INTRODUCTION

The restoration of endodontically treated teeth can be a challenge because, in general, the teeth that undergo this treatment lose a large amount of coronal tissue, making it necessary to use posts as intraradicular retention elements for restoring the coronal nucleus. There are several types of posts; however, fiber posts are preferred by many clinicians because of their properties, such as elastic modulus close to that of dentin, esthetic appearance, and compatibility with different types of resins. For example, some studies mention that endodontically treated teeth, due to previously existing lesions and the procedures performed, often lose coronal tissue, requiring the placement of intraradicular posts that allow restoration of the nucleus or coronary stump, ultimately enabling final coronal restoration. However, several factors could influence the clinical performance of endodontically treated teeth restored with a combination of intra-root posts and crowns.

Cementation is a critical procedure for adequate clinical performance of fiberglass posts, as it is important to achieve an adhesion force capable of withstanding masticatory forces in order to ensure adequate functionality and longevity of the posts/restorations. Therefore, it is necessary to investigate the adhesive strength of different protocols involving the use of adhesive cementation and fiberglass posts in root canals.

During the last few decades, many studies have focused on a variety of materials that can be used to prepare intraradicular posts and restore the coronal nucleus with different properties and fixing mechanisms, e.g., gold, stainless steel, titanium, or zirconium alloys, which are usually rigid, and fiberglass, which are flexible. Some studies analyzed the influence of adhesion on the transmission of forces from the post to the root dentin using finite element analysis; they found that the central placement of the post did not contribute to the transmission of loads, as opposed to the contribution of adhesion when intact. Ubaldini et al. reported that the adhesive failure of fiberglass poles accounted for 37% of all failure cases.
Thus, the aim of this study was to compare the bond strength of fiberglass posts using different adhesive cementation protocols.

**Materials and Methods**

**Sample Size**

The sample was calculated by the mean comparison formula using Stata 15 software, with an Alpha of 0.05 and a beta of 0.8. A sample size \( n = 30 \) of specimens was obtained for each group. The entire manuscript was written according to CRIS guidelines (Checklist for Reporting in vitro Studies).

**Preparation of Specimens**

Thirty single-rooted bovine teeth without structural defects and of similar dimensions were selected. Bovine teeth were used because they share similar characteristics to human incisors. Dental pieces were collected from animals slaughtered for reasons unrelated to the present study. They were disinfected by immersion in 0.1% thymol solution for 24 hours and then stored in distilled water and refrigerated. The crowns were cut at the level of the cement-adamantine junction with low-speed, water-cooled rotary instruments with a 22 mm diameter and 0.15 mm thick diamond bioactive disc (KG Sorensen, Sao Paulo, Brazil), obtaining roots that were 16 mm in length (Fig. 1A).

**Endodontic Treatment**

To facilitate endodontic treatment and subsequent placement of the fiberglass post, monoradicular teeth were used. Endodontic treatment was performed using rotary files (Protaper Universal System; Dentsply Maillefer, Ballaigues, Switzerland); 2.5% sodium hypochlorite solution was used for irrigation; gutta-percha tips (Dentsply Maillefer, Ballaigues, Switzerland) were used with the side condensation technique and an epoxy-based sealer (AH Plus; Dentsply Maillefer, Ballaigues, Switzerland) for sealing. After storage in distilled water at a temperature of 37°C for a day, the spaces for the posts in the root canals were prepared with the rotary instruments provided by the manufacturer of the posts (Whitepost DC No. 1; FGM, Sao Paulo, Brazil), with a length of 12 mm, in order to maintain 4 mm of apical sealing material, irrigating with sodium hypochlorite in 2.5% solution and then with distilled water (Fig. 1B).

