Cement layer thickness and shear stress resistance in cylindrical dowel spaces: pull-out test

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SUMMARY

Purpose. This study evaluated the effects of different dowel space (DS) diameters on pull-out bond strength of a cylindrical post, of threaded steel, to dentin.
Materials and methods. Forty-five extracted human teeth were divided in 3 groups with DSs, with the same depth (6 mm), differing for the diameter (i.e. 1.5 mm, Group 1; 1.75 mm, Group 2; 2.00 mm, Group 3). Both the diameter of the post (1.3 mm) and the composite resin cement (Panavia 21) were the same for all the samples. The samples were submitted to pull-out test by means an Universal Testing Machine (Mod. 1193, Instron) (1KN load cell, crosshead speed 0.5 mm/min).
Results. The mean values of the bond strength (BS) were: Group 1, 442±128.3N; Group 2, 411.3±111N; Group 3, 448.7±142.29N. While the calculated average shear bond strengths (SBSs) were: Group 1, 14.7±4.27MPa; Group 2, 11.6±3.14MPa; Group 3, 11±3.5MPa. ANOVA test showed not significative differences, among the groups, concerning the BS: Group 1 *vs* Group 2 ($p = 0.490$); Group 1 *vs* Group 3 ($p = 0.894$); Group 2 *vs* Group 3 ($p = 0.431$). Significative differences were observed, among the groups, concerning the SBS for Group 1 *vs* Group 2 ($p = 0.032$) and Group 1 *vs* Group 3 ($p = 0.014$). While a not significative difference was found, concerning this parameter, for Group 2 *vs* Group 3 ($p = 0.641$).
Conclusion. The cement thickness can influence the SBS of the adhesively luted posts, in our setting, the best values were obtained with a thickness of 100 μm.

Key words: endodontic posts, endodontically treated teeth, composite resin cement, dowel space, pull-out test, cement thickness, different cement thicknesses.

Introduction

The improving socio-economic conditions, the lengthening of life in most industrialized countries and the growing attention to the maintenance of teeth has led to an increase in endodontic treatments.
The current needs of patients require aesthetic and durable solutions in consideration of fundamental role played by post endodontic reconstruction in the success of the treatment plan (1).
For many years it was believed that the main weakness of the endodontically treated tooth was due to dentine dehydration (2). On the contrary other Authors found that this event does not involve significant changes in the mechanical properties of this latter (3).
Many Authors agree that the main factor responsible for the strength loss in devitalized teeth is the amount of lost tooth substance (4, 5). In endodontically treated teeth (ETT) the missing tooth substance will be reconstructed by means of a restoration. In order to increase the retention

of the restoration it is often indicated the use of a root post (1, 4).
Therefore an incorrect choice, of radicular anchoring systems, may involve not only the failure of the reconstructive therapy, for detachment of the post, but also serious damage to the tooth itself.
In recent decades we have seen a progressive evolution of both the anchoring systems (fiber posts) and their adhesive cementation. Currently a wide range of composite and adhesive systems is available in order to achieve great success in the coronal reconstructions of ETT (1, 4).
The composite cements are those mainly used for the cementation of the post into the root canal, after it has been suitably flared by means of calibrated drills (5).
Some Authors have shown that the cementation of posts, by means of composite cements, leads to an increase of the retention of the post, an increase in fracture resistance and a reduction in microleakage compared to traditional cement systems (6).
The more common cause of failure in reconstructed ETT is the detachment of the cement-post-restoration complex, due to debonding between fiber post and resin cement and/or between the cement at the interface with the dentine of the root canal due to inadequate bonding forces (7).
The bond strength between post, cement and interface with the root canal dentin is affected by many factors, including the agents used for the conditioning of the root, the type of post used, the different anatomy and the different density and orientation of the dentinal tubules in the different zones of the root canal (8-10).
A fundamental role in the resistance to detachment of the post is dependent by the film thickness of the composite cement; it has been seen that with very large cement thicknesses the resistance to post detachment significantly decreased (10).
Although there are some studies which state that the resin cements are able to provide an adequate bond strength even with larger dowel spaces (DSs) and thus with an increased cement thickness (CT) (11).
The aim of this work is to analyze the relationship between the pull-out bond strength of the post and the CT.

