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AN IN-VITRO COMPARISON OF THE RETENTION OF PREFABRICATED PARALLEL-SIDED VENTED TITANIUM POSTS CEMENTED WITH THREE DIFFERENT DUAL-POLYMERIZABLE RESIN CEMENTS

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This is to certify that the thesis prepared by Maha M. El-Sayed, B.D.S., D.M.D., entitled An In-Vitro Comparison of the Retention of Prefabricated Parallel-Sided Vented Titanium Posts Cemented with Three Different Dual-Polymerizable Resin Cements has been approved by her committee as satisfactory completion of the thesis requirement for the degree of Master of Science.

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A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science at Virginia Commonwealth University.

by

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This work is dedicated to my late father, Dr. Mamdouh M. El-Sayed, who was my first dentist and the reason I was inspired to enter into this profession.

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Abstract

AN IN-VITRO COMPARISON OF THE RETENTION OF PREFABRICATED PARALLEL-SIDED VENTED TITANIUM POSTS CEMENTED WITH THREE DIFFERENT DUAL-POLYMERIZABLE RESIN CEMENTS

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Purpose: The purpose of this in-vitro study was to compare the retentive strength of an autopolymerizing resin cement to three dual-polymerizable resin cements when used to cement pre-formed posts without light activation and to correlate diametral tensile stress, hardness as a measure of the degree of polymerization and the retentive strength of the different dual-polymerizable resin cements.

Material and methods: 60 human extracted premolar teeth were endodontically-treated and randomly divided into 4 test groups (n=15). Parapost XP posts (size 5) were cemented using Panavia 21(control), Panavia F, RelyX Unicem and Linkmax resin cements. The latter three cements were dual-polymerizable and were not light-activated, and the control cement was autopolymerizable. Also, 140 resin cement samples were fabricated for diametral tensile stress and Knoop hardness testing. Each test had 70 samples, 10 of each of the following groups: Panavia 21, Panavia F dual-polymerized, Panavia F autopolymerized, RelyX Unicem dual-polymerized, RelyX Unicem autopolymerized, Linkmax dual-polymerized, Linkmax autopolymerized. Post retention, diametral tensile stress and Knoop hardness tests were performed 1 week after sample fabrication or post cementation.

Results: ANOVA and Tukey-Kramer statistical analysis revealed significant differences among the test groups for the three tests. Scatterplots of the data revealed no correlation between the three tested properties.

Conclusions: Within the limitations of this in vitro study, tested dual-polymerization resin cements had similar or superior parapost retention to the control autopolymerizing resin cement without photoactivation. Dual-polymerizable resin cements had improved diametral tensile stress and surface hardness when light-activated than when autopolymerized. No correlation was observed between surface hardness and diametral

tensile stress or between the mechanical properties of the resin cements and their retentive qualities.

Introduction

Endodontically treated teeth frequently have lost substantial coronal tooth structure from the most common precursor to endodontic therapy- dental caries, as well as the access preparation for the endodontic treatment and preexisting restorations. Restoration of these teeth requires special consideration. The overwhelming number of studies in this area is reflective of the importance of restoring endodontically treated teeth in the practice of dentistry and the attention it has received over the years. Hudis and Goldstein [1] identified the following objectives and considerations in restoring endodontically treated teeth in the literature: 1. restoration of form and function, 2. prevention of fracture of the residual root, 3. esthetics, 4. prevention of caries, and 5. retention of the final restoration. Post failures can be attributed to structural failure of either the tooth or the post due to fracture or recurrent caries, or to loss of retention, with the latter being the most common failure occurrence.[2] Numerous factors have been found to affect retention of cemented posts including post length, diameter, design, surface configuration of the post and the canal, lubricant used for direct pattern fabrication, canal shape and preparation procedure, type of luting agent, thickness of cement layer, method of cementation, as well as location in the dental arch.[1-20] A cast post or a commercially prefabricated post is frequently selected for the restoration of root canal treated anterior and premolar teeth to aid in the retention of the core.[2-4, 21-23] Several investigators have determined that the parallel-sided, serrated posts (cast or pre-fabricated) show the highest success rates.[2, 4, 23, 24] Standlee et al [2] demonstrated superior retentive abilities of the parallel-sided post over a tapered post in resisting tensile, shear and torque forces. Sorenson and Martinoff [4] found in a retrospective study that the parallel-sided posts had no failures caused by tooth fracture. The retention of parallel-sided posts can be further improved by the type of luting agent used. A commonly used luting agent is zinc phosphate cement. It has the longest track record and has been serving as a standard to which newer systems can be compared. When properly manipulated, its advantages include reasonable working time and proven longevity in the oral cavity when used for cementation of a well-designed and well-fitting restoration. Its disadvantages, however, include solubility, low tensile strength, lack of adhesiveness to tooth structure and no anticariogenic properties.[25] With the development of adhesive dental materials and the introduction of resin-based cements, the ability to achieve better retention of restorations has been reported.[12, 13, 26, 27] Hagge et al [15] compared retention strength of five luting cements on prefabricated posts and found significantly greater retention with Panavia 21, an autopolymerizing resin cement, compared with zinc phosphate cement. In a similar in-vitro study, Duncan and Pameijer [14] found greater retention with a hybrid resin-ionomer cement, followed by 2 resin cements, all of which were significantly more retentive than zinc phosphate cement. It was speculated that along with superior tensile strengths, resin cements may also reinforce the endodontically treated tooth, if the root/cement/post complex acts as a bonded unit. In 1984 Sorenson and Martinoff [22] retrospectively examined 1273 endodontically treated teeth and found no increase in resistance to fracture or dislodgment when posts were present.

Their finding was in agreement with Guzy and Nicolls' [21] conclusion in 1979 that posts may not provide any reinforcement to endodontically treated teeth. Mendoza et al [28], however, have found in an in vitro study that roots in which parallel-sided posts were cemented with Panavia were significantly more resistant to fracture than those where zinc phosphate cement was used.

Resin-based cements have become popular with the development of direct-filling resins with improved properties, the acid etch technique for enamel bonding, and the relatively new potential to bond to dentin. Their composition is similar to resin-based composite filling material (an organic resin matrix with silane-treated inorganic fillers) along with dentin bonding functional groups such as organophosphanates, hydroxyethyl methacrylates (HEMA) and 4 methacrylethyl trimellitic anhydride (4-META).[25] In addition to the previously mentioned advantages of resin cements, they are also virtually insoluble in oral fluids, display reduced microleakage, have a film thickness of 25 μm or less, and possess good esthetics under translucent restorations (e.g. porcelain laminate veneers and all ceramics).[25] Resin cements can be chemically activated, light activated or dual-polymerized. The chemically activated resin cements are manufactured in a two-component system (powder and liquid or two pastes). An activator is present in one and the initiator in the other component. Their uses include cementation of all-metal and ceramometal restorations, prefabricated and cast posts as well as ceramic restorations. They are very technique sensitive due to their limited working time. The light-activated resin cements on the other hand are a single component system. Exposure to light is needed for polymerization and thus they are mainly used in cementing ceramic and resin restorations.[25, 29] In an effort to consolidate the favorable characteristics of autopolymerizing and light-activated resin cements, the dual-polymerizable resin cements were developed. According to manufacturers' claims, they possess extended working time and fully polymerize in either the presence or absence of light, making them suitable for almost all cementation purposes in dentistry. A number of studies have compared physical properties of resin cements.[29-32] Braga et al [29] evaluated the hardness as an indirect measure of degree of polymerization, flexural strength, and flexural modulus of four resin cements with different polymerization modes. They found no correlation between hardness and flexural strength. Stewart et al [30] evaluated the shear bond strength between four different resin cements and dentin. They found that cements with auto- or light-polymerized adhesives were associated with higher bond strengths to dentin than those with dual-polymerized adhesives. This result was only statistically significant for one dual-polymerizable resin cement group (Calibra). Hoffman et al [32], on the other hand, have verified the efficiency of the chemical activation of dual-cured cements. Caughman et al [33] evaluated the curing potential of dual polymerizable resin cements in simulated clinical situations in a 2001 study and found product-specific results when it came to the ability of a dual polymerizable resin cement to autopolymerize. They questioned whether a decrease in polymerization reaction would have any deleterious effects on the clinical performance of the luting agent and stressed the need for further studies to help clarify the absolute relationship between percentage conversion and physical properties for a composite resin.

