Experimental strength of restorations with fibre posts at different stages, with and without using a simulated ligament

Running title: Strength of restorations with fibre posts

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Abstract

The aim of this study was to analyse the strength and failure mode of teeth restored with fibre posts under retention and flexural-compressive loads at different stages of the restoration and to analyse whether including a simulated ligament in the experimental setup has any effect on the strength or the failure mode. Thirty human maxillary central incisors were distributed in three different groups to be restored with simulation of different restoration stages (1: only post, 2: post and core, 3: post-core and crown), using Rebilda fibre posts. The specimens were inserted in resin blocks and loaded by means of a universal testing machine until failure under tension (stage 1) and 50º flexion (stages 2-3). Half the specimens in each group were restored using a simulated ligament between root dentine and resin block and the other half did not use this element. Failure in stage 1 always occurred at the post-dentine interface, with a mean failure load of 191.2 N. Failure in stage 2 was located mainly in the core or coronal dentine (mean failure load of 505.9 N). Failure in stage 3 was observed in the coronal dentine (mean failure load 397.4 N). Failure loads registered were greater than expected masticatory loads. Fracture modes were mostly reparable, thus indicating that this post is clinically valid at the different stages of restoration studied. The inclusion of the simulated ligament in the experimental system did not show a statistically significant effect on the failure load or the failure mode.

Introduction

Endodontically treated teeth are more susceptible to fracture than vital teeth. The main reason for this is the loss of tooth structure because of caries, access cavity preparation and endodontic treatment (1). Posts are often required to restore these teeth and to provide retention and resistance for the core material and to provide coronoradicular stabilization (2). The artificial post connects to the core, which the restored crown is placed over, thereby facilitating the transmission of the dental loads from the coronal structure to the root.

Metal posts, both cast and prefabricated, have been used for the restoration of non-vital teeth for a long time, with a survival rate as high as 90% (3, 4). However, they also present some drawbacks. Metal posts have been associated with root fractures which are irreparable, resulting in the extraction of the tooth (1, 5-9); in a recent study, short metal posts were proposed to achieve a more favourable failure mode (10). Non-precious alloys also present biocompatibility problems (11). Removal of metal posts from the root canal is considered to be very difficult and in some circumstances may result in root fracture (1). And finally, they present aesthetic problems. In anterior teeth, metal posts alter the transmission of light and become visible, especially when all-ceramic restorations are used or when gingival tissue is thin (1, 11).

In recent years, various types of fibre posts have been introduced commercially (12). They have the ability to bond to dentine and the core material (13) and they have a similar elastic modulus to that of dentine (1, 7), leading to a pseudo-isotropic behaviour of the restored teeth materials system. As fibre posts distribute stresses uniformly, they are less likely to cause root fractures, as reported in the literature (7-9, 14-18). More favourable failure modes are reported for restorations with fibre posts than with metal posts (6, 11), debonding of the core being the main failure mode observed (6, 10, 11). Teeth prepared with a ferrule also tend to fail in a more favourable mode (19-21).

Furthermore, removal of fibre posts from the canal is easier than with other post systems (22).

Although there has been an increase in the number of studies published in recent years concerning fibre posts, clinical data are still scarce (1, 11). Some retrospective studies of restorations with fibre posts have reported good clinical success for up to 6 years (23, 24). In particular, very few root fractures have been detected in these clinical findings. Another retrospective study, however, reported 35% of teeth failing and 32% resulting in extraction after a mean of 6.7 years (25).

In vitro studies comparing the fracture strength of teeth restored with fibre posts and other post systems provided contrasting results. Some of them found a higher fracture strength for metallic posts (5-7, 9-11, 13, 26, 27), and others for fibre posts (8, 15, 24, 28-32). Studies from the literature seem only to agree that restorations with fibre posts have a lower fracture strength compared to restorations with cast posts and cores (5, 7, 9, 26, 33) and that a more favourable failure mode is observed with fibre posts (1, 5, 11). The differences in fracture strength found in the literature may be due to the different parameters used to define the experimental setup in each study. Different tooth types are sometimes tested, the risk of failure of the restoration being higher for incisors/canines than for other teeth (34). Post dimensions are not always the same. Different core, crown or cement materials are often used; in a recent work, the cementation technique was seen to have a significant effect on the fracture strength (21). Different materials are also considered for root embedment. Differences in ferrule height (sometimes there is no ferrule) are often observed, which have been found to exert a potentially significant effect on the mode of failure and associated fracture strength (19-21). Different load orientations and application zones are sometimes used, which affect the stress distribution and system deformation, and therefore the mode of failure and associated fracture strength. Sometimes the final crown is not included for the sake of simplification (35). A layer of material simulating the periodontal ligament is used in some works (8, 13, 17), but is missing in others for simplicity or other reasons such as avoiding dislodgment (9, 19, 35-37). Different materials based on rubber (13) or silicone (16, 17, 32, 38) have been used to simulate the ligament, but few studies have analysed the effect of this simulated ligament on the experimental results. Soares et al. (39) found that including an artificial ligament modified the fracture modes, although they were working with bovine specimens. The effect of the periodontal ligament on the experimental results is a very interesting matter, because it may influence the failure mode and the fracture load of the system, thus affecting the validity of the conclusions obtained with *in vitro* tests. Hayashi et al. (5) even claimed to have observed in their preliminary experiments fracture strengths of restored teeth without artificial ligaments approximately twice as great as those with a ligament.

