Research Square

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Veneer-Based Fixed Lingual Retainer: In Vitro Evaluation of Shear Bond Strength and Adhesive Remnant Index

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Abstract

Objectives

Orthodontic relapse, the tendency of teeth to return toward their pre-treatment positions, remains a major challenge and has led to widespread use of fixed lingual retainers to preserve stability. However, conventional metal-wire retainers frequently exhibit high failure rates and limited longevity. Therefore, the aim of the study was to evaluate the shear bond strength (SBS) and failure pattern of a novel veneer-assisted fixed retainer compared with a conventional wire-only retainer design.

Materials and Methods

Seventy-six bovine incisors were allocated into 38 matched pairs (n = 19 per group). In the experimental group, multistranded wire was embedded within prefabricated composite shells (Filtek™ P60) and bonded using Transbond™ LR. Control specimens used conventional wire-only bonding. All samples underwent thermocycling (5,000 cycles, 5–55°C). SBS was measured with a universal testing machine, and failure modes were assessed using the Adhesive Remnant Index (ARI).

Results

Veneer-assisted retainers demonstrated significantly higher SBS compared with controls (2.89 ± 1.53 MPa vs. 1.99 ± 1.01 MPa; p = 0.036). ARI scores of 2–3, indicating that more than 50% of adhesive remained on the enamel surface, were significantly more frequent in the veneer group (p = 0.043).

Conclusions

Within the limitations of this in vitro study, the veneer-based fixed lingual retainer demonstrated improved bond performance and more favorable adhesive failure patterns compared with a conventional multistranded retainer.

Clinical Relevance

The novel design of the lingual retainer may improve bonding behavior at the adhesive interface; however, the underlying mechanisms were not directly evaluated.

Background

Orthodontic relapse, defined as the tendency of teeth to return toward their pre-treatment positions, remains one of the most persistent challenges in orthodontics. Despite successful active treatment, long-term stability is unpredictable, which has led to widespread clinical reliance on fixed lingual retainers to preserve alignment [1]. Numerous biological and mechanical factors contribute to relapse, including neuromuscular influences, occlusal forces, periodontal fiber elasticity, late craniofacial growth, and changes in arch form, particularly in growing individuals [2, 3].

Fixed lingual retainers, typically composed of braided or solid stainless-steel wires bonded to the lingual surfaces of the anterior teeth with composite resin, provide esthetic and compliance-free retention. However, their long-term performance remains limited. Clinical studies have reported high failure rates within the first six months after placement, though retainers that remain intact during the initial period often continue to function successfully thereafter [4, 5]. Still, relapse may occur even 10–20 years post-treatment, and many clinicians now recommend lifelong retention to maintain alignment [6, 7]. Recent study by Jedlinski et al. [8] further emphasize the critical role of orthodontic retention protocol and demonstrated that most tooth displacement occurs during the first three months of retention and then slows down significantly. Therefore, they additionally recommended that patients wear a removable retainer (vacuum-formed splint) for 22 hours per day during the first six months of retention, in conjunction with the fixed retainer.

One of the most common failure modes involves debonding of the wire from the composite, often due to cohesive failure within the resin or adhesive-to-wire interface breakdown [9, 10]. Composite resins used for bonding retainers experience volumetric polymerization shrinkage, generating internal stresses that compromise marginal integrity and long-term adhesion [11]. While restorative dentistry strategies — such as incremental placement and the use of low-viscosity liners — attempt to mitigate shrinkage stress [14, 15], most orthodontic bonding materials retain relatively low filler content, reducing stiffness and potentially compromising durability [15]. Jedlinski et al. [16] reported that orthodontic bonding material with higher filler content demonstrated greater resistance to mechanical stress, which may contribute to improved durability of bonded orthodontic retainers.

To address these limitations, we propose a novel approach incorporating pre-formed, highly filled, high-stiffness composite veneers threaded over the retainer wire. These veneer shells are filled internally with low-viscosity orthodontic resin to bond to enamel, while the veneer itself provides a rigid, stress-resistant outer structure. This configuration is designed to minimize polymerization shrinkage stress, improve marginal integrity, and increase shear bond strength (SBS).

The aim of this study was to establish and evaluate this veneer-based fixed retainer system by comparing its SBS and Adhesive Remnant Index (ARI) outcomes with those of conventional multistranded wire retainers.