Statement of the Problem

Resin-based cements have been widely used in the cementation of endodontic posts for their superior retention. Most manufacturers recommend the use of their dual-polymerizable resin cements for the cementation of prefabricated endodontic posts or cast post and cores. Photo activation is not possible with such restorations that are impervious to light transmission. According to the manufacturers, polymerization of the resin would occur in the absence of light due to the auto-polymerizing component of the cement. Research has been concerned about the degree of polymerization achieved and the effect of incomplete conversion on the physical properties of the cement. A search of the literature revealed no investigations on the dual-polymerizable resin cements and endodontic post retention. Additionally, there is a continuous development and surging of resin-based cements. New studies evaluating the performance of newer dual-polymerizable resin luting agents are indicated.

Specific Aim and Hypothesis:

The purpose of this in-vitro study was two-fold: 1. to compare the retentive strength of an autopolymerizing resin cement to three dual-polymerizable resin cements when used to cement prefabricated, parallel-sided, vented and serrated titanium posts without light activation; and 2. to correlate diametral tensile stress, surface hardness as a measure of the degree of polymerization and the retentive strength of the different dual-polymerizable resin cements. The hypothesis was that the three dual-polymerizable resin cements have comparable, clinically acceptable, retentive strength to the autopolymerizable resin cement when only the chemical activation component is relied upon for the setting reaction irrespective of the degree of polymerization of these cements.

Materials and Methods

Part I: Post Retention

Sixty extracted single-rooted human mandibular premolars were selected for this part of the experiment. The teeth were disinfected in 5.25% aqueous solution of NaOCl (1:10 dilution of Ultra Clorox, Clorox Inc, Oakland, CA) for 24 hours, and then stored in distilled water at room temperature. The teeth were then sectioned perpendicular to their long axes using a diamond separating disc (Brassler USA, Savannah, GA) at their cemento-enamel junction and the pulp tissue was manually debrided using barbed broaches (Densply Maillefer, Tulsa, OK). Specimens with two or more canals, pronounced canal curvatures, significantly smaller or larger root canal spaces or evidence of calcification or internal resorption were replaced with new teeth in an effort to achieve as much standardization as possible. The root canals were negotiated using size 10 and 15 K-Files (Dentsply Maillefer, Tulsa, OK) until the tip of the file could be seen at the apical foramen. This length was marked, measured and the working length was determined 0.5-1.0 mm short of this measurement. The root canal was thereafter instrumented using manual instrumentation and the step back technique. The canal was irrigated using 5.25% sodium hypochlorite introduced into canals after every instrument using a 3 cc irrigation syringe with notched-tip 27-gauge needle (Monoject irrigation syringes) and the canal was recapitulated with a size 10 K-File to ensure patency of the apical foramen. Canal instrumentation was completed to a size 60 master apical file and obturation was performed using a size 60 gutta percha master cone (Densply Maillefer, Tulsa, OK) and Nogenol Sealer (GC America, Inc., Alsip, IL). The roots of the teeth were notched on their buccal and lingual surfaces to prevent dislodgement from the embedding material during testing. A Teflon (polytetrafluoroethylene) mold 2X 2.5X 0.75 inches in dimensions with a central cylindrical hole with a diameter of 5/8 inch was custom fabricated. The teeth were mounted using this Teflon mold secured horizontally over a glass slab of the same dimensions (2X2.5 inches) on the survey table of a dental surveyor (Degussa-Ney, Yucaipa, CA) and autopolymerizing acrylic resin (Trayresin Self Curing Resin, Densply Int. Inc, York, PA). A parapost drill mounted on the surveyor was engaged 3-4 mm in the prepared canal and the tooth was slowly lowered into the resin-filled mounting mold until the CEJ was at the same level with the top of the mold (Figure 1). This technique ensured post removal during testing in a direction parallel to the post's long axis. To facilitate mounting the specimen in the center of the mounting mold, the glass slab under the Teflon mold had its geometrical center marked and was used to align the parapost drill prior to attaching the tooth to be mounted. The top of the mounted specimen was finished by sanding the resin surface and coronal aspect of the root using wet sandpaper of progressively finer grit (Gator Grit Multi-Surface Sandpaper, Ali Industries, Inc., Fairborn, OH) to create a flush smooth surface perpendicular to the long axis of the canal and cylinder. The access openings were closed using a cotton pellet and Cavit-W (3M ESPE, Seefeld, Germany) and the teeth were stored in tap water temperature until the time of post

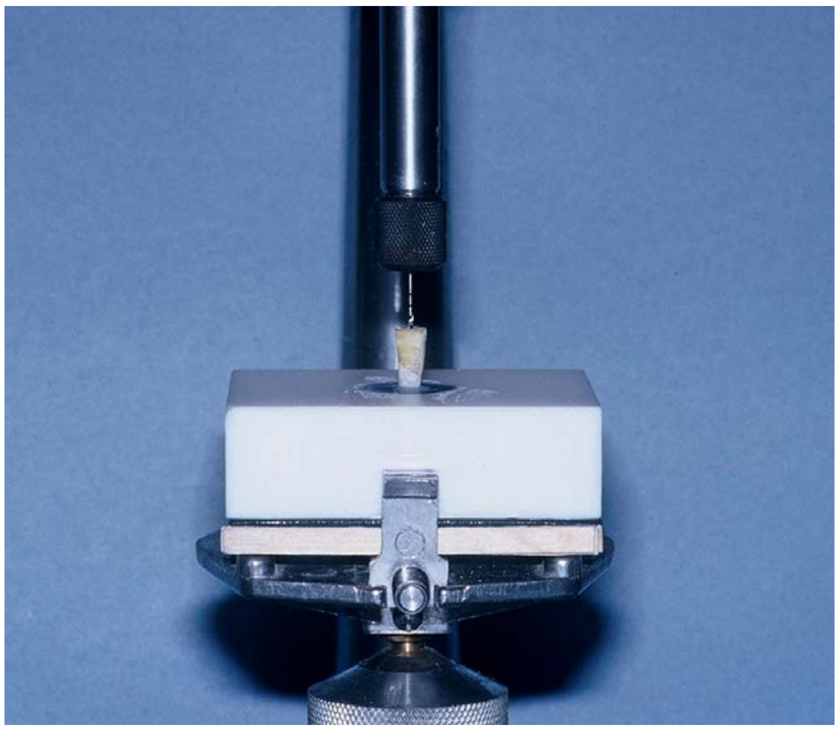


Figure 1. Mounting of tooth samples using a custom made Teflon mold secured horizontally on a dental surveyor.