Very few studies in the literature have analysed the differences in strength at different stages of the restoration. This can be interesting because in some cases the crown is missing either temporarily or permanently due to economic or other reasons (40). Cormier et al. (9) studied the strength of premolars at four stages (post, root-post, root-post-core, root-post-core-crown), with a loading angle of 90º with respect to the tooth axis, which simulated a hypothetical accident. In a previous work (41) the authors compared the strength of maxillary incisors restored with glass fibre posts with and without a crown, without a simulated ligament, and under a load at 30º to the radicular axis in the vestibular direction, and no significant differences in the fracture load were observed. The use of a different type of tooth and loading direction made it difficult to establish a comparison between fracture load and fracture modes in the two studies.

The aim of this study was to analyse the strength and failure mode of maxillary incisors restored with fibre posts under retention and flexural-compressive loads and to analyse whether including a simulated ligament in the experimental setup (or not) affects the strength or the failure mode. The study considered three different stages of the dental restoration. The first stage was the restoration without the core and crown; retention was tested at this stage. The second stage corresponded to the restoration without the final crown; flexural strength was tested at this stage. And the third stage involved the final restoration; flexural strength was tested at this final stage. Half the specimens at each stage used a simulated ligament and this element was omitted in the other half.

Materials and methods

Endodontic restoration

Thirty sound human maxillary central incisors, with straight roots, extracted for periodontal reasons, were selected for the study. Dental plaque, calculus and periodontal tissues were removed. Patients were informed that their extracted teeth were to be used for experimental purposes and written informed consent was subsequently obtained. After extraction, the teeth were preserved in humidity saturation conditions until they were used in order to prevent loss of moisture from the root structure. Endodontic therapy was completed for the teeth by the same operator. They were decoronated so as to leave only the root. The coronal and medial root canal regions were prepared using Gates Glidden drills (Mani Inc, Tachigi-ken, Japan), sizes 1–3. The step-back technique was used for the rest of the canal, with #30 K-type files (Dentsply-Maillefer, York, PA, USA). The specimens were obturated with gutta-percha using the lateral condensation technique and AH Plus sealer (Dentsply-Maillefer, York, PA, USA). Subsequently, the specimens were sectioned 3 mm above the cement-enamel junction (CEJ). Endodontic restoration was undertaken on the teeth with the Rebilda post system (VOCO GmbH, Cuxhaven, Germany), which is a glass fibre reinforced composite post, following the manufacturer's instructions. This post was selected because it is commonly used in clinical practice and its elastic modulus is similar to that of dentine and it has a high flexural strength. All posts used in restorations had the same diameter (1.5 mm).

The specimens were randomly distributed in three groups of ten specimens, corresponding to three different stages of endodontic restoration (Figure 1): only post (stage 1), post and core (stage 2) and post, core and crown (stage 3). After restoration, the teeth were inserted in acrylic resin blocks (Vertex Self-Curing Liquid, Zeist, The Netherlands), which performed the function of the supporting bone. The root was embedded in resin to a level 3 mm below the sectioned surface. For half the specimens in each group, a simulated ligament was used between the root and the resin block, while the other half were inserted directly in the resin without any simulated ligament. This resulted in six different experimental groups of five specimens each: three groups with a simulated ligament (groups 1-L, 2-L and 3-L) and three groups without a ligament (groups 1-N, 2-N and 3-N).