**Cementation Protocols**

The posts were cleaned with 70% alcohol using a gauze for 15 seconds and air-dried; then, two layers of silane were actively placed for 1 minute each (Prosil; FGM, Brazil), allowing the solvent to evaporate. For the first group, an etch-and-rinse protocol with 37% orthophosphoric acid (Universal Scotchbond Etcher; 3M ESPE AG Dental Products Seefeld, Germany) was used, followed by the application of a universal adhesive (Single Bond Universal; 3M ESPE AG Dental Products Seefeld); for the second group, a self-etching protocol was used with the same universal adhesive and a dual-curing resin cement (Relyx Ultimate; 3M ESPE AG Dental Products Seefeld, Germany); for the third group, a protocol with self-adhesive cement was used (Relyx U200; 3M ESPE AG Dental Products Seefeld, Germany). The root canals of the teeth of the first group underwent acid etching for 15 seconds, followed by profuse washing with water for 60 seconds. The root canals of the first and second groups were dried with paper cones, and two layers of universal adhesive (single universal bond) were applied, followed by active rubbing; any excess was eliminated using paper cones and the solvent was allowed to evaporate for 15 seconds. Next, to the posts that were already cleaned and silane-embedded, in the first and second groups, a layer of adhesive was applied, and the solvent was allowed to evaporate using an air bulb for 15 seconds; next, the posts were cemented with dual polymerization resin cement (Relyx Ultimate). In the third group, only the canals were dried with paper cones, and the posts were cemented with self-adhesive cement (Relyx U200). The polymerization of the cement was carried out using a third-generation LED lamp (Valo, Ultradent, United States of America) for 40 seconds each on the buccal side and lingual side (Fig. 1C).

**Assessment of Adhesion Strength**

After cementation, the teeth were stored in distilled water at a temperature of 37°C for 24 hours. The samples were sectioned perpendicular to the long axis of the post, following ISO standards, using a 0.15 mm thick, 22 mm diameter diamond disc (KG Sorensen; Sao Paulo, Brazil) with low-speed rotary instruments, cooled with water. Specimens with a thickness of 2 mm were obtained for each third to be evaluated (cervical, middle, and apical). Thickness was measured using a digital caliper (Mitutoyo Corp, Kanagawa, Japan). Finally, the push-out test was performed using an Amsler universal testing machine (Amsler Equipment Inc., Ontario, Canada) (Fig. 1D).

**Statistical Analysis**

The collected data were analyzed using Stata® 15. Descriptive statistics and univariate analysis were performed to determine the mean, standard deviation, and maximum and minimum values. Normality was evaluated using the Shapiro–Wilk test. To determine the presence of a statistically significant difference among the group means, ANOVA was performed with a significance level of 0.05. In cases where significant differences were found, Bonferroni correction was performed for multiple pairwise comparisons.

**Results**

The following in vitro results were obtained: the first group showed a mean adhesion strength of 21.2 ± 4.7 MPa; the second group of 22.6 ± 5.1 MPa; and the third group, of 12.3 ± 2.1 MPa (Table 1). At the cervical level, the average adhesion forces were 17.5 ± 5.2 MPa. At the level of the middle third, the average bond strength was 17.7 ± 5.4 MPa, while at the apical third level, it was 21.0 ± 7.3 MPa (Table 1).

The normal distribution of the data was contrasted using the Shapiro–Wilk test; the data were normally distributed according to the adhesive cementation protocol \((p > 0.05)\) and according to the apical third level \((p > 0.05)\). Analysis of variance revealed significant differences \((p = 0.001)\) between the groups according to the adhesive cementation protocol used, while no differences were found according to the root third level \((p = 0.05)\) (Table 1). Therefore, using the Bonferroni post-hoc test, we found significant differences between Group 3 versus Group 1 and Group 3 versus Group 2 \((p = 0.001)\) (Table 2).

Therefore, when performing the Bonferroni post-hoc test, it was found that there were only significant differences between Group 3 versus Group 1 and Group 3 versus Group 2 with \(p = 0.001\) respectively (Table 2).