Materials and Methods

Samples Design

Seventy-six bovine incisors were divided into 38 paired-tooth specimens and randomly allocated into two groups (n = 19):

1. Experimental Group (Veneer-Based Fixed Retainer)

2. Control Group (Conventional Multistranded Wire Retainer)

1. Veneer based fixed retainer group (experimental group)

For veneer fabrication, Filtek P60 composite resin (3M, St. Paul, MN, USA) was selected due to its higher filler content, offering advantages of increased stiffness and resistance to fracture compared to flowable composites. Filtek P60 contains zirconia/silica fillers, with an inorganic filler loading of 61% by volume and a particle size range of 0.01–3.5 μm [17]. This specific formulation makes Filtek P60 particularly suitable for indirect restorations such as inlays, onlays, and veneers.

To create the veneer, we used a silicone-based dental putty template [Figure 1A, B]. This template was used to create a lingual veneer model [Figure 1C]. Each veneer measured 5 mm in length, 3mm in width, and 2 mm in depth [Figure 1D], replicating the lingual surface morphology of incisors [Figure 1E, F]. The composite resin was carefully inserted into the silicone putty template and sculpted into a shell using a microbrush, leaving openings on both sides to allow threading of a multistranded round wire (0.0175", 3M Unitek, CA, USA). The interior of the veneer was then filled with Transbond™ LR, identical to the bonding material used in the control group, to ensure proper adhesion to the enamel surface.

2. Conventional Multistranded Wire Retainer (Control group)

For the control group, 0.0175" multistranded wire segments (2 cm length) were bonded directly to enamel using Transbond™ LR.

Transbond™ LR bonding material (3M Unitek, CA, USA) was selected due to its low marginal leakage and high shear bond strength, ensuring the longevity of the retainer [18]. This material performs particularly well with multistranded wires [19], and contains approximately 80% silane-treated quartz filler, which contributes to its low polymerization shrinkage (Table 1) [20, 21].

Table 1
Filler content details of Transbond™ LR (product usage manual).

INGREDIENT	**% by weight**
Silane treated quartz	75–85
Bisphenol a diglycidyl ether dimethacrylate(bisgma)	5–15
Triethylene glycol dimethacrylate (tegdma)	< 10
Silane treated silica	< 2
N.N dimethylbenzocaine	< 0.5

Specimen preparation

Seventy-six recently extracted bovine mandibular incisors were selected due to their widely accepted similarity to human enamel in bonding behavior [22–25]. Soft tissue remnants were removed with a scalpel, and the teeth were cleaned under running water using a toothbrush to remove gross debris and

calculus prior to bonding [26]. Teeth with enamel cracks, caries, or surface defects were excluded. The specimens were stored in distilled water at room temperature until use.

Each pair of teeth was embedded in fast-setting acrylic resin within a rectangular metal mold, leaving the crowns exposed and spaced 2 mm apart to allow unobstructed tensile loading. Stainless-steel stoppers were positioned adjacent to the wire to prevent sliding during testing, and a metal stabilization frame secured the acrylic block during mechanical loading [Figure 2]. For additional safety, the wire ends were marked with pink ink to allow visual verification of wire displacement. A metal square loop with reinforcement screw was used at each edge of the mold to prevent sliding of the acrylic during the mechanical test [Figure 2].

Bonding procedure

Enamel surface preparation prior to bonding was performed using a dental air-abrasion system with fluoride-free aluminum oxide powder (COXO CA-1 Air Abrasion System, COXO Medical) at a 45° angle from a distance of 5 mm for 10 seconds, followed by rinsing with water and air-drying [27], then etched with 37% phosphoric acid etching gel (Etch-37, Bisco, Schaumburg, Illinois USA) for 30 seconds, rinsed and air dried. Adhesive primer (Transbond XT Primer, 3M Unitek™ Monrovia, CA, USA) was applied and light cured for 20 seconds per tooth.

Multistranded spiral wires (0.0175" 3M Unitek, CA, USA) were cut to a standardized length of 2 cm per segment [28]. To achieve a standardized experimental procedure, all specimens were prepared by the same operator to minimize fluctuations during fabrication. For the veneer based fixed retainer group, veneers were threaded onto the wire before bonding, and their internal cavities were filled with Transbond™ LR to ensure intimate contact with the tooth surface. For the control group, the wire segments were bonded to the lingual enamel surface at the center slightly above the cingulum of each paired teeth by using conventional orthodontic bonding material (Transbond™ LR, 3M Unitek, CA, USA).

All orthodontic bonding material was light-cured using Strauss Diamond Megicure soft Mode for 20 seconds per tooth.