Both post luting and core build-up were performed with the same composite-based, dual-curing and flowable adhesive, namely, Rebilda DC (VOCO GmbH, Cuxhaven, Germany). Futurabond DC adhesive (VOCO GmbH, Cuxhaven, Germany) was applied on the root canal for 20 seconds. A thin layer of the luting cement was then applied over the post surface and the post was inserted with a rotating movement, producing a slight excess of cement. The excess of luting material was removed from the specimens restored at stage 1. In specimens from stages 2 and 3, a standard core was prepared using Rebilda DC and it was photopolymerized for 40 seconds. Twenty-four hours later, the core was finished with a high-speed diamond bur. In specimens from stage 3, the restoration was completed with a crown. The crown material was IPS Empress® (Ivoclar Vivadent AG, Schaan, Liechtenstein), which is a leucite-reinforced glass-ceramic. Root preparation design of a standard all-ceramic crown was followed. Cementation of the crowns was performed between 45 and 60 days after finishing the core, using Dual cement (Ivoclar Vivadent AG, Schaan, Liechtenstein). Photopolymerization lasted 40 seconds. Prior to cementation, the teeth were kept moist by storing them in physiological saline solution at room temperature.

The radicular post length was adjusted to maintain 5 mm of apical seal with gutta-percha, following widespread recommendations (2, 42). The length of post outside the dentine finish line was 5 mm for the stage 1 specimens and 2 mm for stages 2 and 3 (see Figure 1). A ferrule preparation with a height of 1.5 mm was made in the coronal aspect of the root for stages 2 and 3.

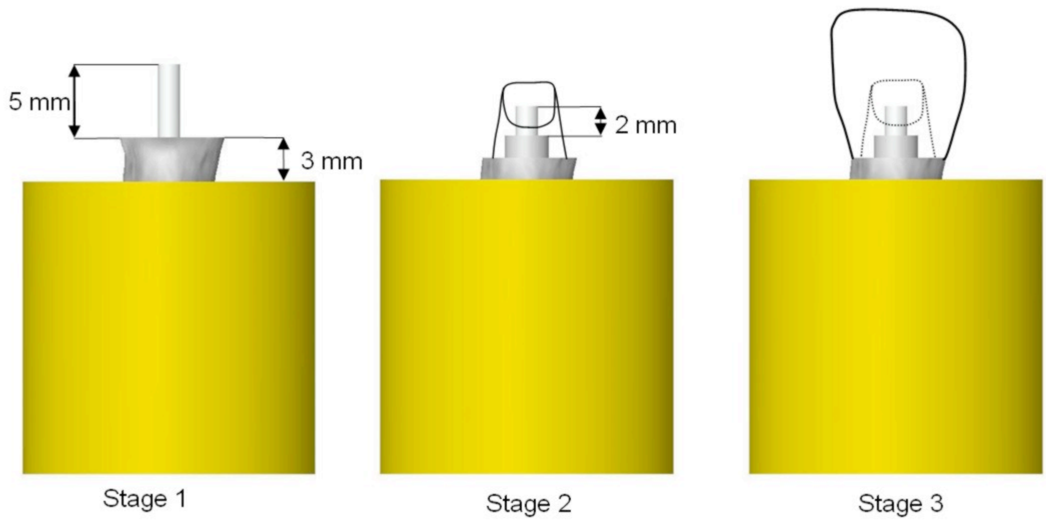

Figure 1. The three stages of restoration

In specimens with a simulated ligament (groups 1-L, 2-L and 3-L), the root was painted using a brush with a layer of Visco-gel (DENTSPLY DeTrey GmbH, Konstanz, Germany), prior to being embedded in the resin block. Visco-gel is a tissue conditioner and temporary soft denture liner based on polyethyl methacrylate. A layer with a thickness close to 0.2 mm and a Young modulus near 1.5 MPa, similar to that of a periodontal ligament (43-45), was obtained with this procedure, as observed in some preliminary tests that were performed.

Testing procedure

The specimens were subjected to static testing using a universal testing machine (ELIB-30/W, Ibertest, Madrid, Spain). The testing procedure was different for specimens at each restoration stage.

Specimens in stage 1 (groups 1-L, 1-N) were tested under a tension load. Resin blocks with the specimens were mounted in a cylindrical bronze mould which was fixed to the test rig. The post was held in the jaws of the machine by means of two aluminium plates with a groove along the inside that were clamped against the post with the aid of connecting bolts. Dislodgement of the specimen from the mould during the test was prevented with additional plates (Figure 2). Applied force and measured displacement were registered during the test. The load was applied at a rate of 5 mm/min, until the specimen failed. Failure was achieved when a sharp reduction in the registered force was observed. The highest force registered by the machine was considered to be the maximal retention load.