space preparation and post cementation. The teeth were prepared to a depth of 9 mm to receive the titanium prefabricated parallel-sided posts (Parapost XP size 5; Coltene/ Whaledent, Mahwah, NJ) using Gates Glidden drills (Densply Maillefer, Tulsa, OK) and size 5 parapost drills.[18] The teeth were randomly assigned into four groups (n=15) and the paraposts were cemented using the following resin cements:

Table 1: Post Retention Test Groups

Luting Agent	*Polymerization*	*Dentin Bonding Agent*	*Shade*	*Lot #*	*Manufacturer*
Panavia 21 (P21)	Autopolymerization	ED Primer	TC	61197	Kuraray Med. Inc., Okayama, Japan
Panavia F (PF)	Dual-Polymerization	ED Primer	TC	61192	Kuraray Med. Inc., Okayama, Japan
RelyX Unicem (RXU)	Dual-Polymerization	Not applicable	A3 opaque	139194 144028(a)	3M ESPE, Seefeld, Germany
Linkmax (LM)	Dual-Polymerization	Self-Etching Primer EP-A, EP-B	A3	0207261	GC America Inc., Alsip, IL

Following manufacturers' recommendations, all posts were prepared by sandblasting using 50 Micron Aluminum Oxide for 2-3 seconds to produce a matte finish. Each parapost was thereafter washed under running water and the ultrasonically cleaned in distilled water. Manufacturers' instruction were followed in cementing the posts with each type of cement. Panavia 21 group acted as the control group and each tooth specimen in this group was c. To ensure that the posts were seated at the predetermined length, all posts were carefully marked at 9mm using a felt tip pen. The dual-polymerizable resin cements (Panavia F, RelyX Unicem and Linkmax) were allowed to autopolymerize without photoactivation.

The specimen were stored in a humid environment for 1 week 37˚ Celsius until testing began. The dual-polymerizable cement groups were additionally stored in light-proof conditions. Before testing, any film of resin cement on the top of the mounted tooth complex was carefully removed using a #25 carbon steel surgical blade. The mounting rings were consecutively secured in a Universal Testing Machine (Instron Corp, Canton, MA) using a custom-fabricated metal plate described by Burns et al .[7] The plate had a hole in its center large enough to allow the post to pass through it. The plate was attached to the upper member of the Instron. The post was passed through the hole in the plate toward the lower grip of the Instron so that the coronal portion of the tooth and upper surface of the mounting resin was flat against the top surface of the plate. The paraposts were securely gripped by a screw-wedged grip attached to the lower member of the Instron. The specimen were loaded along their long axes at a crosshead speed of 0.05 inch/min to determine the amount of load required to dislodge the posts (Figure 2a,b). Determination of failure was related to a sudden release of load observed on the recording graph indicating initial displacement of the post and cement failure. The load at failure was recorded in pounds. The stress was calculated in pounds per square inches (PSI) by calculating the approximate surface area of the paraposts and following the equation Stress= load/ surface area.[25] The results were then converted into megapascals (M Pa).

Part II: Diametral Tensile Stress

Cylindrical specimen were fabricated using a custom-fabricated Teflon mold for diametral tensile stress testing. The number of specimen were as follows:

Figure 2a: Post Retention Specimen Positioned in the Instron Machine

Figure 2b: Post Pulled Out of Canal

Table 2: DTS and Knoop Hardness Test Groups

Group	#	Material
P21 (*control*):	10	Panavia 21 autopolymerizable resin cement
PF-dc	10	Panavia F, dual-polymerizable resin cement, dual-polymerized
PF-cc	10	Panavia F, dual-polymerizable resin cement, autopoloymerized
RXU-dc	10	RelyX Unicem, dual-polymerizable resin cement, dual-polymerized
RXU-cc	10	RelyX Unicem, dual-polymerizable resin cement, autopoloymerized
LM-dc	10	Linkmax, dual-polymerizable resin cement, dual-polymerized
LM-cc	10	Linkmax, dual-polymerizable resin cement, autopoloymerized

The specimen were mixed and fabricated at room temperature, according to each manufacturer's instructions. The Teflon mold was placed on mylar strips over a glass slab. Each cement was mixed according to manufacturer's instructions, and the cement mix was loaded into an orange Accudose tube and plug Centrix syringe tip and injected into the Teflon mold. Care was taken not to entrap any air into the cement specimen by keeping the syringe tip submerged in the cement during injection. The resin cement was then covered with another mylar strip and gently pressed with another glass slab to squeeze out excess material and produce a smooth and even surface. An 8 pound weight was placed over the top glass slab in the P21, PF-cc, RXU-cc and LM-cc groups and the cements were allowed to autopolymerize in a dark environment for the time indicated by the manufacturer before separating the specimen from the mold. Samples requiring photo-activation were fabricated 2-at-a-time and were subjected to the curing light each for an initial 10 seconds through the top glass slab, then for the recommended amount of time (20 seconds) through the mylar strip from each surface before the specimen were removed from the mold. Each specimen was 0.25 inch in diameter and 0.125 inch in height. All specimen were stored in tap water in an incubator at 37˚C. Specimen in PF-cc, RXU-cc and LM-cc groups were additionally stored in a light-proof environment. After 1 week the samples were subjected to diametral tensile stress testing. The specimen were loaded on a Universal Testing Machine (Instron Corp, Canton, MA) at a constant crosshead speed of 0.02 inch/min until fracture occurred (Figure 3a, b). The fracture loads were recorded in pounds. The diametral tensile stress (DTS) was calculated in PSI according to the following equation DTS= 2P/ π x D x T, where P=load in pounds, D=sample diameter in inches and T= sample thickness in inches.[25] The results were then converted into megapascals.

Part III: Surface Hardness

Specimen were fabricated as described for the diametral tensile stress testing with same groups and sample numbers. Following storage for 1 week, the surface microhardness of each sample was determined using a Tukon microhardness tester (Acco industries Inc., Wilson Instrument division, Bridgeport, CT) with a Knoop indenter, a 100-g weight and an 18 seconds dwell time (Figure 4). Four rhombic-shaped indentations were made in each specimen. Through the Filar eyepiece with an attached Microton micrometer, the long diagonals of the indentations were measured at X20 magnification (i.e. Filar reading). Larger indentations were measured under X 10 magnification. When performing the test on PF-cc, RXU-cc and LM-cc groups , an orange light filter was used to prevent any light activation. Knoop hardness number was calculated from the average filar reading for each sample using a circular slide ruler designed to calculate the KHN from the filar measurement.