**Discussion**

We evaluated the retention and resistance forces of the post systems’ adhesion to the root canal, such as conventional tensile or shear, microtension, and pull-out/push-out forces. In this study,
Figs. 1A to D:  (A) Biomechanical preparation, irrigation, drying and filling sequence;  (B) Root canal preparation;  (C) Fiberglass post cementation;  (D) Push-out test of posts on 2 mm specimens
Bond Strength of Fiberglass Posts with Different Cementation Protocols

Table 1: Adhesion strength according to adhesive cementation protocol and according to root thirds

| Groups             | Adhesión strength | SD  | Min | Max  | p*   | p**  |
|--------------------|-------------------|-----|-----|------|------|------|
| Protocol           |                   |     |     |      |      |      |
| Group 1            | 21.2              | 4.7 | 14.4| 34.5 | >0.05| 0.001|
| Group 2            | 22.6              | 5.1 | 15.5| 34.5 | >0.05| 0.001|
| Group 3            | 12.3              | 2.1 | 8.9 | 16.6 |      |      |
| Root third         |                   |     |     |      |      |      |
| Cervical           | 17.5              | 5.2 | 10.3| 29.8 |      |      |
| Middle             | 17.7              | 5.4 | 8.9 | 28.8 | >0.05| 0.05 |
| Apical             | 21.0              | 7.3 | 11.5| 34.5 |      |      |

Group 1: Bovine teeth with posts with an etch and rinse protocol with universal adhesive and adhesive resin cement
Group 2: Bovine teeth with a self-etching protocol with universal adhesive and resin cement
Group 3: Bovine teeth with a self-adhesive cement protocol

*Shapiro-Wilk test
**ANOVA, significance level (p < 0.05)

Table 2: Post-hoc analysis of multiple comparisons between groups with Bonferroni test

| Groups        | Group 1 | Group 2 |
|---------------|---------|---------|
| Group 2       | 0.596   | –       |
| Group 3       | 0.001   | 0.001   |
|   Cervical    |         |         |
|   Middle      | 1.000   | –       |
|   Apical      | 0.082   | 0.104   |

Group 1: Bovine teeth with posts with an etch and rinse protocol with universal adhesive and adhesive resin cement
Group 2: Bovine teeth with a self-etching protocol with universal adhesive and resin cement
Group 3: Bovine teeth with a self-adhesive cement protocol

In this study, the bond strength was evaluated using different adhesive cementation protocols for bovine teeth. Limeira et al.9 found that the bond strength values, when using different adhesive cementation protocols, were not significantly different between young human teeth and young bovine teeth, which is why bovine teeth were used in this study. Furthermore, the adhesion strength values obtained with self-etching universal adhesive resin cement (Single Bond Universal and RelyX Ultimate) were not significantly different from those obtained with self-adhesive resin cement (RelyX U200). Similarly, Liu et al.10 found no significant differences between self-adhesive cement (RelyX Unicem) and etch-and-wash cement (Panavia F2.0); similarly, in the study by Pereira et al. (2014), no significant differences were found between etch-and-rinse resin cement (Panavia F, Allcem) and self-adhesive resin cement (RelyX Unicem and BisCem), but modified glass ionomer resin cement (RelyX Luting 2) showed significantly lower values than both. In a similar vein, Lorenzetti et al.11 found similar values when using self-adhesive resin cement (RelyX U200) and luting glass ionomer cement (GC Gold Label 1), taking into account the mechanical limitations of ionomers compared to conventional luting resins.

Similar to the results of the aforementioned studies, no significant differences were found between the groups using universal adhesive resin cements with the etch-and-rinse protocol and self-etching protocol; in contrast to previous studies, significant differences were found between the other groups and the self-adhesive cement group (RelyX U200), which obtained significantly low values. Ubaldini et al.5 found that the groups in which cementation was carried out using a universal adhesive and resin cement (Scotchbond Universal and RelyX Ultimate) with the etch-and-wash protocol generated significantly higher adhesion strength forces than the group that used self-adhesive cement (RelyX U200). Similarly, Amiri et al.12 found significant differences in the values obtained with fourth-generation etch-and-rinse systems in conjunction with conventional resin cement (All Bond 2 and Duo-Link) when compared to those obtained with self-adhesive cement. In contrast, in the study by Graiff et al.13 significantly higher values were recorded with the use of self-adhesive cement (RelyX Unicem) than with the use of an etch-and-rinse system (Scotchbond Multi-Purpose Plus and RelyX ARC), although in this study, cementation was performed in Plexiglass simulators to evaluate the bond strength of the posts without taking root dentin into account.