Thermocycling

After bonding the retainers, both groups underwent aging via thermal cycling (between 5° and 55°C, soaking time of 15 seconds) to simulate the intra oral environment [29]. The thermocycling test consisted of 5000 thermal cycles in distilled water.

Debonding procedures

The specimens were tested using a universal testing machine [Instron Model 4502, Instron 3Corp, Buckinghamshire, U.K [Figure 2] similar to a 3-point bending test while applying tensile force with using 10kN loadcell and a crosshead speed of 5 mm/min at the mid-span. The applied force was directed along the apical-occlusal direction via pull by a customized hook. This method employed in this study

has also been utilized in previous studies [26, 29]. The load applied to the wire was gradually increased until detachment from one or both tooth surfaces occurred. The first detachment event was defined as bond failure. Therefore, even partial detachment from one tooth was considered a failure event, and the maximum load required to initiate this detachment was recorded in newtons (N). The SBS was calculated by dividing the maximal load in newtons by 2 (for the 2 supports in each sample) and then divided by the bonding surface area of one of the teeth in each sample (mm^2). This calculation ignores other stresses that might develop during such mechanical test (which is not as theoretical 3 point bending test) especially due to the moment which develops between the bonding material and the tooth. In the veneer-based group, the bonding surface area was standardized because each veneer was fabricated using a silicone template with fixed dimensions (5 mm in length and 3 mm in width). In contrast, in the conventional multistranded-wire group, the composite bonding pad was not template-based and therefore showed some inter-specimen variability.

To address this, the bonded area in the conventional group was measured individually for each specimen using a digital caliper, and these specimen-specific measurements were used for calculation of SBS (MPa), rather than assuming a uniform bonding area for all control samples.

Adhesive Remanent Index (ARI)

To determine the type of failure and the amount of residual adhesive on the enamel, each specimen was inspected visually at ×10 magnification by two operators under a stereomicroscope for inter-reliability. This procedure was performed a second time after 3 weeks under the identical conditions for intra-reliability [30].

The ARI was defined by a scale range between 0–3:

Score 0: no adhesive remaining on the enamel surface.

Score 1: <50% adhesive remaining on the enamel surface.

Score 2: >50% adhesive remaining on the enamel surface.

Score 3: the entire adhesive remaining on the enamel surface.

Statistics

Assumptions of normality of study variables were assessed using Kolmogorov- Smirnov test.

Independent T test was performed to assess the difference regarding SBS between the control and experimental group.

Chi- Square test was used to examine ARI score between control and experimental groups. In order to assess the intra and inter-reliability of the two examiners, Cohen's kappa tests were used.

We performed a sensitivity power analysis using G*Power to determine the effect size that our study was sufficiently powered to detect. For the comparison between the control and experimental groups (19 specimens per group), an independent samples t-test would be sensitive to detect effect sizes of Cohen's f = 0.934 with 80% power (α = 0.05, two tails).

Results

A Kolmogorov-Smirnov test performed on the study variables indicated a normal distribution ($p > 0.05$).

Shear Bond Strength Test

An independent sample t-test revealed a significant difference in SBS (MPa) between the control group and the experimental veneer-based fixed retainer group, with the veneer group showing significantly higher MPa values ($p = 0.036$) [Table 2, Fig. 3]. The mean SBS value was 2.89 ± 1.53 MPa for the experimental group and 1.99 ± 1.01 MPa for the control group, corresponding to an absolute mean difference of 0.90 MPa. The standard deviations were of similar magnitude in both groups, indicating comparable variability between specimens.

Table 2
Shear bond strength values of the control (Transbond LR fixed retainer) and experimental (Veneer based fixed retainer) groups expressed in both Megapascals (MPa) and Newtons (N): Mean, ±SD, range, minimum, maximum, percentiles 25, 50, 75.

	Control group (MPa)	**Experimental group (MPa)**	**Control group (N)**	**Experimental group (N)**
Mean	**1.99**	**2.89**	**103.87**	**97.44**
±SD	1.01	1.53	50.15	51.05
Range	3.45	4.53	145.80	141.80
Minimum	0.60	0.71	29.70	20.00
Maximum	4.05	5.24	175.50	161.80
P25	0.88	1.40	66.00	45.10
P50	2.31	2.85	102.10	110.00
P75	2.65	4.07	154.10	151.20

However, no significant difference was found in maximum debonding force expressed in Newtons between the groups (control: 103.87 ± 50.15 N; experimental: 97.44 ± 51.05 N; $p = 0.697$), Table 2. This finding suggests that the difference in SBS should be interpreted in light of differences in bonded surface area between the retainer designs. Since SBS is calculated by dividing force by bonding area, similar absolute failure loads may produce higher calculated stress values in specimens with smaller bonded areas.