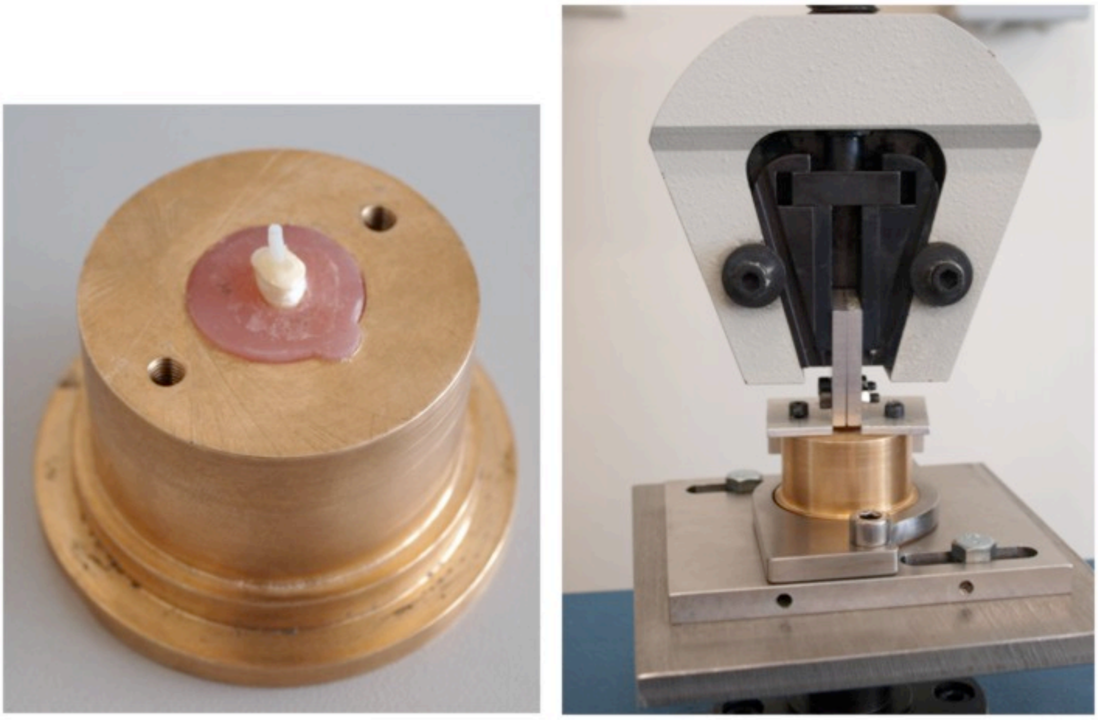

Figure 2. Experimental setup for stage 1

Specimens in stages 2 and 3 were tested under a flexural-compressive load. Specimens were mounted in an inclined bronze mould (Figure 3), so that the tooth was loaded on the palatal side with a force at 50º to the radicular axis in the vestibular direction, thereby simulating the real direction of loads during occlusion type I (35, 46-48). The force was applied on the palatal side on the core or the crown, according to the stage of restoration, at a controlled speed of 5 mm/min, until fracture of the tooth. The distance from the resin surface to the loading point along the root axis direction was maintained for all the specimens in the same stage and was greater for stage 3 (9 mm) than for stage 2 (7.5 mm). Failure was detected by a sharp reduction in the registered force. For all the tests, the applied load and the measured displacement of the loading point were registered. The highest force registered by the machine was considered to be the fracture load.