On the other hand, in the study by Farid et al.14 there were no significant differences between the groups using universal self-etching adhesive with resin cement (Panavia F 2.0) and self-adhesive resin cement (Panavia SA cement Plus); however, when the ducts were overprepared, the film thickness of the ducts increased; the bond strength values of the group that used resin cement and self-etching adhesive were significantly higher than those of the group that used self-adhesive cement. In the study by Rodrigues et al.15 the canals were overprepared, and the posts were anatomized with composite resin for comparison of the adhesive strengths of the three cementation protocols; however, no significant differences were found between the etch-and-rinse (Adper Scotchbond Multi-Purpose and RelyX ARC), self-etch with universal adhesive (Scotchbond Universal and RelyX Ultimate), and self-adhesive cement (RelyX Unicem 2) protocols.

When analyzing the adhesion strength in the root thirds of each group, no significant differences were found between the self-etching protocol with universal adhesive and self-adhesive cement protocol, but with the etch-and-rinse with universal adhesive protocol, the values of the apical third were significantly higher than the values of the cervical third, in contrast with the studies of Limeira et al.9 in which the values at the apical third decreased significantly, of Rodrigues et al.15 in which the values at the apical level were significantly lower than those at the cervical level, and of Amiri et al.12 in which the values were significantly lower at the apical level than at the cervical level, with the same protocol.
One of the limitations was that the research carried out was experimental in vitro, so the results should be interpreted with caution because of the difficulty in extrapolating them accurately to a living organism. Another important factor when evaluating a luting agent is its binding capacity to the dentin substrate. Different studies have shown weak adhesion at this level, so it is important to evaluate the various cementation systems that present different treatments of the dentin surface, with protocols that can be sensitive to difficulties in handling the multiple materials that can be used, in addition to humidity control. It is necessary to consider the increasingly widespread use of universal adhesives, in its etching and rinsing modality, and in its self-etching modality, in addition to self-adhesive cements that allow simplifying the procedure, reducing the number of steps in the procedure.

The present research is a purely in vitro study, the considerations are different from in vivo studies, so the results should be taken with caution, however, its results are useful as a reference in making decisions regarding the protocol to be used for the restoration of endodontically treated teeth, due to the lack of well-designed clinical studies that provide strong evidence for such decision making.

Finally, this research is important because it sheds light on the properties and performance of various dental biomaterials, and in vitro studies were carried out in a controlled environment, future clinical studies can be planned to increase the level of evidence for developing clinical guidelines on the rehabilitation of teeth undergoing endodontic treatment. In addition, given the limited number of well-designed randomized clinical studies on the subject, i.e., the efficacy of fiberglass post cementation protocols, through in vitro studies, with tests that have demonstrated reliability, they provide useful information for clinical practice that can facilitate an adequate selection of materials and procedures, when it is required to rehabilitate teeth with endodontic treatment that requires the use of posts.

Therefore, it is important to carry out research with larger samples and a greater variety of adhesive luting materials than those used in the current study in order to compare the products available in the market that can be used in different protocols. In addition, studies should consider performing mechanical tests and examine the failure mode using a scanning electron microscope to analyze the fracture patterns at the interface level.

**Conclusion**

In summary, there were no significant differences between group 1 (bovine teeth treated with an etch-and-rinse protocol with universal adhesive and adhesive resin cement) and group 2 (bovine teeth treated with a self-etching protocol with universal adhesive and resin cement) with respect to adhesion force.

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**Authors’ Contribution**

Daniel Alvitez-Temoche: Study conception, data collection, data collection and analysis, data interpretation, manuscript writing. Roman Mendoza: Data collection, data collection and analysis, data interpretation, manuscript writing. Iván Calderón: Data interpretation, manuscript writing. Doris Salcedo-Moncada: Data collection and analysis, data interpretation. Romel Watanabe: Data interpretation, manuscript writing. Frank Mayta-Tovalino: Data collection and analysis, data interpretation, manuscript writing.

**Data Availability Statement**

All data that support the study results are available from the corresponding author (Dr. Frank Mayta, e-mail: fmayta@cientifica.edu.pe) on request.

**Ethical Aspects**

Because the study was an in vitro experimental study that worked with bovine teeth collected from animals that were slaughtered for human consumption, it was exempted from potential ethical conflicts.

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