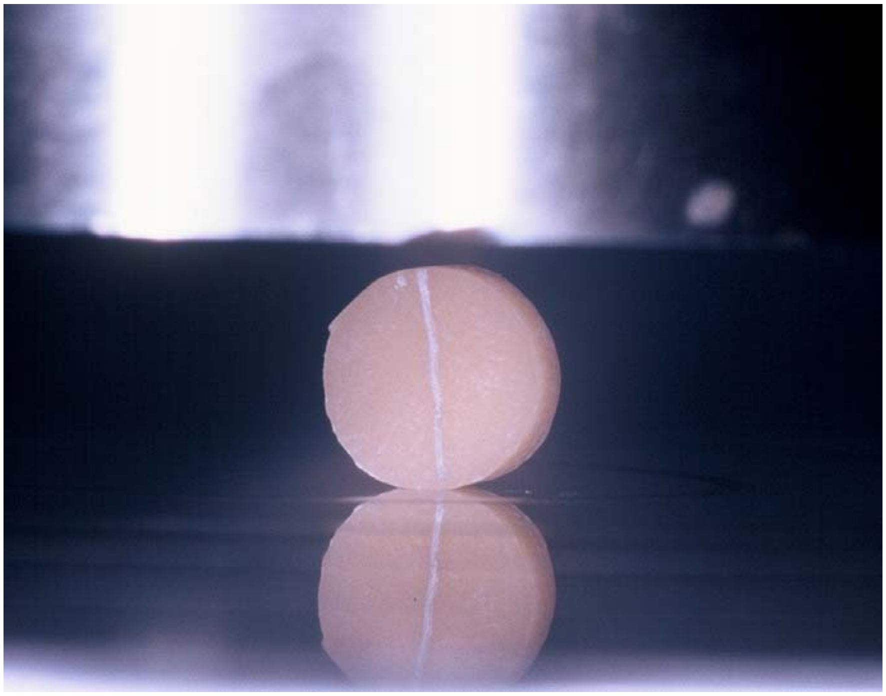


Figure 3a: Diametral Tensile Stress Specimen Positioned in the Instron Machine

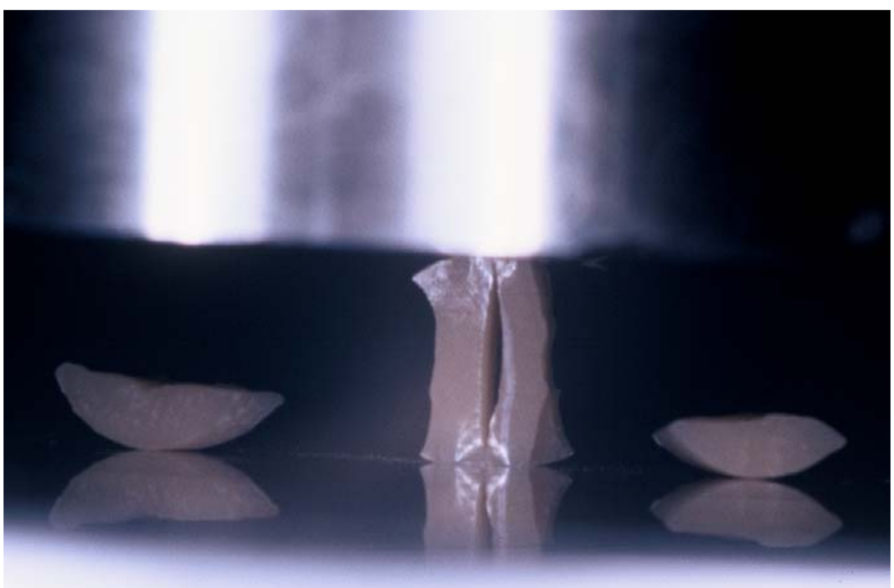


Figure 3b: Fractured Diametral Tensile Stress Sample

Figure 4: Knoop Hardness Test Sample Positioned on a Tukon Microhardness Tester

Results

Data Analysis

The materials were designated as follows:

Table 3: Data Analysis Group Designation

Designation	**Material**
P21 (*control*)	Panavia 21 autopolymerizable resin cement
PF-dc	Panavia F, dual-polymerizable resin cement, dual-polymerized
PF-cc	Panavia F, dual-polymerizable resin cement, autopolymerized
RXU-dc	RelyX Unicem, dual-polymerizable resin cement, dual-polymerized
RXU-cc	RelyX Unicem, dual-polymerizable resin cement, autopolymerized
LM-dc	Linkmax, dual-polymerizable resin cement, dual-polymerized
LM-cc	Linkmax, dual-polymerizable resin cement, autopolymerized

ANOVA and Tukey – Kramer HSD (honestly significant difference test) were used for analysis of the data for post retention, hardness, and diametral tensile stress.

Part I: Post Retention

Table 4 shows the means, standard deviations and confidence intervals for the four materials, in regard to post retention, measured in megapascals. (See Appendix A for complete data).

Table 4. Post Retention Measures

Material	Number	Mean	Std Dev	Lower 95%	Upper 95%
P 21	15	3.03	1.18	2.37	3.68
P F-cc	15	4.45	1.32	3.72	5.18
RXU-cc	15	7.60	2.74	6.08	9.12
LM-cc	15	6.80	2.23	5.56	8.03

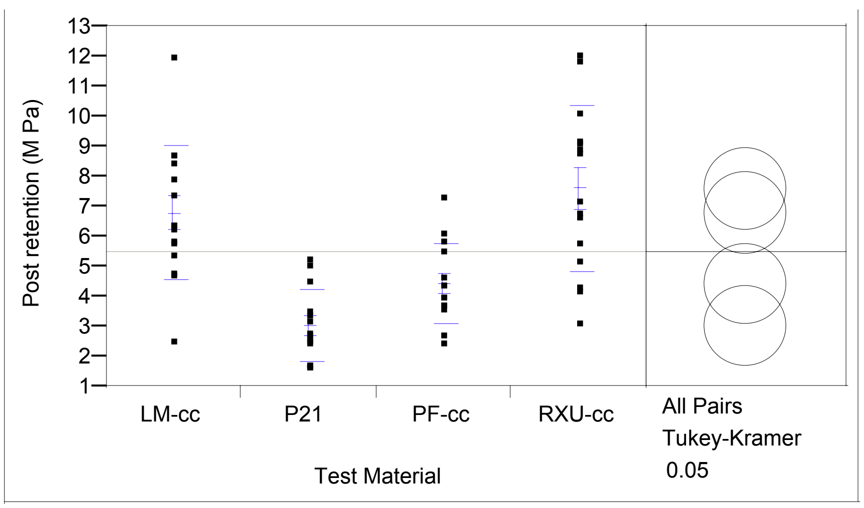
ANOVA results appear in Table 5, which show significant difference across all materials (p < 0.0001).

Table 5: Analysis of Variance- Post Retention

Source	DF	Sum of Squares	Mean Square	F Ratio	Pr >F
Test Material	3	199.51	66.50	17.02	<.0001
Error	56	218.84	3.91		
Corrected Total	59	418.35			

Figure 5 illustrates the data for post retention across the four different materials designated by test material LM-cc, P21, PF-cc and RXU-cc. The middle line of each data group mark the mean, bounded by the standard error of the mean, and the wider bars marking the standard deviation.

Figure 5. One-way Analysis of Post Retention (M Pa) by Test Material



The circles in Figure 5 allow visual comparison of the Tukey – Kramer analysis. Table 6 shows there was no significant difference (at p = 0.05) between materials LM-cc and RXU-cc; and material P21 and PF-cc. However, material P21 and material PF-cc are significantly different from materials LM-cc and RXU-cc, with the greatest difference existing between groups P21 and RXU-cc.