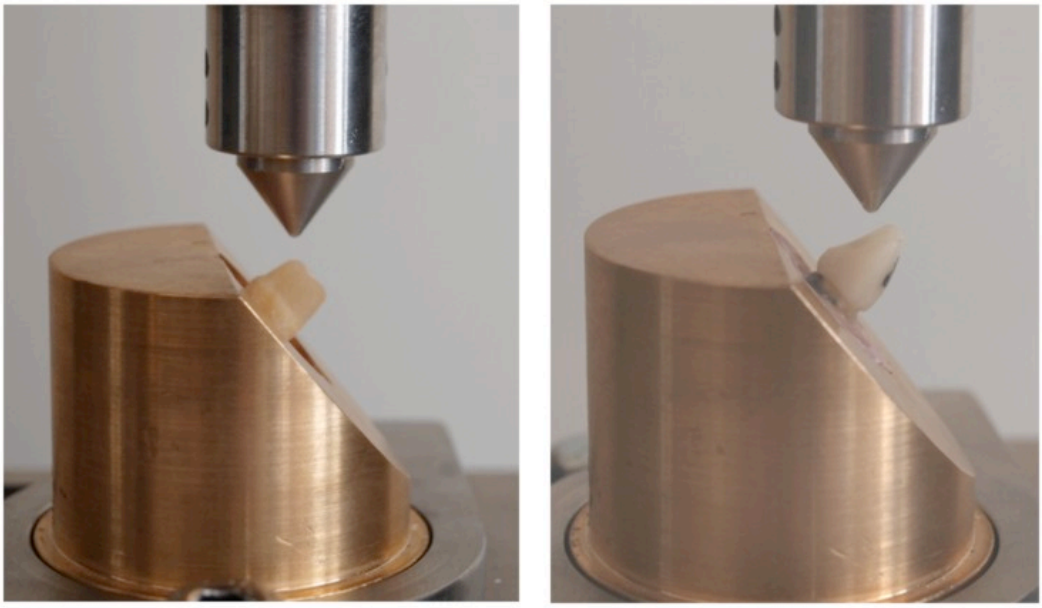

Figure 3. Experimental setup for stages 2 and 3

Results analysis

The analysis of the results was performed using the SPSS statistical software version 18 (SPSS Inc, Chicago, IL, USA). Different analyses of variance (ANOVA) were carried out using the *failure load* as the dependent variable, in order to analyse the significance of the factors *restoration stage* and *simulation of the ligament*. To ensure that differences in teeth dimensions were not affecting the results, an analysis of covariance (ANCOVA) was previously performed using the *root length* and *mean cervical dimension* (average between mesiodistal and buccolingual dimensions) as covariates and the failure load as the dependent variable. A significance level of 5% was used in all the tests ($\alpha = 0.05$).

Results

The mesiodistal cervical dimension of the restored teeth used in the experiment ranged from 4.5 to 7 mm, whereas the buccolingual cervical dimension ranged from 6.0 to 9.0 mm. Root length ranged from 10.5 to 17.5 mm. Results of the ANCOVA performed using the failure load as the dependent variable and the mean cervical dimension and root length as covariates did not reveal any significant effect of the dimensions of the restored teeth used in the experiment on the failure load ($P = 0.367$ for mean cervical dimension, and $P = 0.354$ for root length).

Mean failure load was calculated for all groups and restoration stages (Table 1). The highest failure load was observed for group 2-L, corresponding to stage 2 with a simulated ligament. The boxplots of the results are shown in Figure 4 (tension load, stage 1) and Figure 5 (flexural-compressive load, stages 2 and 3).

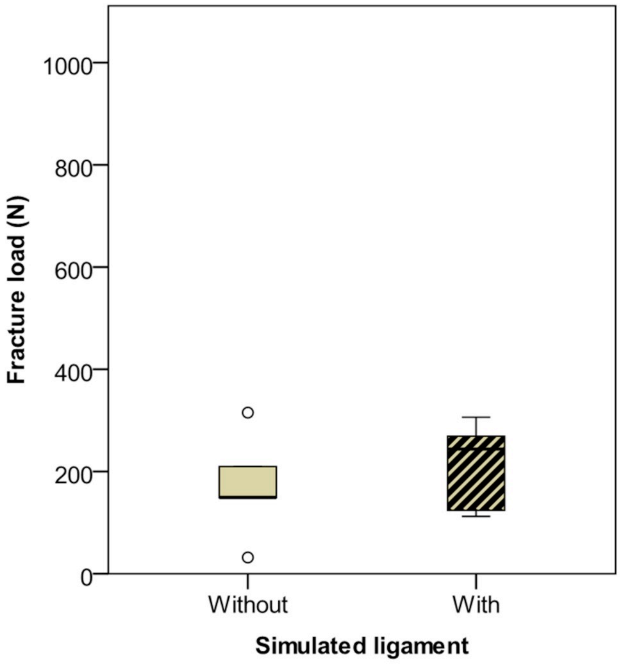

Figure 4. Fracture load for stage 1 with and without using a simulated ligament

Table 1. Mean failure loads for each group

Group	n	Mean (N)	SD (N)
1-L	5	211.2	87.9
1-N	5	171.1	103.2
2-L	5	647.5	114.1
2-N	5	364.4	276.2
3-L	5	440.8	307.2
3-N	5	354.0	163.1

Stage	n	Mean (N)	SD (N)
1	10	191.2	92.8
2	10	505.9	248.9
3	10	397.4	236.4

The results of the one-way ANOVA on failure load (maximal retention load) at stage 1 (groups 1-L and 1-N) are shown in Table 2. Including the simulated ligament in the retention test was not found to have any significant effect on the failure load (see also Figure 4). Failure of all specimens at stage 1 finished with the dislodgement of the post, the most typical situation being the loss of adhesion between cement and post (four specimens). From observation of the fractures, it was not possible to establish different patterns in the failure for the specimens with or without the simulated ligament.

