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Original Article

Dentistry Section

Comparison of Shear Bond Strength, Adhesive Remnant and Precision Fit between Conventional Lingual Retainers and Customised CAD/CAM Fabricated Lingual Retainers: An In-vitro Study

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ABSTRACT

Introduction: Fixed lingual bonded retainers offer the comfort of aesthetics and reduced tissue irritation after orthodontic treatment but are wrought with frequent bond failures. Numerous techniques have been used to adapt the retainer to the lingual surface of the lower anterior teeth, but research on customised lower lingual retainers is scarce.

Aim: To evaluate and compare the Shear Bond Strength (SBS), Adhesive Remnant Index scores (ARI), and precision fit of a novel Computer-aided Designing-Computer-aided Machining/Manufacturing (CAD-CAM) fabricated retainer and conventional retainers.

Materials and Methods: This invitro study was conducted at the Department of Orthodontics, and Dentofacial Orthopaedics, SRM Dental College, Ramapuram, Chennai-89 from June 2022 to February 2023. It included a total of 360 human mandibular anterior teeth were collected and embedded in acrylic blocks in groups of six to simulate the mandibular anterior arch form. A total of 60 retainers made of braided Stainless Steel (SS) wires, co-axial wires, customised through CAD/CAM technology were evaluated. The retainers were bonded to the lingual aspect of the teeth using composite resin. A universal testing machine was used for testing SBS. Precision fit was observed using Exocad software. Statistical analysis included one-way Analysis of Variance (ANOVA) for SBS, Kruskal-Wallis for ARI score, and Mann-Whitney U test for precision fit.

Results: The CAD-CAM retainers had a more precise fit when compared to conventional retainers (p=0.009). SBS was highest for CAD-CAM fabricated retainer and lowest in the co-axial retainer, and this finding was statistically significant (p<0.001). The CAD-CAM retainer had the highest mean rank in ARI scores (33.90) when compared to braided SS and co-axial wire.

Conclusion: The CAD-CAM fabricated retainers would be more effective clinically, as higher bond strength due to precise fit would reduce the failure rate, thus preventing relapse and minimising chairside time.

Keywords: Bond failure of lingual retainers, Computer-aided designing-computer-aided machining/manufacturing, Fixed lingual retainer, Orthodontic retention

INTRODUCTION

Moyers defined orthodontic retention as maintaining newly moved teeth in position long enough to aid in stabilising their correction [1]. Orthodontic retainers are passive appliances used to hold the teeth moved by orthodontic mechanotherapy until the supporting tissues are reorganised [2].

Fixed retainers, attached to the lingual aspect of teeth, are more advantageous when compared to removable retainers and have a reduced need for patient cooperation. They can be used when conventional retainers cannot provide the same degree of stability. Bonded retainers are more aesthetic, do not cause tissue irritation or affect speech, and are also used for semi-permanent and permanent retention [3,4].

Knierim RW in 1973 described the practice of direct bonding fixed retainers [5]. In 1977, Zachrisson BU presented the advantages of using multi-stranded wires as bonded retainers [6]. Multi-stranded wires, being flexible, ensure some physiological tooth movement of the retained teeth; hence, they became the gold standard of lingual retainers. They have the advantage of being discreet, reducing patient compliance, and Zachrisson proved the same, claiming improved retentive efficacy and reliability with direct bonded retainers [5-7].

Resin fibreglass bands were more aesthetic and smaller in size but associated with higher failure rates [8]. Lingual bonded retainers made of co-axial, braided, or glass fibre-reinforced composite have been commonly used to prevent relapse after active orthodontic treatment in the mandibular anterior region [9].

The CAD-CAM was introduced to dentistry by Duret F and Preston JD [10]. Ceramic Reconstruction (CEREC) was used to fabricate indirect restorations and prosthetic replacements for teeth [11,12]. CAD-CAM technology has been used in the fabrication of retainers, claiming greater accuracy, better fit, and, most importantly, offering passive positioning of the retainer [13]. Numerous materials have been used for designing CAD-CAM retainers. Memotain is a fixed retainer made of a nickel-titanium alloy and processed by CAD/CAM technology [14]. Various aspects of CAD-CAM retainers like positional accuracy, alignment stability, ability to retain teeth in corrected position and failure rate of CAD-CAM retainers have been studied [15].