Adhesive remnant index (ARI):

In order to assess the intra and inter-reliability of the two examiners, Cohen's kappa tests were used. There was near perfect agreement between the two examiners' judgements (k = 0.899, p = 0.0005, CI [0.77,1.00]). After three weeks, the agreement between examiners was also near perfect (k = 0.851, p = 0.0005 CI [0.697,1.00]). The Kappa for intra-examiner reliability of examiner 1 was significant and near perfect between the two-time points (k = 0.803, p = 0.0005 CI [0.637, 0.969]). With intra-examiner reliability of examiner 2 high agreement between the two-time points was found (k = 0.746, p = 0.0005 CI [0.57, 0.922].

Chi- Square tests revealed no significant differences between experimental and control groups regarding ARI score of examiner 2 at first (p = 0.09) and second (p = 0.061) measurements, although higher ARI score of 2 (more than half of the adhesive remained) and 3 (all adhesive remained on the enamel surface) was found on experimental group [Fig. 4].

No significant differences were found between experimental and control groups regarding ARI score of examiner 1 at first measurement (p = 0.09) with significant differences after three weeks of measurement with higher score of 2 and 3 for experimental group compared to control group, p = 0.043, [Figure 4].

Discussion

The veneer-based fixed lingual retainer demonstrated significantly higher post-thermocycling shear bond strength (SBS) and more favorable ARI patterns compared with the conventional multistranded wire retainer. Encasing the adhesive within a high-stiffness composite veneer may influence stress distribution at the adhesive interface; however, the present study did not directly evaluate polymerization shrinkage stress, and therefore no definitive conclusions can be drawn regarding this mechanism. The extensive thermocycling protocol and the application of combined loading across two teeth likely produced conservative but clinically relevant SBS values. The observed ARI patterns are consistent with previous reports linking higher ARI scores to stronger enamel–adhesive bonding interfaces and altered failure modes [10].

Fixed lingual retainers are widely used following orthodontic treatment to maintain tooth position over time. Despite their clinical effectiveness, debonding and fracture remain common complications, potentially leading to relapse and partial loss of treatment outcomes. The long-term success of fixed retainers is influenced by several factors, including adhesive properties, bonding technique, and intraoral environmental conditions.

Two main categories of orthodontic adhesives are commonly used: conventional highly filled composites and flowable composites. Flowable composites are often preferred due to improved handling and ease of placement, whereas highly filled composites generally demonstrate superior mechanical properties and bond strength. In the present study, Transbond™ LR was selected as the

bonding adhesive in both groups because of its well-documented performance in orthodontic applications [31, 32]. This material is a Bis-GMA–based composite (bisphenol A glycidyl dimethacrylate) with a relatively high filler content, which contributes to enhanced mechanical strength but may compromise handling characteristics [33].

The aim of this study was to evaluate a modified retainer system combining improved handling characteristics with post-thermocycling bond performance. The veneer-based design incorporates a prefabricated high-stiffness composite shell that is bonded to the enamel surface using Transbond™ LR. When compared with the conventional fixed retainer, the veneer-based system demonstrated higher post-thermocycling SBS values (2.89 ± 1.53 MPa vs. 1.99 ± 1.01 MPa), indicating improved bond performance under the experimental conditions of this study. However, these findings should be interpreted with caution, as the study design does not allow assessment of bond strength changes over time or direct evaluation of long-term durability.

From a clinical perspective, the veneer-based approach may offer potential advantages in handling and application, particularly if prefabricated units are developed. Future systems could incorporate digitally designed or size-matched veneers corresponding to tooth morphology, allowing improved standardization and potentially reducing chairside time. However, these potential clinical benefits were not directly evaluated in the present study and require further investigation.

Because this study was conducted under controlled in vitro conditions, its direct clinical applicability remains uncertain. Variations in lingual tooth anatomy, moisture control, and operator technique may influence the adaptation and performance of veneer-based retainers. Accurate adaptation of the veneer unit to the individual tooth surface is likely to be critical for predictable clinical outcomes. Future developments may include digitally customized veneer units tailored to each tooth’s lingual morphology, as well as further evaluation of clinical handling, adaptation, and long-term performance.