Materials and methods

Forty-five caries-free human teeth were extracted, in a span of 2 weeks, since periodontally involved. Each tooth, immediately after the extraction, was deprived of any residual of plaque, blood and tartar then immersed in a 5% hypochlorite solution for 5 min, for a first disinfection and finally stored in a saline solution, until the time of the experiment.
Once reached the desired number of teeth, all the samples were immobilized, in a perpendicular position, with their apical root portion, within self-curing polyester resin base. Then in each tooth the crown was cutted, perpendicular to its long axis, at the level of the pulp chamber floor, by means a diamond disk, to obtain the coronal portion of the root.
Subsequently for each root with a single canal, the DS was prepared while, in the case of teeth with a root having 2 or more canals or teeth having 2 or more roots, the canal with the most possible parallel path to the long axis of the tooth was selected for DS preparation.

Dowel Space Preparation

In each tooth the DS was prepared with cylindrical burs to a depth of 6 mm. The burs, running at 2000 rpm under profuse watery cooling, were mounted on a dental milling machine with parallelometer (Cruise 440, Silfradent, Santa Sofia - FO, Italy). Three different groups of DSs were created differing for the diameter (i.e.1.5, 1.75, 2.00 mm) (Figure 1 d-f). Each group was constituted of 15 samples.
Each root canal was then further flushed from the bottom of his DS with water by means a disposable 5 ml siringe equipped with 21G needle

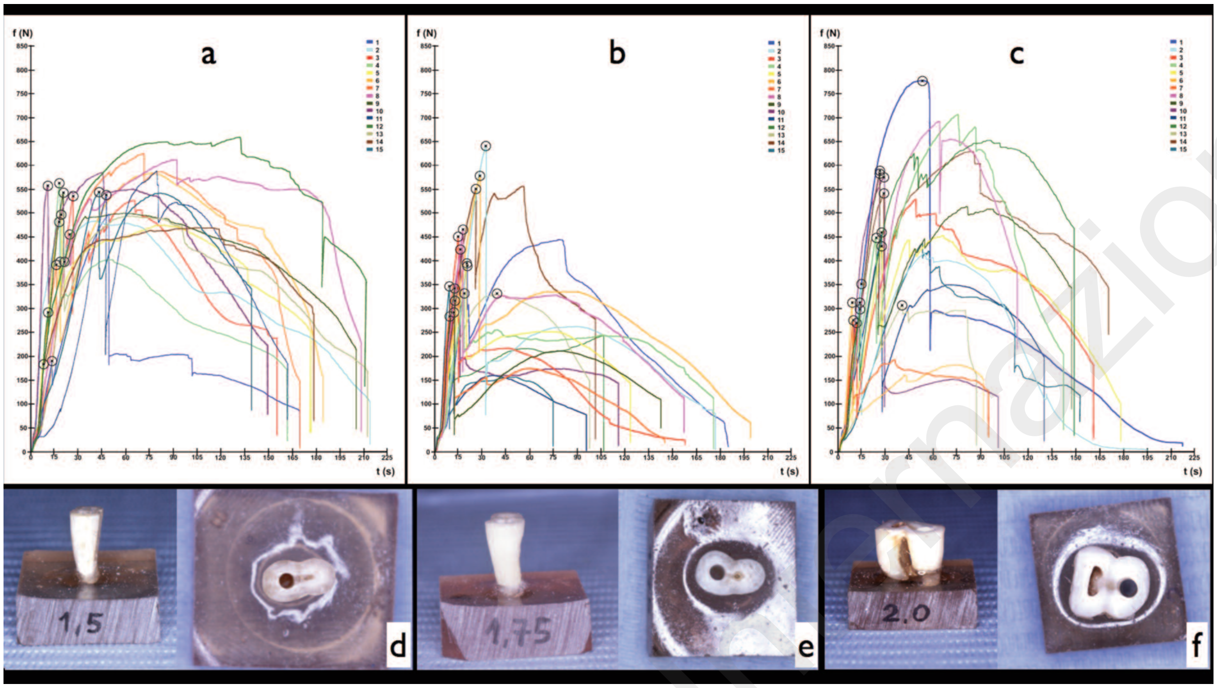

Figure 1
a-c) Graphics describing the trend of tensile force as a function of the time (a = Group 1, b = Group 2, c = Group 3). The failure of the adhesive bond failure is indicated by circled crosses; d) Group 1, dowel space (DS) 1.5 mm, cement thickness (CT) 100 µm; e) Group 2, DS 1.75 mm, CT 225 µm; f) Group 3, DS 2 mm, CT 350 µm;

and blown with compressed air so that the dental debris were totally removed.
At the end of this procedure all the samples were deprived of their polyester resin base, that has been replaced with a new self-curing acrylic resin base (Formatray, Kerr, Orange, US). The new base was shaped so as to allow a suitable grip of the sample inside the pulling test machine. In order to ensure the sample maintain its axial position during the new resin base creation, each root was kept with the last drill used for the DS preparation in place, and verified with the parallelometer.