The CAD-CAM-designed retainers, by virtue of their fit and accuracy, claim to reduce the failure rate [16-18]. Cobalt-chromium alloys have been used in orthodontics as archwires for a long time. They have an elastic modulus and strength similar to SS [19]. CAD-CAM technology can be effectively used to bend blocks made of cobalt-chromium alloy and adapt them to the lingual surface of lower anterior teeth [13,20]. Customised lingual bonded retainers have been restricted to the idea of adapting either co-axial wire or Nickel-titanium alloy wire to the lingual surface of lower anterior teeth thus far [14,15]. Evaluation of the Shear Bond Strength (SBS) of the specially designed lingual retainers and comparing the same with conventional wire retainers to assess their probable success rate would be an interesting area of research in orthodontic retention. Therefore, the purpose of the study was to evaluate and compare the SBS, Adhesive remnant Index (ARI) scores, and precision fit between conventional braided Stainless Steel (SS) wire retainers, co axial wire retainers, and CAD/CAM customised and fabricated retainers.

MATERIALS AND METHODS

This in-vitro study was conducted in the Department of Orthodontics and Dentofacial Orthopaedics, SRM Dental College, Ramapuram, Chennai, Tamil Nadu, India from June 2022 to February 2023 after obtaining approval from the Institutional Review Board of SRM Dental College, Ramapuram, Chennai-89 (SRMDC/IRB/2020/MDS/No.104).

Sample size calculation: Sample size was calculated using A priori software. A total sample size of 60 was estimated with an alpha error of 0.05 and 90% power for the study. The samples (60) were divided into three groups of twenty each: Group-1- Braided SS wire retainers; Group-2- Co-axial wire retainers; Group-3- CAD/CAM fabricated and customised retainers.

Study Procedure

Sample tooth collection: A total sample of 360 human mandibular anterior teeth with sound enamel surfaces was collected. Teeth with enamel defects like hypoplasia, caries, cracks, fractures, or those pre-treated with chemical agents like hydrogen peroxide were excluded from the study. The teeth were preserved in deionised water (4°C) for a period of one month. Afterward, all the teeth were cleaned and polished to remove calculus and soft-tissue remnants. Polishing was done using non fluoridated pumice and a prophylactic rubber cup, and the teeth were then rinsed in a stream of water for 10 seconds.

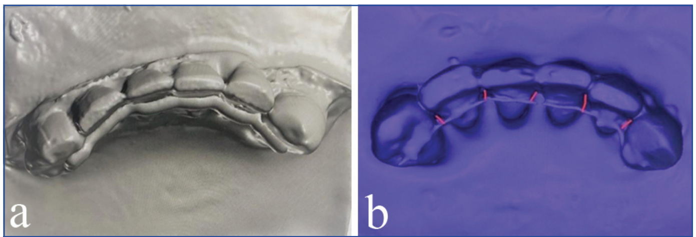
Preparation of acrylic blocks: To simulate the normal mandibular arch form, six anterior mandibular teeth were positioned so that the labial surface of the teeth followed the anterior curvature of a preformed 0.019×0.025-inch SS archwire. The teeth were arranged in an arch form using SS wire and embedded in blocks made of chemically polymerised acrylic resin to enable the stimulation of proper contact points. The arrangement of teeth was done in a way that their long axis was perpendicular to the acrylic block [Table/Fig-1a-d].

[Table/Fig-1]: Preparation of acrylic blocks.

Wire fabrication: The braided wire retainers were made by twisting ligature SS wire (0.009"), which was bent to conform to the lingual surface of the mandibular anterior teeth embedded in arch form in acrylic blocks [Table/Fig-1a]. Co-axial wires (Rabbit Force SS, Libral traders) were purchased from a dealer in a spool from which they were cut and bent to the contour/configuration of the lower lingual arch form [Table/Fig-1b].