Table 6. Tukey – Kramer HSD Comparison of all Post Retention Pairs

Material			Mean
RXU-cc	A		7.60
LM-cc	A		6.80
PF-cc		B	4.45
P21		B	3.03

Materials not connected by same letter are significantly different.

In addition ANOVA between materials reveal P21 and PF-cc are significantly different ($p = 0.0043$), and RXU-cc and LM-cc are not significantly different ($p = 0.3855$). There is also a significant difference between materials P21 and PF-cc, and RXU-cc and LM-cc in regard to post retention ($p < 0.0001$).

Part II: Diametral Tensile Stress

Results from RelyX Unicem were verified by repeating the diametral tensile stress test. This was decided to be a necessary step, since the material used in the post retention test came from a newer batch than the one used for the mechanical properties testing . Wilcoxon Rank Sum test revealed a statistically insignificant difference when dual-polymerized ($p = 0.3601$) and a statistically significant improvement over the original batch ($p = 0.0067$) when autopolymerized. Table 7 lists the mean, standard deviation and confidence intervals for material RXU-dc and RXU-dc (a), the latter being the newer batch. (See Appendix B for complete data).

Table 7. Diametral Tensile Stress Measures for RXU-dc and RXU-dc (a)

Material	Number	Mean	Std Dev	Lower 95%	Upper 95%
RXU-dc	9	37.07	3.31	34.52	39.61
RXU-dc(a)	8	38.47	3.57	35.48	41.46

Table 8 lists the mean, standard deviation and confidence intervals for material RXU-cc and RXU-cc (a), the latter being the newer batch. (See Appendix B for complete data).

Table 8. Diametral Tensile Stress Measures for RXU-cc and RXU-cc (a)

Group	Number	Mean	Std Dev	Lower 95%	Upper 95%
RXU-cc	10	28.73	2.47	26.96	30.50
RXU-cc (a)	8	33.03	2.28	31.12	34.94

However, when the data of the new autopolymerized samples were analyzed against the remaining test groups, this difference became insignificant. Therefore, the statistical analysis was performed with RelyX Unicem samples from both batches combined together for the purpose of simplification.

Table 9 shows the measures for diametral tensile stress in megapascals. (See Appendix B for complete data).

Table 9. Diametral Tensile Stress Measures

Material	Number	Mean	Std Dev	Lower 95%	Upper95%
P21	10	39.55	3.45	37.08	42.02
PF-dc	10	42.60	2.48	40.83	44.37
PF-cc	10	42.61	3.22	40.31	44.92
RXU-dc	17	37.73	3.41	35.98	39.48
RXU-cc	18	30.64	3.20	29.05	32.23
LM-dc	10	51.19	3.72	48.53	53.86
LM-cc	10	48.05	3.07	45.85	50.24

ANOVA results appear in Table 10, which show significant difference across all materials ($p < 0.0001$).

Table 10. Analysis of Variance DTS by Test Material

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Test Material	6	3689.82	614.97	58.18	<.0001
Error	78	824.45	10.57		
C. Total	84	4514.27			

Figure 6 illustrates the data for diametral tensile stress across the seven different materials.

Figure 6. One-way Analysis of DTS (M Pa) By Test Material

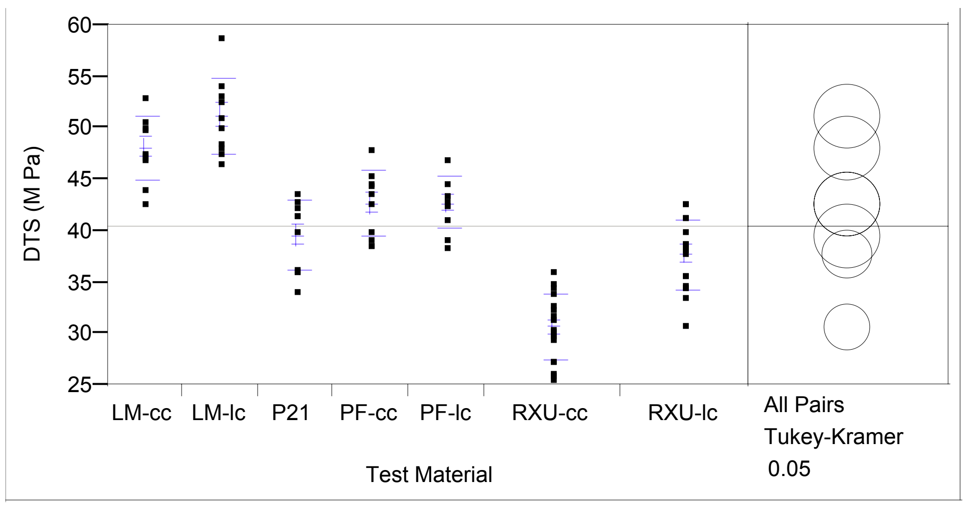


Table 11 outlines the Tukey – Kramer analysis, for diametral tensile stress, and reveals the following significant differences: material RXU-cc is significantly different from all other materials (at p = 0.05); material LM-dc and LM-cc are not significantly different from each other but are significantly different from all other materials; materials P21, PF-dc and PF-cc are not significantly different from each other but are significantly different from all other materials; and materials P21 and RXU-dc are not significantly different from each other, but are significantly different from all the other materials.

Table 11. Tukey – Kramer HSD Comparison of All Diametral Tensile Stress Pairs

Material					Mean
LM-dc	A				51.19
LM-cc	A				48.05
PF-cc		B			42.61
PF-dc		B			42.60
P21		B	C		39.55
RXU-dc			C		37.73
RXU-cc				D	30.64

Materials not connected by same letter are significantly different

Part III: Surface Hardness

In regard to Knoop Hardness testing, Table 12 shows the means, standard deviations and confidence intervals for the seven materials. (See Appendix C for complete data).

Table 12. Knoop Hardness Measures

Material	Number	Mean	Std Dev	Lower 95%	Upper 95%
P21	10	18.07	13.12	8.69	27.45
PF-dc	10	45.35	4.12	42.40	48.30
PF-cc	10	19.70	8.13	13.88	25.52
RXU-dc	10	34.37	6.26	29.89	38.84
RXU-cc	10	9.13	4.12	6.18	12.07
LM-dc	10	31.81	2.09	30.32	33.30
LM-cc	10	15.86	2.62	13.99	17.73

Again ANOVA revealed significant difference across all materials ($p < 0.0001$), which appear in Table 13.

Table 13. Analysis of Variance Knoop Hardness

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Test Material	6	9597.08	1599.51	34.73	<.0001
Error	63	2901.58	46.06		
C. Total	69	12498.65			

Figure 7 illustrates the data for Knoop Hardness and the Tukey – Kramer analysis.