Post preparation

Our objective was to measure the tensile strength of the adhesive interface between cement and dentin. For the pull-out test a threaded metal post has been chosen, for different reasons: its high tensile strength; its strong chemical bond with the adhesive cements; its shape which ensures a high macro-mechanical adhesion with the luting material.
Cylindrical steel screws (10.9 UNI EN 20898/1) (diameter 1.3 mm, pitch 0.3 mm) were selected as post. In order to allow the proper grip in the pulling test machine the head, of each screw, was covered with a cylindrical casting brass, obtained by means of the lost-wax technique. Then the screws surface were sand blasted with aluminum oxide (average granulometry 50µ, pressure 100PSI), and cleaned with acetone.

Post cementation

An adhesive self-curing resin cement was selected (Panavia 21 OP, Kuraray Noritake Dental Inc., Tokio, Japan) for the experiment. The procedures used for surface preparation, cement mixing and post seating were all performed according to the manufacturer's instructions. In addition, for our purposes, the axial placement of the post was parallelometer-assisted. Then, after the post cementation, the samples were left unaltered for 24h (Figure 2 a). This way 3 groups of samples were created: Group 1 with DS 1,5 mm wide and a CT of 100 μm; Group 2 with DS 1,75 mm wide and a CT of 225 μm; Group 3 with DS 2 mm wide and a CT of 350 μm.

Pull-out test

All the samples were submitted to the pull-out test by means a Universal Testing Machine (UTM) (Mod. 1193, Instron, Norwood, US) equipped with a 1000N load cell. During the test the crosshead speed was 0.5 mm/min while the recording speed was 20 mm/min (i.e. the speed with which the behavior of the sample, during pulling test, was recorded) (Figure 2 b). On each graph, representing the trend of the force as a function of time, the peak, corresponding to the bond strength (BS), was identified (Figure 1 a-c). Then both the force average values and the relative standard deviations were calculated for each group. Considering that, during the pull-out test, the force is exerted on the sliding adhesive interface both the surface, of the adhesive interfaces of the three groups, and the consequent shear bond stress (SBS) mean value were calculated and expressed as N/mm^2(MPa).

Statistical analysis

The data were statistically compared, within the groups, by means of analysis of variance (ANOVA), carried out with a confidence level of 95% ($\alpha = 0.05$) (Primer Biostatistics Ver. 4.02i; McGraw-Hill Comp., US).

Figure 2
a) A sample of the Group 3 prior to the mechanical test; b) a sample during the pull-out test; c) representative samples, of the three groups, after the test; d) all the samples of the three groups after the test.

Microscopic analysis

The samples after the pull-out test were observed at different magnification (16X, 32X, 56X), with a stereomicroscope (MBC-10, Lomo, St. Petersburg, Russia) equipped with a digital camera (D70, Nikon Corp., Tokyo, Japan).

Results

Mechanical test

The resulting graphs show, even if the values involved are different among the groups, a similar trend of the force as a function of time: the curve, which represents the tensile mechanical behavior of the post-cement-root system, is generally constituted by an initial ascending segment, in which the adhesive interface is stressed but does not undergo a decrease of the adhesive bond. This segment is followed by a peak, which indicates the BS, then followed by a bottom concavity curve, which represents the intimate sliding of the interfaces (Figure 1 a-c). This latter is generated by the forced extrusion of the post. The sliding of the interfaces sometimes offers a resistance that can even exceed the maximum peak value, due to the friction. It is possible to observe that in the samples of both Group 1 and Group 3, and even if in Group 1 this phenomenon lasts longer (Figure 1 a, c).

The average BSs and relative standard deviation, in the three groups of samples, are described in Table 1.

The average shear BSs and relative standard deviation, in the three groups of samples are described in Table 2.

No significative differences, among the groups, were observed concerning the BS: Group 1 *vs* Group 2 ($p = 0.490$); Group 1 *vs* Group 3 ($p = 0.894$); Group 2 *vs* Group 3 ($p = 0.431$).

Significative differences were observed, among the groups, concerning the SBS for Group 1 *vs* Group 2 ($p = 0.032$) and Group 1 *vs* Group 3 ($p = 0.014$). While a not significative difference was found, concerning this parameter, for Group 2 *vs* Group 3 ($p = 0.641$).