For the customised CAD/CAM fabricated lingual bonded retainer, extracted mandibular anterior teeth were mounted on an acrylic base to simulate the mandibular anterior arch-form. The acrylic model was scanned using a 3D scanner (5-axis scan, Amann Girrbach). A three-dimensional retainer pattern with a thickness of 1.2 mm and a height of 1.8 mm was designed using ExoCAD software and milled using resin (Amann Girrbach machine) [Table/Fig-1c]. Then the 3-D milled retainer (Anycubic 3D printing resin) was invested by means of type V gypsum (Wirovest, Bego), which has high strength and high expansion properties, and cast using cobalt-chromium alloy.

Precision fit: The CAD-CAM fabricated retainers and conventional braided SS wire retainers placed on the model were scanned (5-axis scan, Amann Girrbach) and digitised (ceramill mind, Amann Girrbach) [Table/Fig-2a, b]. Both conventional braided SS and co-axial wire were adapted to the lingual surface by a manual method for the first part of the study. Since both were bent by hand, only the economical conventional braided SS wire was used as a control to check the precision fit. Precision fit was analysed by measuring the adaptation of the retainer at the deepest part of the interproximal embrasure near the contact point to the wire and was measured in millimetres [Table/Fig-2b].



[Table/Fig-2]: Scanning and digitisation of the model.

Lingual wire placement: The lingual retainers to be bonded were marked at the center of their long axis on the lingual surface of the teeth with a marker. All the retainers were bonded with the same adhesive. Teeth were etched using 37% orthophosphoric acid (Eazetch, Anabond Stedman) for 15 seconds, rinsed with water using a three-way syringe for 30 seconds, and air-dried for 20 seconds. Primer (Orthofix, Anabond Stedman) was applied to the etched lingual surface of mandibular anterior teeth and light-cured for 10 seconds. Retainers were placed on the lower part of the contact points of the teeth in such a way that they were parallel to the base of the acrylic block. Flowable composite resin (3M Espe Filtek Z350 XT supreme) was used as an adhesive on the teeth and the wire and cured with an Light-emitting Diode (LED) curing device (RTA Mini S, Guilin Woodpecker) for 40 seconds per tooth.

Shear bond testing: All bonded samples were stored in distilled water at 37°C for 24 hours before testing SBS. This was done to ensure simulation of oral temperature and environment. The acrylic blocks with lingual retainers bonded to the mandibular anterior teeth were engaged to the base plate of the Instron Universal Testing Machine. When the vertical force was applied by the machine during shear testing, it was exerted in such a way that the tip aligned with the center of the wire and not in contact with any other surface. The speed of the piston in the Instron testing machine was set to 1 mm/min, and the maximum load at bond failure was recorded. Force values were expressed in newton.

Adhesive Remnant Index (ARI) score: The ARI scores were recorded for each sample to check the bond failure [21]. The ARI scoring scale is as follows: 0 = all composite resin remains on the bracket base, 1= less than 50% composite remaining on the enamel, 2= greater than 50% composite remains on the enamel, 3

= all composite remains on the enamel. The most desired situation is a high ARI when all composite remains on the enamel surface; the likelihood of enamel fracture on debonding decreases when ARI scores are consistently high.

STATISTICAL ANALYSIS

Statistical analysis was carried out using International Business Machines (IBM) Statistical Package for Social Sciences (SPSS) (version 22.0). The normality of the data was assessed using the Kolmogorov-Smirnov test, and the significance level was fixed at 5%. One-way ANOVA was used to find the difference between the three groups, and Tukey's HSD post-hoc analysis was used for intergroup comparison. Data for ARI scores were not normally distributed, so the Kruskal-Wallis test was performed. Precision fit was assessed using the Mann-Whitney U test.

RESULTS

Descriptive data for SBS (in Newton) are given in [Table/Fig-3]. The mean SBS values in descending order of severity noted are as follows: CAD-CAM retainers exhibited the highest SBS values during debonding (189±55.10 N), followed by braided SS wire retainer (112.75±25.83 N), and the least by co-axial retainer (83±15.93 N). ANOVA revealed a statistically significant difference between the mean SBS of all the retainers (p<0.001).