Figure 7. One-way Analysis of Hardness Test (KHN) by Test Material

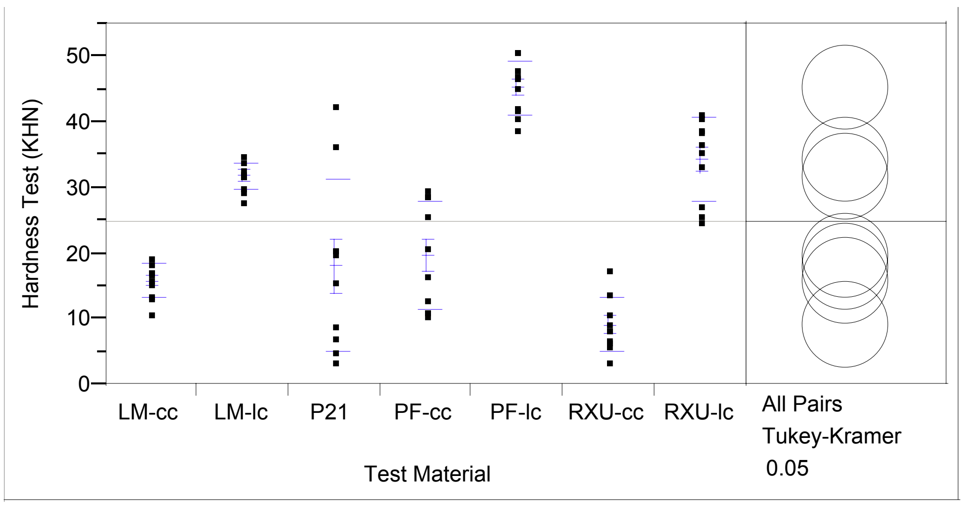


Table 14 outlines the Tukey – Kramer analysis, for Knoop Hardness, and reveals the following significant differences: material PF-dc is significantly different from all other materials (at p = 0.05); materials RXU-dc and LM-dc are not significantly different from each other but are significantly different from all other materials; materials P21, PF-cc and LM-cc are not significantly different from each other but are significantly different from all other materials; and materials P21, RXU-cc, and LM-cc are not significantly different from each other, but are significantly different from all the other materials.

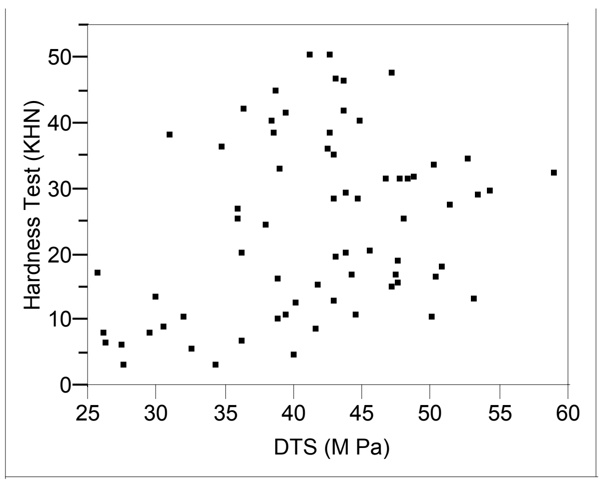
Table 14. Tukey – Kramer HSD Comparison of All Knoop Hardness Pairs

Material					Mean
PF-dc	A				45.35
RXU-dc		B			34.37
LM-dc		B			31.81
PF-cc			C		19.70
P21			C	D	18.07
LM–cc			C	D	15.86
RXU-cc				D	9.13

Materials not connected by same letter are significantly different

Statistical analysis revealed no correlation between hardness and diametral tensile stress (r_s = 0.107). Figure 8 shows a plot of the data.

Figure 8. Plot of Hardness Test (KHN) By DTS (M Pa)



In addition, no correlation was found between post retention and diametral tensile stress (r_s = 0.182); and no correlation was found between post retention and hardness (r_s = 0.052). Figure 9 and 10 show plots of these data.

Figure 9. Plot of Post retention (M Pa) By DTS (M Pa)

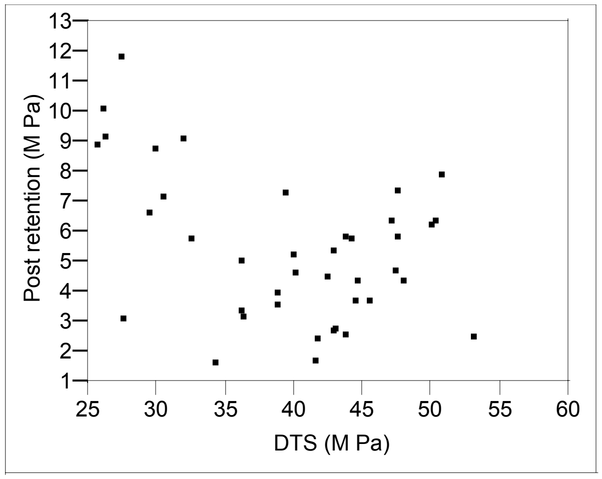
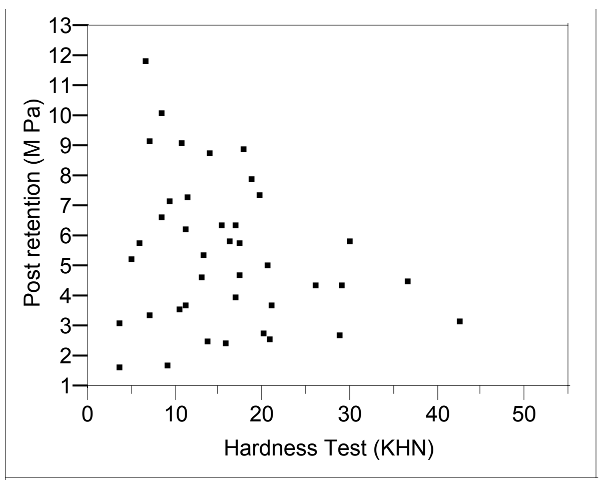


Figure 10. Plot of Post retention (M Pa) By Hardness Test (KHN)



Discussion

The retentive strength values obtained in this study were lower than expected. This finding may be attributed to the following factors:

1. The definition of failure load in this study was the initial sudden release of load observed on the recording graph as described by Lund et al[20]. This is believed to indicate the onset of separation of the post due to cement failure. Other studies evaluating post retention have recorded the peak force of post separation, which is the total force required to separate, dislodge, extract or remove the posts.[7-9, 12-15, 18, 34]

2. In this study, the post space preparation was performed using the same size parapost drill as the post used. This allowed for approximately 25 μm of cement film. In a study by Chana et al [17] evaluating the influence of cement thickness on the tensile strength of two resin cements the authors have found the highest tensile forces for Panavia 21 at a thickness of 100 μm, beyond which there was a significant decrease in strength. Their results were in agreement with Diaz-Arnold et al [35] who have found an optimum strength for Panavia X at 80 μm. Hagge et al[18] concluded in their study that paraposts cemented with Panavia 21 showed significantly greater retention in oversized post spaces compared with spaces prepared with the manufacturers' matched post and drill set.

3. In this study, the cement was carried into the canal following manufacturers' instructions by applying an even layer of cement on the post and then seating the post into the canal. Some investigators have additionally used a Lentulo spiral to carry the cement into the canal[6,10], others have injected the resin cement into the canal as well as applied it to the post.[9,18] Fakiha et al [19] have studied the effect of different cementation techniques on the retention of posts cemented with zinc phosphate cement and concluded that injection of cement into the root canal space followed by the use of a spiral has produced an even, bubble-free layer of cement and resulted in the highest level in post retention. A similar study investigating the safety and effects of different cementation techniques on the retention of posts cemented with resin cements is needed.
4. Concern about the effect of NaOCl on the bond strength of resin cements to root canal dentin: NaOCl is a nonspecific proteolytic agent used in this study in the endodontic therapy and to disinfect the tooth samples. An SEM study by Valera et al [36] compared different post cementation protocols to analyze the effect of NaOCl treatment on bond adhesion and tensile strength of resin cements. They found no significant alteration in tensile strength with NaOCl treatment. In fact, they observed a significant rise in strength when NaOCl was combined with the dentin adhesive ED Primer. On the other hand, Ari et al [37] also investigated the effect of NaOCl on the bond strength of resin cements on root canal dentin and observed an 18% reduction in the bond strength of all resin cements. They attributed this finding to the generation of oxygen at the resin-dentin interface which may

interfere with the interfacial polymerization as well as with infiltration of the resin cements into the dentinal tubules. Further investigation of this factor is necessary.