Microscopic analysis

The microscopic observation of the samples, after the test, has highlighted the presence of cohesive fractures at various levels of the cement joint (Figure 3 a-c). In the posts of the Group 1, in which the CT was 100 µm, the fracture lines are more numerous and run predominantly orthogonally to the long axis of the post and seem to coincide with the apex of the threads (Figure 3 a). While in the samples, pertaining to the Groups 2 and 3, which had a higher CT, respectively of 225 and 350 µm, the fracture lines do not seem to coincide with the trend of the thread, their direction is often oblique and does not keep a specific pattern (Figure 3 b, c).

In the dowel spaces, pertaining to the Group 1, has been possible to highlight the presence of small fragments of cement, still adherent on the dentin surface (Figure 3 d). Yet, longitudinally to the cement joints, some areas of foamy-chalky appearance, were observed, in particular in case of samples pertaining to the Group 1 (Figure 3 e). On the contrary, in the samples of both Group 2 and 3 the smoothness of the surface was the most frequent finding (Figure 3 b, c).

Table 1 - The average bond strength and relative standard deviation, in the three groups of samples.

	Group 1	Group 2	Group 3
Mean (N)	442	411.3	448.7
St. Dev.	128.3	111	142.9

Table 2 - The average shear bond strength and relative standard deviation, in the three groups of samples.

	Group 1	Group 2	Group 3
Mean (MPa)	14.7	11.6	11
St. Dev.	4.27	3.14	3.5

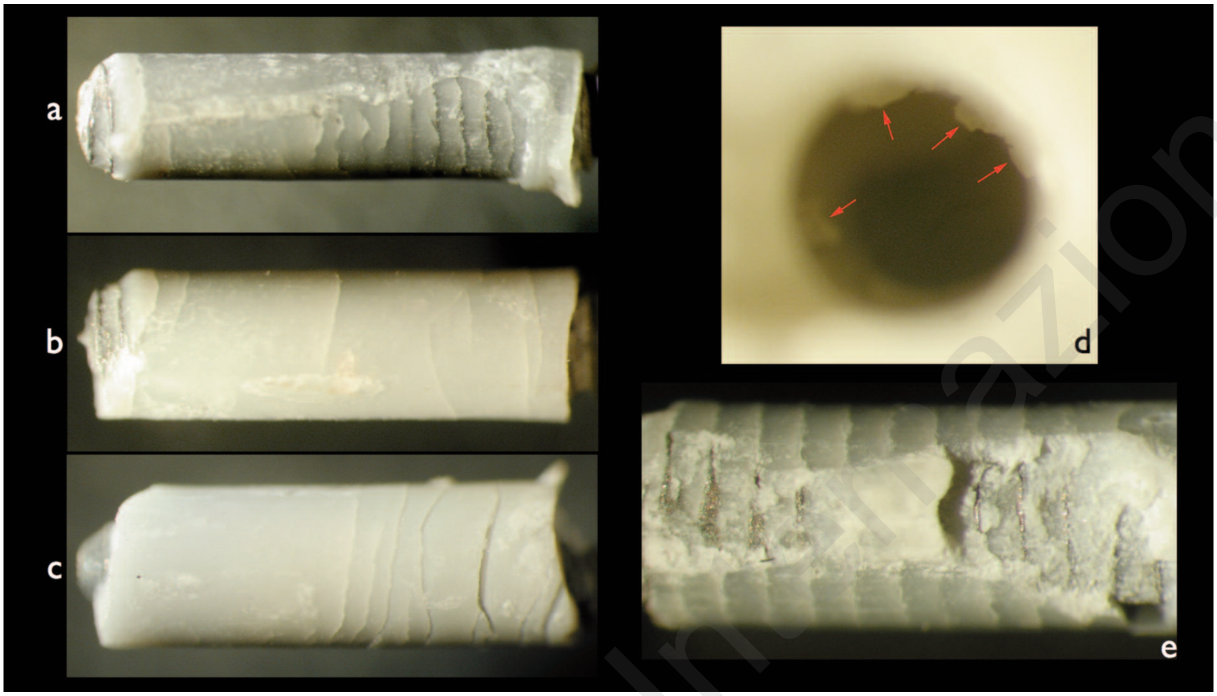

Figure 3
a-c) Side vision, representative samples of the three groups, the cohesive fracture of the cement joints was observed in all groups but exhibiting a typical pattern in Group 1 only (original magnification 16X); d) in the dowel spaces, pertaining to the Group 1, has been possible to highlight the presence of small fragments of cement (arrows), still adherent on the dentin surface (original magnification 32X); e) area of foamy-chalky appearance. These are more frequent in Group 1, it is likely that their genesis can be attributed to residues of adhesive not completely removed (original magnification 56X).

