets was 23.07 MPa. This appears to indicate that the light penetration is greater with the transparent ceramic brackets, resulting in better curing ability and bond strength. This observation validates the results of P. Kalidass et al. (2022) [21].

Comparison of bond strength between the two materials did not indicate any change in pattern; it was observed that ceramic brackets were always stronger than stainless steel ones at all curing distances. For instance, at 5 and 10 mm, the bond strength of Radiance Plus brackets was 28.30 and 24.47 MPa, whereas stainless steel brackets reduced to 20.57 and 14.09 (Tables 4 and 5). This decrease of bond strength on curing distance is in accordance with work from J Chalipa et al. (2016) [22], bond strength decreases as the distance of curing light from the bracket increases.

Besides bond strength, the location of bond failure was assessed according to the ARI. In this study, ceramic brackets had more predictable bond strength at the enamel-adhesive interface than stainless steel brackets, which presented with adhesion failures between bracket-adhesive and a tooth structure as curing distance increased. These findings align with those of Nasiri M et al. (2019) [23], who also observed that tooth-adhesive failure was significantly less frequent in ceramic brackets. When the light-curing distance was 10 mm, bond failures occurred at the bit–adhesive interface in most groups, indicating poor light penetration and weak adhesive bonding. These results are also consistent with previous reports. For example, Gwinnett et al. [24] showed that the bond strength of ceramic brackets was significantly higher than those of metal ones, particularly under ideal curing conditions. However, H Shamsan et al. (2024) [25] which found that metal brackets had the greatest bond strength possibly due to their cyclic thermocycle routine and high-water percentage used on teeth in their study.

CONCLUSION

Shear bond strength and ARI analyses showed that increasing the curing distance reduced bond strength for both bracket types, with stainless-steel brackets being more affected. Radiance Plus ceramic brackets demonstrated higher and more consistent shear bond strength at all distances due to their transparency, which enhances light transmission and adhesive curing. ARI results indicated that bond failures in stainless-steel brackets shifted from the adhesive–enamel interface at 0 mm to the bracket–adhesive interface at greater distances, while Radiance Plus brackets consistently failed at the bracket–adhesive interface. These findings highlight the importance of curing distance and bracket transparency in achieving optimal bonding performance.

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AUTHOR CONTRIBUTIONS:

Anila Rupa Kujur: Conceptualized the study, developed the research design, and oversaw the entire project. He was responsible for data analysis and interpretation, and also drafted the manuscript.

Simran Suhani, Chandra Lekha: Assisted in the design and implementation of the study, contributed to the development of the research framework, and was involved in data collection and analysis. She provided critical revisions to the manuscript.

ABBREVIATIONS USED IN THE STUDY:

a) **ARI**: Adhesive Remnant Index
b) **LED**: Light Emitting Diode
c) **MPa**: Megapascal
d) **3M ESPE**: 3M Company – ESPE Dental Division
e) **Instron**: A brand of universal testing machines used for measuring bond strength
f) **Transbond XT**: A type of orthodontic adhesive used in the study

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