5. Even though the concern about bond strength of resin cement has been linked to eugenol-containing endodontic sealants, several studies have found no statistically significant difference to validate avoiding their use [7-9]. The sealant used in this study was Nogenol, a eugenol-free, salicylate-based endodontic sealant. A study by Mayhew et al [8] investigating the effect of root canal sealants and irrigation agents on the retention of preformed posts luted with a resin cement found the lowest retentive values with Nogenol and Panavia 21. Further investigation is required.

Despite the relatively low values, statistical analysis has revealed significant intergroup differences in all three tests performed. Regarding post retention, Panavia 21 (control) and Panavia F did not differ significantly from each other, even though autopolymerized Panavia F had a slightly higher failure load. RelyX Unicem, a self-adhesive universal resin cement, and Linkmax had significantly higher values than the former two groups. However, both groups did not differ significantly from each other. The standard deviations in all 4 groups were higher than what would be considered ideal. This finding was attributed by Burns et al[7] to the clinically relevant nature of their similar study including hand machining of each sample, differences in cement thickness in the flared coronal portion of the canal and the resultant varying degree of parallel engagement between the post and the canal walls apically.

Microscopic evaluation of samples representative of high, medium and low retentive strength values in all study groups revealed the following:

1. Lower values were associated with predominantly adhesive failures at the dentin-cement interface with occasional microscopic evidence of porosity in the cement layer, a void in the cement layer or contamination from residual gutta percha or acid etchant.
2. Medium values were associated with a combination of adhesive (tooth-cement and post-cement interface) as well as cohesive failures, one-surface canal anatomy undercuts and less evidence of contamination.
3. Higher values were associated with predominantly cohesive failures within the cement layer or adhesive at the post-cement interface, larger canals hence greater bonding surface area, canal anatomy undercut in two or more surfaces and overall less porosity in the cement layer.
4. Different failure modes, adhesive as well as cohesive could sometimes be seen at different locations of the same post.

Regarding diametral tensile stress and hardness testing, the general observation was that the autopolymerized samples of each dual-polymerization cement have performed less favorably than the light-polymerized samples of the same resin cement with the exception of Panavia F which had similar diametral tensile stress when light- or auto-polymerized. The diametral tensile stress values obtained in this study are close to previously reported values for resin cements (approximately 45 M Pa); reported diametral tensile stress for zinc phosphate cement being approximately 10 M Pa[38,39].

Hardness testing has been used in previous studies to serve as an indication of degree of conversion or polymerization of dual-polymerization resin cements.[29,32,40,41] The findings in our study are in agreement with other previous reports that evaluated the influence of light exposure on the rate of conversion of dual-polymerization resin cements and suggest incomplete polymerization of all auto-polymerized dual-polymerizable resin cements.[33,40,41] Insufficient hardening or polymerization of a dual-polymerizable resin cement is thought to be associated with postoperative sensitivity, increased microleakage and recurrent decay.[42]

The relationship between the degree of conversion of dual-polymerization resin cements and their mechanical and clinical behavior is not clear. In our study, Panavia F had a significantly higher Knoop hardness number when dual-polymerized than when autopolymerized, yet there was no significant difference in diametral tensile stress between both groups. Similarly, Linkmax had the highest diametral tensile stress of all groups tested in both polymerization modes, but had a relatively low KHN when autopolymerized. There appears to be no logical correlation between hardness and diametral tensile stress. This was confirmed with statistical analysis which found no correlation between the two properties. Furthermore, when considering the hardness and diametral tensile stress against post retention test results the following observations were made: While RelyX Unicem had significantly lower diametral tensile stress and hardness than all remaining test groups in its autopolymerized group, it recorded the highest values in the post retention test. The diametral tensile stress and hardness of Linkmax's autopolymerized group are significantly higher than those of RelyX Unicem autopolymerized group, however both cements had retentive values that were not significantly different from each other. Autopolymerized Linkmax despite having a hardness number that was statistically not different from the hardness number of autopolymerized Panavia F and Panavia21, had retentive strength significantly higher than the other two groups. No statistical correlation could be made between the tested mechanical material properties and the retentive strength of the tested resin cements. It would have been of interest to test the retentive strength of the three dual-polymerizable resin cements when light-activated as well.

RelyX Unicem has rendered the most surprising results. The retentive strength was significantly higher or not significantly different than the other test groups, while the diametral tensile stress and hardness test for the autopolymerized material was significantly lower than all other tested groups. Additionally, despite the fact that the material was provided in premeasured Applicaps that are simply activated and triturated, it is the only material that is a powder-liquid component cement and the only material where 5 samples had to eliminated from the diametral tensile stress groups because of macroscopic voids that resulted in markedly low DTS values. Microscopic examination of 5 Applicap RelyX Unicem resin cement mixes between 2 glass slides revealed multiple large voids. All lower values in all other test groups were inspected both macroscopically and microscopically. No other macroscopic voids were identified. All materials tested exhibited some microscopic porosity. Further testing of this material would be necessary to further understand the material physical and clinical behavior.

Conclusions

Within the limitations of this in-vitro study, the following conclusions may be drawn:

1. Dual-polymerization resin cements tested had similar or superior retention to the control autopolymerizing resin cement when used to cement prefabricated, parallel-sided, vented, titanium posts without photoactivation.
2. Dual-polymerizable resin cements have improved diametral tensile stress and surface hardness when light-activated than when autopolymerized.
3. No correlation was observed between the tested mechanical properties of the resin cements and their retentive qualities.
4. Further studies are needed to investigate whether light-activation would affect the retentive strength of the tested dual-polymerization resin cements.
5. Further investigations of effects of autopolymerization of dual-polymerizable resin cements are needed.
6. Standardization of dental research is necessary to facilitate comparisons between previous and new study results.