Previous studies have reported higher SBS values for conventional retainers. For example, Al-Nimri et al. [34] reported higher bond strength values, which may be attributed to methodological differences, including fewer thermocycles and variations in bonding area. In the present study, the use of 5000 thermocycles, combined with a three-point bending test applying forces across two teeth, likely contributed to lower calculated SBS values. Differences in enamel surface preparation protocols may also influence bond strength outcomes, and comparisons with studies employing alternative preparation techniques should be interpreted with caution [35].

Similarly, Baysal and Uysal [36] reported lower tensile stress values using direct debonding tests, whereas Uysal et al. [37] demonstrated higher SBS values with smaller bonding areas. More recently, Liu et al. [38] reported higher SBS values using direct shear forces on bovine teeth, although the bonding area was not clearly defined, which may limit comparability. These methodological differences, including variations in loading conditions, bonding area calculations, and aging protocols, complicate direct comparison between studies and highlight the need for standardized testing approaches in orthodontic materials research.

The ARI analysis in the present study demonstrated a higher frequency of scores indicating greater adhesive retention on the enamel surface in the experimental group. This suggests a shift in failure mode toward the adhesive–retainer interface, which may reflect differences in bonding behavior or stress distribution. Similar associations between ARI scores and bond strength have been reported in previous studies [10, 39, 40]. However, these findings should be interpreted within the limitations of the current study design.

Limitations

Several limitations should be considered when interpreting the results of this study. First, the absence of pre-thermocycling bond strength measurements does not allow for assessment of changes in bond strength over time or direct evaluation of bond degradation following aging. Second, the use of different composite materials between the experimental and control groups may have introduced a confounding effect, making it difficult to fully distinguish the influence of the veneer design from the material properties.

Additionally, the manual fabrication of the veneer units may have introduced variability in geometry and marginal adaptation. Although efforts were made to standardize bonding conditions and account for bonding area, some variability remains inherent to the methodology.

Finally, as an in vitro study, the findings may not fully reflect clinical conditions, where factors such as saliva, occlusal forces, and patient-specific anatomy may influence performance.

Future studies incorporating both pre- and post-thermocycling measurements, standardized materials, and clinical evaluation are recommended.

Conclusion

The veneer-based fixed lingual retainer demonstrated significantly higher shear bond strength and more favorable adhesive failure patterns compared with conventional multistranded retainers under the conditions of this in vitro study. These findings indicate improved bond performance following thermocycling. However, the underlying mechanisms and long-term clinical performance were not directly evaluated. Further research is required to assess bond durability over time and clinical applicability.

Declaration

Data availability

The datasets of the study are available from the corresponding author on reasonable request.

Conflict of interest

The authors declared no potential conflicts of interest with respect to the research, authorship, and/ or publication of this article.

Ethical approval and patient consent

Not applicable

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Consent for publication

All authors have read and agreed to the published version of the manuscript.

Author Contribution

H.T. Conceptualization, Methodology, Software, Writing- review and editing. D.L. Conceptualization, Software, Validation, Formal analysis, Writing- review and editing. T.B. Conceptualization, Methodology, Writing-reviewing and editing. N.S. Writing, review and editing. M.D. Conceptualization ,Methodology, Writing- review and editing.