Group (n=20/ group)	SBS mean (N)	Std. deviation	Minimum (N)	Maximum (N)	F	p-value
Braided SS	112.75	25.83	75	150	45.331	<0.001
Co-axial wire	83.00	15.93	55	110		
CAD-CAM retainers	189.00	55.10	110	255		

[Table/Fig-3]: Descriptive statistics of Shear Bond Strength (SBS) for three groups in Newton (N).
One-way ANOVA test; p-value ≤ 0.05 is significant

Post-hoc Tukey analysis revealed a significant difference between any two compared groups [Table/Fig-4]. Co-axial retainers had the least SBS, and this variation may be the reason for the significant result.

Group	Group	Mean Difference	p-value	95% confidence interval	
				Lower Bound	Upper Bound
Braided SS	Co-axial wire	29.750*	0.032	2.11	57.39
	CAD-CAM retainers	-76.250*	<0.001	-103.89	-48.61
Co-axial wire	CAD-CAM retainers	-106.000*	<0.001	-133.64	-78.36

[Table/Fig-4]: Post-hoc analysis.
Tukey's post-hoc analysis. p-value ≤ 0.05 is significant

Data for ARI scores are given in [Table/Fig-5]. The mean rank of ARI scores for braided SS wire, co-axial wire, and CAD-CAM retainer were 29.18, 28.43, and 33.90, respectively [Table/Fig-6]. A Kruskal-Wallis test showed that there was no statistically significant difference in ARI scores across the groups (p=0.509).

Score	Braided SS n=20	Co-axial n=20	CAD/CAM
0	1 (5%)	0 (0%)	0 (0%)
1	4 (20%)	7 (35%)	5 (25%)
2	12 (60%)	9 (45%)	8 (40%)
3	3 (15%)	4 (20%)	7 (35%)

[Table/Fig-5]: Descriptive statistics for ARI scores.

When precision fit was studied [Table/Fig-7], it was found that CAD-CAM retainers had the most precise fit (0.038±0.022 mm) when compared to conventional retainers (0.204±0.065 mm). This finding was statistically significant (p=0.009).

Group	Mean rank	X^2 value	p-value
Braided SS	29.18	1.35	0.509
Co-axial	28.43		
CAD/CAM	33.90		

[Table/Fig-6]: Comparison of ARI scores between the groups.
Kruskal Wallis test. p-value ≤0.05 is significant

Group	Minimum (mm)	Maximum (mm)	Mean	Std. Deviation	Mean Rank	Sum of Ranks	U statistic	p-value
Conventional	0.12	0.27	0.204	0.065	8	40	0.000	0.009
CAD/CAM	0.02	0.07	0.038	0.022	3	15		

[Table/Fig-7]: Descriptive statistics and comparison of precision fit between groups.
Mann-Whitney U test. p-value ≤0.05 is significant

DISCUSSION

In the present study, it was found that the CAD-CAM fabricated retainer had significantly higher SBS and precision fit compared to conventional braided SS and co-axial wires.

The second retainer used in the present study was a commercially available co-axial wire. It consists of five SS wires wound around a single core wire. The core wire gives co-axial wires improved resiliency and flexibility to sustain bending to a great degree [22].

Aldrees AM et al., discovered that co-axial wire had higher bond strength values than the twisted SS retainer. The co-axial wire has been suggested as an initial arch wire because of its light force [22]. This wire is extremely flexible and has excellent spring-back characteristics. The results of the present study reveal that the co-axial wire has the least bond strength values compared to either braided wire or CAD-CAM fabricated retainer.

Baysal A et al., compared three different orthodontic wires for bonded lingual retainers and found that five-stranded wires have more SBS than co-axial and bond-a-braid wires. This result correlates with the results of the present study as the retainer made of co-axial wire has the least SBS compared to other retainers [9].

The third retainer was fabricated using CAD-CAM technology from blocks of cobalt chromium alloy in a laboratory. All three retainers were bonded to acrylic-mounted teeth, simulating the anterior arch form. Bonding was done using light-cured flowable composite resin Filtek Z350 (3M). The bond strength of the three different retainers made of braided SS wire, co-axial wire, and CAD-CAM fabricated cobalt-chromium retainer was tested using a universal testing machine. CAD/CAM fabricated lingual retainers were found to be more stable and efficient than conventional retainers [20].