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APPENDIX A

Post Retention Test Results (Data in M Pa)

NO.	Panavia 21	Panavia F	RelyX Unicem	Linkmax
1	5.32	7.40	6.71	7.95
2	4.54	4.45	5.82	5.82
3	1.69	3.74	3.18	7.43
4	3.41	3.76	7.23	2.58
5	2.51	5.89	8.80	4.76
6	1.78	4.01	8.94	6.27
7	5.08	4.44	10.19	6.44
8	2.66	3.64	9.18	5.42
9	3.23	4.70	11.91	6.43
10	2.86	2.76	9.24	5.89
11	2.78	2.48	4.39	8.78
12	2.58	6.17	5.24	8.78
13	3.55	4.01	6.86	12.03
14	1.76	3.74	12.10	8.50
15	1.70	5.54	4.24	4.86
Mean	**3.03**	**4.45**	**7.60**	**6.80**
Standard Deviation	**1.18**	**1.32**	**2.74**	**2.23**

APPENDIX B

Diametral Tensile Stress Test Results (Data in M Pa)

Sample	P21	PF-dc	PF-cc	RXU-dc	RXU-dc(a)	RXU-cc	RXU-cc(a)	LM-dc	LM-cc
1	40.02	42.54	39.31	35.80	38.89	29.49	32.85	48.72	50.69
2	42.40	43.53	48.02	30.89	41.42	32.57	33.98	51.25	44.23
3	34.26	47.04	45.49	34.68	40.02	27.52	35.10	47.74	47.60
4	36.22	42.96	44.51	42.82	34.68	30.47	30.33	53.35	53.07
5	41.70	43.53	43.67	38.33	42.82	29.91	***	54.20	47.32
6	41.56	42.54	38.75	38.89	41.42	25.69	31.45	52.65	49.98
7	36.22	41.14	44.65	37.91	33.70	26.12	29.91	48.30	47.04
8	43.81	39.31	38.75	***	***	31.87	***	46.61	42.82
9	36.36	38.61	40.16	35.80	***	27.38	34.54	50.12	50.26
10	42.96	44.79	42.82	38.47	34.82	26.26	36.08	58.97	47.46
Mean	**39.55**	**42.60**	**42.61**	**37.07**	**38.47**	**28.73**	**33.03**	**51.19**	**48.05**
Standard Deviation	**3.45**	**2.48**	**3.22**	**3.31**	**3.57**	**2.47**	**2.28**	**3.72**	**3.07**

*** Specimen eliminated due to macroscopic voids

APPENDIX C

Knoop Hardness Test Results (Data in KHNs)

Sample	**P21**	**PF-dc**	**PF-cc**	**RXU-dc**	**RXU-dc(a)**	**RXU-cc**	**RXU-cc(a)**
1	4.91	50.75	11.30	27.20	8.31	32.20	18.60
2	36.60	47.00	25.90	38.60	5.94	28.10	17.20
3	3.56	48.20	20.90	36.70	3.49	32.00	19.50
4	7.10	47.10	11.18	35.50	9.25	29.50	13.60
5	15.60	42.30	29.80	40.90	13.90	30.20	17.20
6	9.10	39.00	16.80	33.60	17.66	35.10	11.00
7	20.60	50.75	29.00	25.00	8.40	32.00	15.30
8	20.75	42.00	10.42	41.40	10.75	32.00	13.20
9	42.50	45.50	12.90	25.75	6.57	34.10	16.90
10	20.00	40.90	28.80	39.00	7.00	32.90	16.10
Mean	**18.07**	**45.35**	**19.70**	**34.37**	**9.13**	**31.81**	**15.86**
Standard Deviation	**13.12**	**4.12**	**8.13**	**6.26**	**4.12**	**2.09**	**2.62**

APPENDIX D

Filar Readings - Knoop Hardness Test (X20)

Sample	Filar 1	Filar 2	Filar 3	Filar4	Sample	Filar 1	Filar 2	Filar 3	Filar4
1a	5.33	5.28	5.75	5.49	1f	5.23	5.16	2.36	3.3
1b	4.02	4.06	4.22	4.18	1g	5.32	6.8	5.94	4.25
1c	8.08	8.19	4.85	4.62	1h	3.80	5.18	4.94	5.32
1d	4.91	4.77	4.28	4.24	1i	4.15	3.84	4.38	3.18
1e	6.83	5.84	8.43	4.6	1j	4.84	8.92	4.42	4.45
2a	3.63	3.66	3.58	3.40	2f	4.08	3.86	4.13	4.16
2b	3.64	3.63	3.79	3.76	2g	3.63	3.51	3.54	3.60
2c	3.61	3.77	3.77	3.49	2h	3.85	4.05	4.00	3.78
2d	3.74	3.72	3.80	3.55	2i	3.72	3.83	3.80	3.71
2e	3.87	4.07	3.87	3.82	2j	3.50	3.94	4.54	3.90
3a	7.57	7.15	8.25	7.14	3f	5.18	7.43	5.90	6.24
3b	5.07	5.38	5.08	4.35	3g	4.02	4.69	5.00	5.09
3c	5.25	5.32	5.76	5.79	3h	8.48	8.17	7.38	7.31
3d	7.77	7.,35	7.32	6.37	3i	8.12	6.52	7.07	6.44
3e	4.92	4.22	5.28	4.14	3j	5.16	4.00	4.44	5.26
4a	5.10	4.09	5.20	5.07	4f	4.41	4.43	4.36	4.32
4b	4.00	3.80	4.23	4.32	4g	4.86	5.11	5.29	5.03
4c	4.50	4.13	4.01	4.11	4h	4.32	4.35	3.27	3.81
4d	4.77	3.74	4.45	4.06	4i	5.67	6.00	4.63	3.69
4e	3.92	4.31	4.13	3.53	4j	3.91	4.30	4.13	3.95
5a	9.06	9.20	9.12	7.66	5f	7.56	4.38	5.54	5.54
5b	5.66	4.88	4.61	4.79	5g	8.90	9.72	7.90	8.83
5c	6.16	5.55	6.47	7.80	5h	6.03	8.51	9.05	7.31
5d	4.00	4.33	3.63	4.00	5i	9.72	9.59	6.41	8.49
5e	6.36	7.70	7.09	6.00	5j	9.80	9.06	10.47	8.94
6a	4.34	4.84	4.70	4.00	6f	4.08	4.17	4.38	4.47
6b	5.00	4.86	4.79	4.48	6g	4.49	4.66	4.48	4.28
6c	4.43	4.60	4.56	4.34	6h	4.24	4.40	4.64	4.62
6d	4.67	4.90	4.60	4.49	6i	4.28	4.40	4.22	4.45
6e	4.43	4.80	4.88	4.32	6j	4.41	4.39	4.40	4.48
7a	5.67	5.46	5.72	6.62	7f	10.63	6.86	62.00	6.86
7b	6.52	6.35	5.92	5.68	7g	5.87	6.82	7.08	6.11
7c	6.00	5.33	5.57	6.07	7h	7.22	6.19	7.00	7.46
7d	6.67	7.03	6.94	6.80	7i	5.90	6.22	6.04	6.47
7e	6.20	6.06	6.00	6.18	7j	6.40	8.00	5.36	5.45

* Underlined values were measured under X10 magnification

VITA

Maha M. El-Sayed was born in Alexandria, Egypt on March 18, 1970. Upon graduating from high-school in 1988, she was admitted to the Faculty of Dentistry, Alexandria University, Egypt. In 1993 she obtained her Bachelor of Dental Medicine and Surgery (B.D.S.) with honors. After completing a 12 months general practice residency, she earned her license to practice dentistry in Egypt and became member of the Egyptian Dental Union.

In 1998, she was accepted into the Program for Advanced Standing Students at the School of Dental Medicine, University of Pennsylvania, and earned her D.M.D. in 2000 with the Pass-International Dentist Award and a membership in the Omicron Kappa Upsilon Honor Society.

She joined the Graduate Prosthodontics Program, School of Dentistry, Virginia Commonwealth University in July of 2000 where she is currently a postgraduate student.

Upon Graduation, she hopes to pursue a career as a Prosthodontist in private practice.