Table 2. One-way ANOVA on failure load for stage 1 (groups 1-L and 1-N)

Source	Sum of squares	df	Mean square	F	P>F
Between groups	4015.214	1	4015.214	.437	.527
Within groups	73506.221	8	9188.278		
Total	77521.435	9			

Table 3 shows the results of the ANOVA on failure load (flexural-compressive fracture load) at stages 2 and 3 (groups 2-L, 2-N, 3-L, 3-N). Neither the stage of restoration nor the use or non-use of the simulated ligament were found to have a statistically significant effect on the failure load, although the variance associated to ligament was higher than that of stage. Figure 6 shows the failure modes observed in groups for stages 2 and 3, represented by lines indicating a cohesive failure in core (A), dentine (B) or crown (D, E) or an adhesive failure in the core-dentine or crown-dentine interfaces (C). The most frequent failure for stage 2 was the fracture of the core (A), which was present in all specimens with a simulated ligament (group 2-L) and in two of the specimens without the ligament (group 2-N). Fracture at the coronal third of the root (B) was observed for three specimens in each group. When the ligament was not used, an adhesive failure between core and dentine (C) tended to appear, which was not present in group 2-L and may suggest some effect of the ligament in the failure mode for this stage. Some effect is also apparent when comparing the fracture load of the specimens with and without a simulated ligament for this stage (Figure 5). For stage 3, the typical failure pattern displayed a loss of adhesion between core-crown and dentine (C) and a fracture at the coronal third of the root (B), which was present in all but one of the specimens for each group. Fracture of the crown (D, E) was observed for two specimens in each group at this stage. Thus, including the simulated ligament or not did not affect the failure mode at this stage (see also Figure 5). Most of the failures for stages 2 and 3 were considered to be reparable. Non-reparable failures presented a fracture line B in figure 6 affecting partially the root below the resin level.

Table 3. ANOVA on failure load for stages 2 and 3 (groups 2-L, 2-N, 3-L, 3-N)

Source	Sum of squares	df	Mean square	F	P>F
Corrected model	278121.609[a]	3	92707.203	1.763	.195
Intercept	4080016.411	1	4080016.411	77.591	.000
Stage	58936.139	1	58936.139	1.121	.305
Ligament	171023.265	1	171023.265	3.252	.090
Stage*Ligament	48162.205	1	48162.205	.916	.353
Error	841341.848	16	52583.866		
Total	5199479.869	20			
Corrected total	1119463.457	19			

a. R^2 = 0.248 (corrected R^2 = 0.108)