Discussion

In the last decades the techniques and the materials used for restoring ETT, have both changed and improved considerably, in particular with the introduction of fiber posts combined with the use of composite resin cements (12). This is relevant since sometime lost teeth can be cause of legal quarrel (13, 14).
Although there are numerous studies analyzing the variables that can affect the longevity of the restoration of the ETT, there are only few studies considering the influence of the cement thickness for the post retention. In the past this has been improperly analyzed because the retention was assessed only as the tensile force (i.e. BS) required to remove the post from its housing (6, 15). More recently it has been better understood, by the researchers, that the force exerted during the removal of the post is applied on the interface of adhesion and consequently is more correct to analyze the phenomenon quantifying the SBS. Some Authors have focused the research on this aspect but the results are contradictory, although it is clear that the cement thickness influences the SBS, in particular in the push-out tests, generally used to evaluate differences in the SBS at various levels of the root (16-18). In the past some Authors evaluated the behavior during tensile stress test of composite cement joints, with different thickness, strongly adhering to the substrate. Although it had been analyzed the tensile stress rather than shear stress, they observed that thinner joints may be considerably stronger than thicker ones and that greater is the CT greater is the occurrence of adhesive failure, while the cohesive failure is typical of thinner thicknesses of material (between 50 and 400 μm) (19, 20). Failure of cement adhesion can be

responsible for losing the reconstruction, crown fractures and consequent need of implant insertion (21-34). Implants can have pathologic bone resorption with high frequencies in patients affected by periodontal diseases (35-49).
In this paper the SBS of identical posts, cemented with different cement thicknesses, was analyzed by means of a pull-out tests, in order to evaluate both the post-cement-root system behavior, even after the appearance of the bond failure, through the study of the curve trends of the tensile strength over time, and to evaluate the microscopic appearance of the interfaces, at the end of the tensile test. The results prove that in Group 1 (CT 100 µm) the occurrence of coesive fractures in the composite joint was more represented in comparison to greater cement thicknesses. The analysis of the curve trends, of the tensile strength over time, shows that in Group 1 is present a greater resistance, to interfaces sliding after the peack of the BS, probably due to the greater friction caused by the reduced flow, in this condition, of the cementing material combined with its cohesive subsidence. Probably due to this latter in the dowel spaces, pertaining to the Group 1, has been possible to highlight the presence of small fragments of cement, still adherent on the dentin surface. Furthermore, in the other groups, the cohesive fractures, on the composite joints, do not seem to coincide with the thread of the post, their direction is often oblique and does not respect a specific pattern, as instead exhibited in the samples of the Group 1.
Analyzing exclusively the average values of the force necessary to obtain the BS, is possible to note that these are not very dissimilar to each other (Table 1). Infact ANOVA test shows that there is not a statistically significant difference among the three groups: Group 1 *vs* Group 2 ($p = 0.490$); Group 1 *vs* Group 3 ($p = 0.894$); Group 2 *vs* Group 3 ($p = 0.431$). On the contrary analyzing the SBS (Table 2) significative differences were observed in the Group 1 *vs* Group 2 ($p = 0.032$) and Group 1 *vs* Group 3 ($p = 0.014$), while a not significative difference was found, concerning this parameter, for Group 2 *vs* Group 3 ($p = 0.641$). This latter result is dependent on the prevalent interface adhesive failure exhibited by thicker cement layers, this also could explain the reason of the smoothness of the surface, in composite joints, of both Group 2 and 3.
Regarding the areas of foamy-chalky appearance, these are more frequent in Group 1. Probably their genesis could be attributed to the presence of residual adhesive, not completely removed. The adhesive used in our experiences contains MDP, an acid monomer. The excess of material not removed and thus not neutralized by the hydroxyapatite of dentine could have superficially compromised the polymerization of the composite cement (9). Probably in smaller dowel spaces (i.e. 1.5 mm) it's more difficult to effectively remove the excesses of adhesive in comparison to larger ones.
Previous studies shown how small cement thicknesses (120 µm) positively increases the SBS of the adhesively luted post (17). In similar manner, in our settings, the best results were observed when the CT was 100 µm. When thicknesses approximately double or triple, they have comparable performances. Furthermore the BS seems not to be influenced by the CT in our settings.
In the clinical practice, it is preferred not to sacrifice healthy tooth tissue during the preparation of the dowel space, creating tapered housings to follow the root canal anatomy. The tendency is therefore oriented to adapt the post to dowel space and not otherwise, therefore dental manufacturers are oriented toward the production of tapered posts, possibly customizable. Further studies are needed both to identify the optimal thickness for the composite resin cement and to analyze the behavior of posts cemented in tapered dowel spaces.

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