Research has shown that thicker and rigid wires are able to retain inter-canine width better than flexible ones [23]. The CAD-CAM retainer made of cobalt chromium is rigid enough to hold teeth in the corrected position. Although previous studies evaluated different lingual retainer wires, adhesive systems, or their combinations, the combination of braided SS wire, co-axial wire, and CAD-CAM fabricated lingual retainer wire has not been tested before [17,18,20].

It was observed in the present study that Group-III (CAD-CAM fabricated retainers) exhibited the highest SBS, and this result was statistically significant. Co-axial wire had the least SBS, and there was a wide difference among the three wires. Post-hoc Tukey test revealed a significant result in intergroup comparison.

The mean ARI ranks show that there was an increased score in the CAD-CAM group, indicating that adhesive was left behind on the tooth surface following debonding. This is a reflection of good SBS [9,24]. The mean ARI score was least for the co-axial group. Baysal A et al., studied the SBS of three different commercially available lingual retainer wires (five-stranded, eight-stranded, and the third co-axial wire) and found no significant difference in their ARI scores [9]. Aycan M and Goymen M conducted a comparative investigation of the SBS of a new CAD-CAM fabricated retainer- Memotain with Everstick and Bond-a-braid retainer and found that there was a significant difference in ARI scores between the three groups, with the Bond-a-braid retainer having the highest value. Nevertheless, the CAD-CAM fabricated lingual retainer was found to be clinically reusable even after failure [18].

Some studies have observed that sandblasting and laser irradiation before acid etching on enamel significantly increased the SBS [25,26]. In the current study, none of the above-mentioned pretreatment methods were used; nevertheless, the bond strength was sufficient to withstand the debonding force. This could be attributed to various factors, with the most important factor being the precision fit.

Precise adaptation to the lingual surface morphology of the individual teeth was found to be a distinctive feature of CAD-CAM retainers compared to traditional retainers [15]. Kang SH et al., studied the accuracy of custom-cut, custom-bent, and manually bent retainers and concluded that custom-cut retainers had the highest degree of accuracy [27]. In the present study, the intraoral precision fit was very good in CAD-CAM fabricated lingual retainers. Precise adaptation to the lingual surface morphology of the individual teeth is a distinguishing feature of this CAD-CAM fabricated retainers (0.038±0.022 mm) compared to conventional retainers (0.204±0.065 mm).

When compared to conventional lingual retainers, the CAD-CAM fabricated retainer provides many advantages. The benefits of CAD-CAM fabricated retainers include the elimination of the necessity for wire measurement or bending, the ability to customise placement to the patient's arch form, improved compliance, tighter tooth surface and interproximal adaptation, less tongue discomfort, better durability, and reduced microbial colonisation. Increased bond strength will minimise breakage, hence viability for use in the maxillary arch is increased.

The use of CAD-CAM fabricated retainer may be extended to other specialties of dentistry like periodontics and traumatology for permanent splinting of periodontally compromised teeth with increased mobility. Retainers fabricated with CAD-CAM need not be limited to nickel-titanium alloy or cobalt-chromium alloy but should extend to other flexible materials.

Limitation(s)

The present study was an in-vitro one; hence, caution should be exercised when applying the findings to clinical practice. Masticatory force, saliva, diet, and oral habits are all factors that influence the intraoral environment. During mastication, strong forces may be applied spasmodically to occlusal contacts. The present study was carried out under ideal, or at least well-controlled, conditions in which the enamel surfaces were cleaned prior to bonding, and no saliva, calculus, or plaque contamination occurred during the bonding procedure. Thus, it is difficult to expect similar values in a clinical scenario.

CONCLUSION(S)

The CAD-CAM-designed and fabricated retainers were found to have the highest SBS and precision fit when tested along with two conventional retainers. No significant difference was found among the groups for the ARI index. Future research could aim at making CAD-CAM-designed cobalt-chromium (Co-Cr) retainers a clinically viable alternative to conventional lingual bonded retainers due to their superior bond strength, which will reduce the failure rate.

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