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Figures

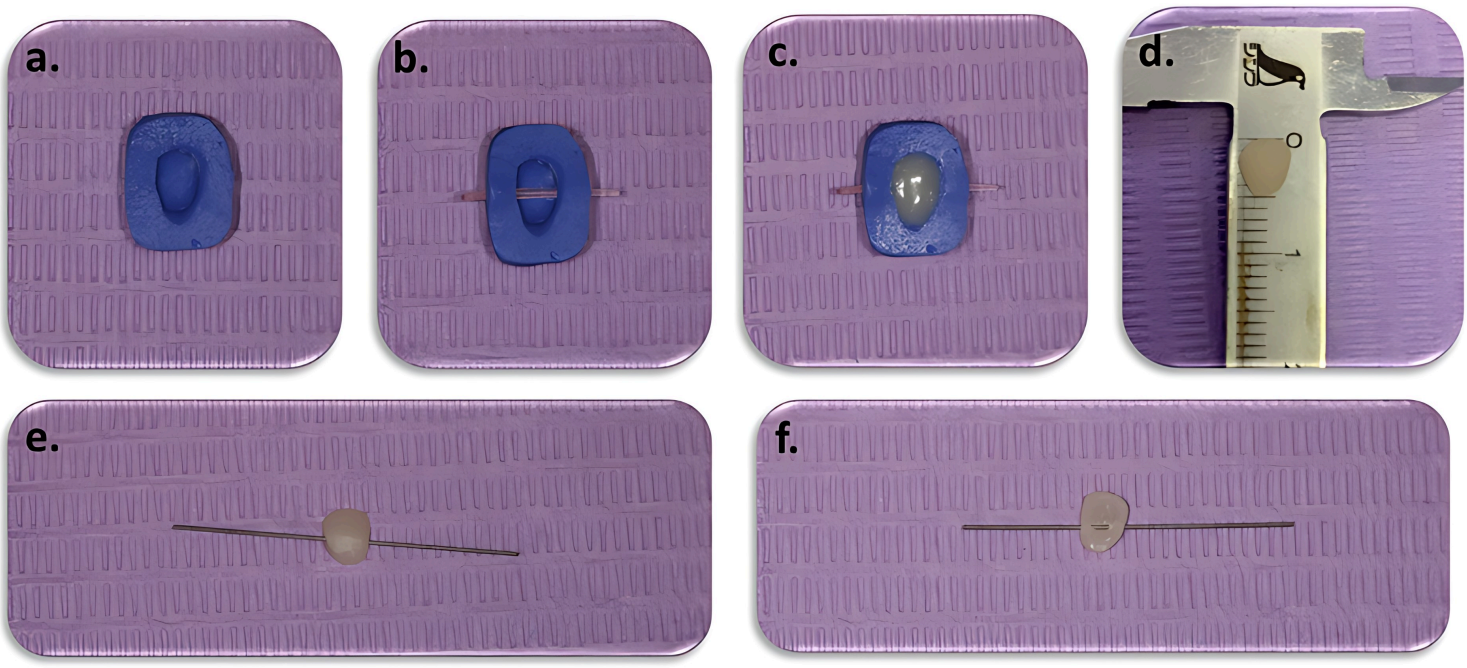


Figure 1

Novel Veneer based fixed retainer. a Silicone-based dental putty template. b. Putty threaded by wire. c. Putty filled by Filtek P60. d. Length of Veneer is 5 mm. e. Outer surface of the veneer. f. Inner surface of the veneer.