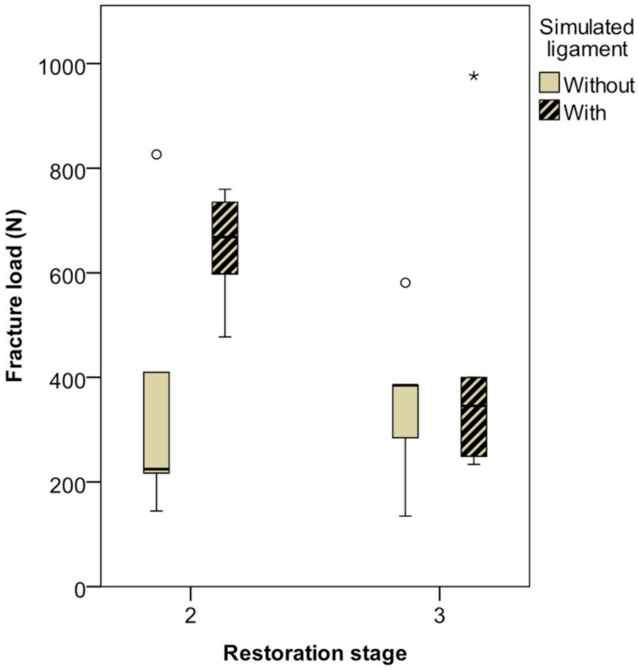

Figure 5. Fracture load for stages 2 and 3 with and without a simulated ligament

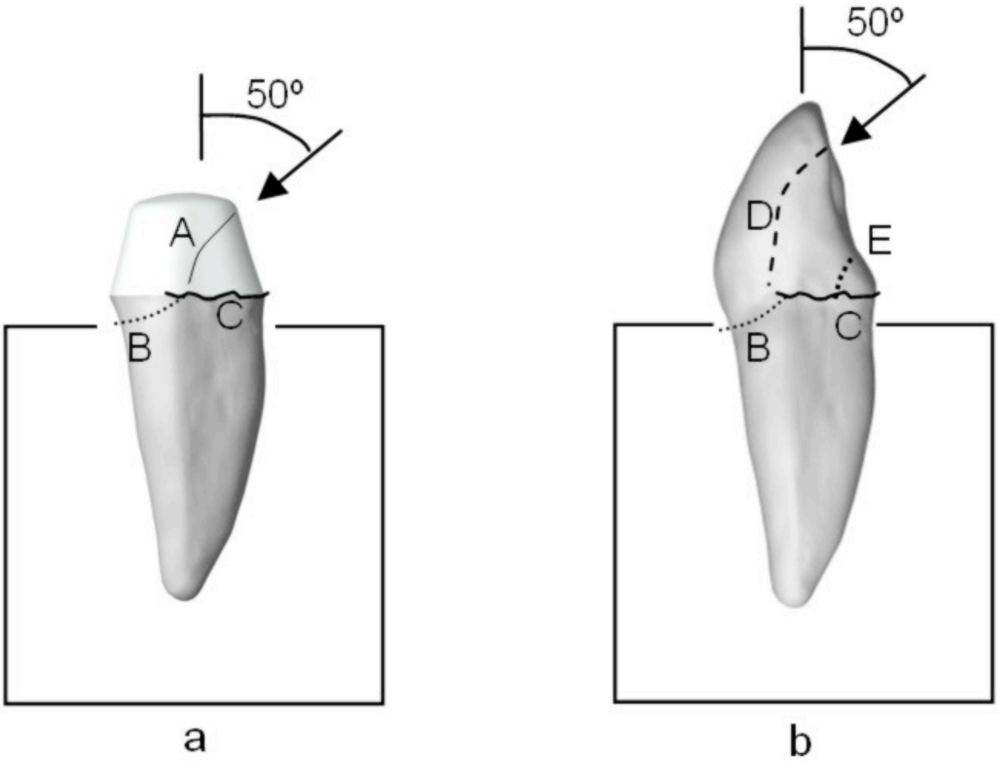

Figure 6. Failure lines in stages 2 (a) and 3 (b)

Discussion
Two main effects were analysed in this *in vitro* study on endodontic restorations of incisors: one was the differences in strength of the system at three sequential stages of

its restoration, while the other was the effect of including a simulated ligament between the root and the embedding resin in the experimental setup.

In the present study, the load was applied at each stage of the restoration to obtain clinically significant information. Mean failure loads obtained for the restoration at the three stages are considered clinically admissible, as compared with normal oral loads (49). A decrease in flexural strength from stage 2 (post-core) to 3 (post-core-crown) was observed in the results. Although some reinforcement of the whole restoration could be expected from adding the crown, it is not confirmed by the results. Analyses of failure modes suggest that this behaviour can be explained by the greater distance from the load to the cervical area (7.5 mm from load to resin in stage 2 and 9 mm in stage 3). This difference increased the flexion applied over the bonding interface between dentine and core-crown, leading to a premature failure at this interface in stage 3 (C in Figure 6) and finally to fracture of dentine (B in Figure 6).

Very few studies in the literature have analysed the differential strength of the restoration at different stages. Cormier et al. (9) studied the strength of the system at four stages but used a loading angle of 90º with respect to the tooth axis and they employed premolars. The differences in the experimental design (tooth type and loading angle) limit the comparability of results with those from our work. In the work by Cormier et al. an increase in fracture load was observed when the crown was added to the root-post-core system, whereas in our work a decrease was observed for the same situation. This difference can easily be explained taking into account the fact that in the work by Cormier et al. the load was applied in both stages at the same distance to the CEJ, whereas in our work the loading point was nearer to the CEJ in stage 2 than in stage 3.

In a previous work (41) the authors compared the strength of maxillary incisors restored with glass fibre posts with and without a crown, without a simulated ligament, but under a load at 30º to the radicular axis in the vestibular direction, instead of 50º. This difference in the load direction has been found to have an important effect on the results. Greater mean strengths were recorded for the load of 30º (737.61 N for teeth restored without the crown and 731.42 N for teeth restored with the crown). This difference is attributed to the lower flexion effect of this load direction, which is corroborated by the typical cohesive failure mode observed that corresponded to a primarily compressive failure. In that case, no significant effect of the crown on the fracture load was observed, which is in agreement with the result for 50º obtained in the present work.

Failure loads obtained in the present work for restoration stage 1 are in the range of previous comparable studies. Braga et al. (50) studied the removal resistance of posts with different root insertion lengths in an experiment on maxillary premolars comparable to our stage 1 and found values between 257 and 357 N for glass-fibre posts, which are slightly higher than the values obtained in the present study for groups 1-N and 1-L (171-211 N). As in the present study, an adhesive failure was seen to be the predominant pattern. This failure was also observed by Gallo et al. with composite fibre posts and resin cement (51).

Failure under flexural loads in stages 2 and 3 of our study can be compared to some previous experiments in the literature performed with the same load orientation. Al-

Omiri and Al-Wahadni (35) found strength values between 381 and 574 N for teeth restored with glass-fibre posts and core, without a crown, these values being similar to those obtained in the present study for groups 2-N and 2-L (364-647 N). Akkayan and Gulmez (8) tested the fracture load of teeth restored using glass-fibre posts with core and metal crowns, incorporating a simulated ligament, and in a posterior work Akkayan (17) tested the effect of variation of the ferrule height on the fracture load. Fracture loads reported in both works were in the range of 75-99 kg. These loads are higher than the results obtained in the present work for group 3-L, although these studies were performed using maxillary canines instead of incisors and teeth were restored with a metallic crown, which may explain the disagreement. Furthermore, differences in the exact location of the loading point could have had an important effect, as explained above, as well as the differences in the material used to simulate the ligament. The prevalent failure mode observed in the present study for stage 3 is similar to that observed by Akkayan (17) in some of the specimens in his work, especially predominant for higher values of ferrule length. However in those previous works (8, 17) some glass fibre specimens ended up with root fracture in the middle of the root, a failure mode that was not observed in our work. In a similar experiment using composite carbon fibre posts, Raygot et al. (36) found that most of the specimens failed with a similar pattern to that observed in our work, with adhesive failure in the crown margin and fracture above the resin.

Very few previous studies have analysed the effect of using a simulated ligament in the experimental protocol for static testing of post-endodontic restorations. Soares et al. (39) tested extracted bovine specimens without endodontic restoration, which were subjected to static flexural tests. They reported different failure modes in specimens with a simulated ligament from those in specimens embedded directly in resin blocks. Furthermore, in that work, a more variable failure pattern was observed when using the simulated ligament, together with a tendency to an increased appearance of fracture modes affecting more apical root portions. This observation is not confirmed in our work, where a similar pattern was observed in the failure mode of restored specimens for groups 3-L and 3-N (Figure 6b). However, the differences in the material used to simulate the ligament and especially in the characteristics of the specimen may explain this disagreement. Soares et al. found a different effect of including the simulated ligament depending on the type of resin used for embedment. For acrylic resin, as used in our work, they found a greater fracture load for specimens without a ligament, while the opposite was observed for polystyrene resin. In our results the mean fracture load was greater in all stages for groups using a simulated ligament than for the groups with direct embedding of the tooth in the resin block (Table 1), but this difference was found not to be statistically significant. Nevertheless, the variance associated to this effect was greater than that of the stage and close to significance ($P = 0.09$). Moreover, the results of our study show that the difference in failure loads between stages 2 and 3 of the restoration process became smaller when the simulated ligament was left out of the experimental setup (see Figure 5). In the authors' opinion more experiments and with a greater number of specimens are needed to obtained definitive conclusions about the effect of the simulated ligament.

Although the present study is based on *in vitro* experiments, some clinical implications can be drawn from it. Biting loads on incisors have been reported to be close to 140-

200 N (49). From the results of the present *in vitro* study it can be seen that endodontic restoration with the Rebilda post system is able to withstand normal oral loads in tension and flexural-compressive directions, even in the case of partial restorations without the final crown. The results also showed failure modes that were in most cases reparable with this post system, and which only affected the coronal dentine or portions of the root near the cervical area. Moreover, the results of the present work about the effect of the simulated ligament suggest that additional work is needed to further our knowledge of this matter in order to improve the way oral conditions are currently represented in *in vitro* experiments of teeth with post-endodontic restorations.

Conclusion

Within the limitations of this study, the use of Rebilda fibre posts was found to provide endodontic restorations capable of withstanding expected masticatory loads, even in the case of partial restorations without the final crown.

The inclusion of the simulated ligament in the experimental system did not appear to have a statistically significant effect on the failure load or the failure mode. However, the variance associated to this factor was high and close to significance. In the authors' opinion more experiments with a greater number of specimens are needed to reach definitive conclusions about the effect of the simulated ligament.

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