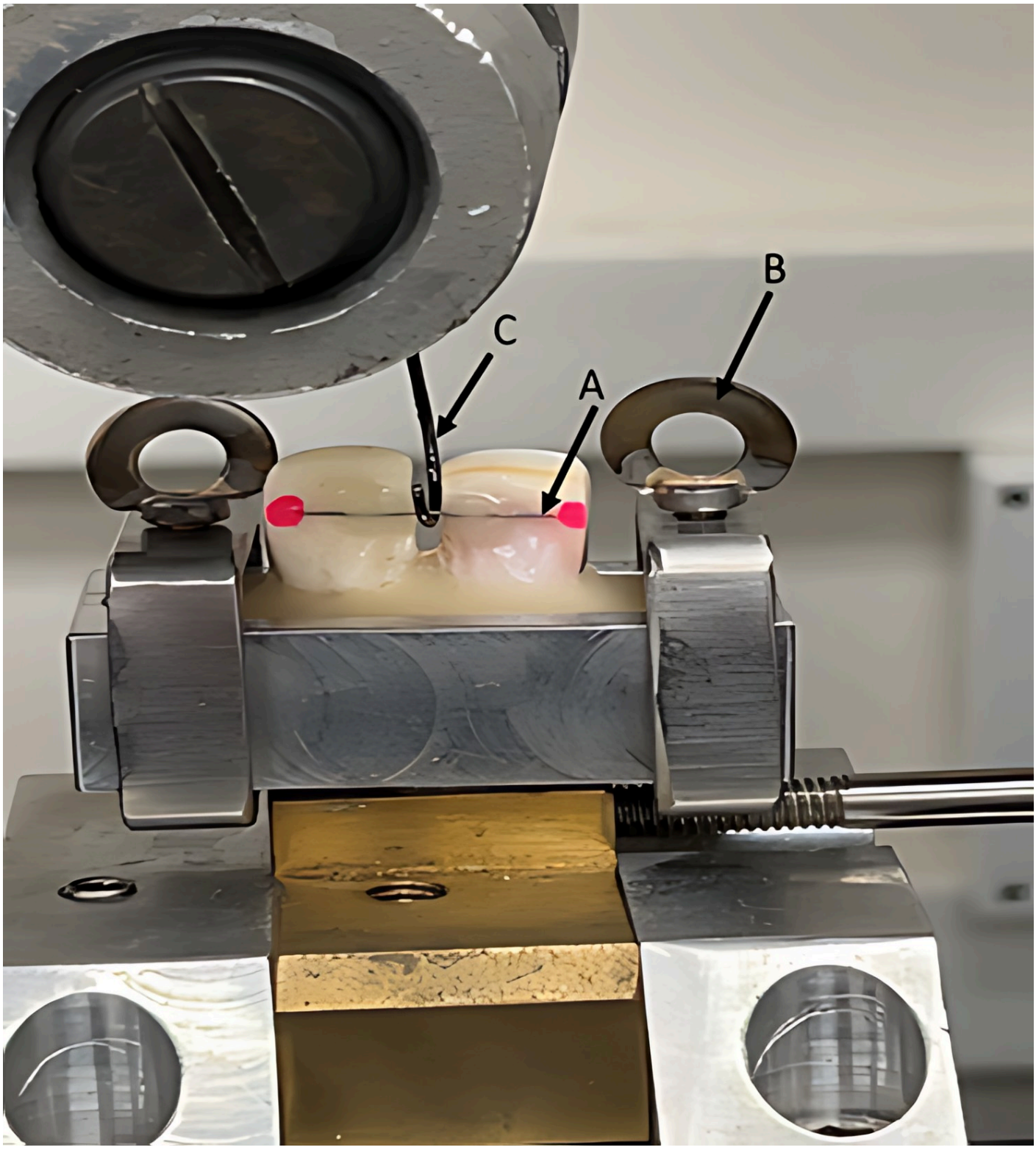


Figure 2

Setup of the mechanical test: The teeth were embedded in the acrylic mold. Stainless steel stoppers (A) were located at both sides of the retainer wire preventing the wire from sliding within the veneer. Two square metal loops with reinforcement screws (B) stabilized the whole model in the loading machine. Loading the retainer wire obtained by a hook (C) connected to the loading machine.

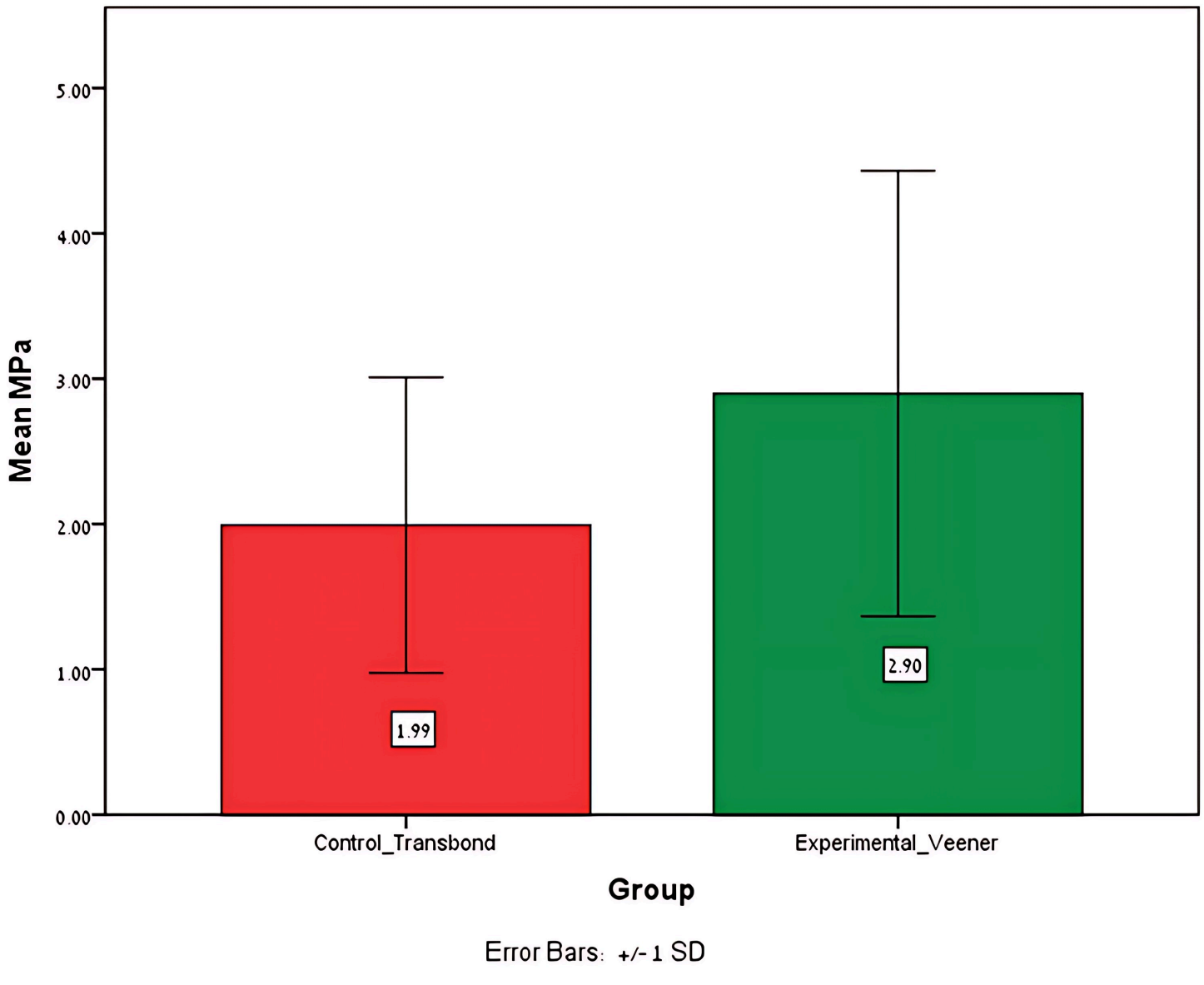


Figure 3

Shear bond strength (MPa) of the control and experimental group.

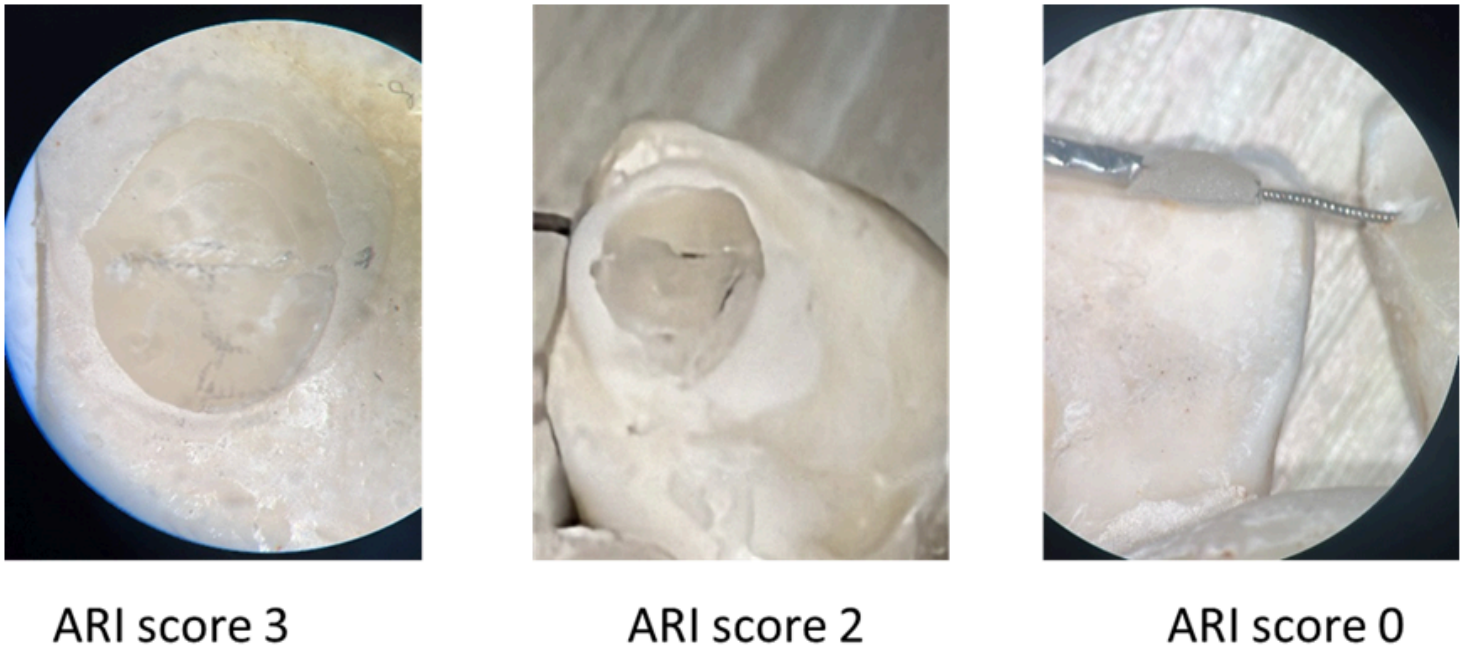


Figure 4

ARI score under stereomicroscope: ARI score 3 and 2 of experimental group and ARI score 0 of control group.